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Glance behaviours when using an in-vehicle smart driving aid: A real-world, on-road driving study ☆

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A B S T R A C T

In-vehicle information systems (IVIS) are commonplace in modern vehicles, from the initial satellite navigation and in-car infotainment systems, to the more recent driving related Smartphone applications. Investigating how drivers interact with such systems when driving is key to understanding what factors need to be considered in order to minimise distraction and workload issues while maintaining the benefits they provide. This study investigates the glance behaviours of drivers, assessed from video data, when using a smart driving Smartphone application (providing both eco-driving and safety feedback in real-time) in an on-road study over an extended period of time. Findings presented in this paper show that using the in-vehicle smart driving aid during real-world driving resulted in the drivers spending an average of 4.3% of their time looking at the system, at an average of 0.43 s per glance, with no glances of greater than 2 s, and accounting for 11.3% of the total glances made. This allocation of visual resource could be considered to be taken from 'spare' glances, defined by this study as to the road, but off-centre. Importantly glances to the mirrors, driving equipment and to the centre of the road did not reduce with the introduction of the IVIS in comparison to a control condition. In conclusion an ergonomically designed in-vehicle smart driving system providing feedback to the driver via an integrated and adaptive interface does not lead to visual distraction, with the task being integrated into normal driving.

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1. Introduction

1.1. Background

Driving can be described as predominantly a visual task (Kramer & Rohr, 1982; Spence & Ho, 2009). However, Hughes and Cole (1986) have suggested that drivers might have up to 50% 'spare' attentional capacity during 'normal' driving, with observations placed in the categories of the immediate road surroundings, general surroundings, vegetation and advertising being considered not relevant to the driving task. Green and Shah (2004) suggest that the goal of the distraction mitigation system should be to keep the level of attention allocated to the driving task above the attentional requirements demanded by the current driving environment, and that during 'routine' driving approximately 40% of attention could be allocated to

non-driving tasks. This suggests that any increase in crash risk may be mitigated if the resources allocated to complete a secondary task are obtained from this spare capacity, compared to if they are reallocated from tasks critical for safe driving. For the crash risk to manifest itself other contributing factors also have to occur concurrently (Angell et al., 2006). Contributing factors may include the presence of a junction, urban driving or unexpected events. The presence of such driving situations occurring simultaneously as the driver is conducting a secondary task can impair the reactions of a distracted, or overloaded, driver since their spare attentional capacity has been absorbed by the secondary task. With the increasing prevalence and potential of new in-vehicle information systems (IVIS) coming to market, this spare capacity could soon get accounted for, thus creating workload issues if not carefully managed. The understanding of how drivers interact with these systems when driving is key to minimising distraction and workload issues while maintaining the obvious benefits to the user provided by Satnavs, infotainment and emerging driving related Smartphone applications.

The issue of driver distraction is a very difficult factor to quantify, firstly because it can take different forms (visual, cognitive, physical etc.), but also measuring distraction itself is almost impossible. We have certain techniques to infer distraction which range from self-completed questionnaire, peripheral detection tasks, or measuring the time taken to complete a cognitive task. One of the most effective ways to record driver distraction is by assessing glance behaviour, and recording the length of time that the driver spent with their eyes off the road. The introduction of an in-vehicle information system will inevitably lead to drivers spending some time looking at the display while driving. As described above this may not be a problem in itself; however, this allocation of visual resource should not be taken from the driving critical tasks such as looking at mirrors, the instrument panel and most importantly the road in front.

For this reason the 'Visual-Manual NHTSA Driver Distraction Guidelines for In-Vehicle Electronic Devices' proposed in 2012 were devised to help limit potential driver distraction associated with non-driving-related, visual-manual tasks (National Highway Traffic Safety Administration (NHTSA), 2012). Along with other factors aimed at limiting physical interaction with the IVIS (such as limiting manual text entry to 6 key presses or fewer or not requiring the use of two hands), they propose certain guidelines for limiting glance behaviours. Most relevant to this study, and paraphrased below, are:

- For all other secondary, non-driving-related visual-manual tasks, the NHTSA Guidelines recommend that devices be designed so that tasks can be completed by the driver while driving with glances away from the roadway of 2 s or less and a cumulative time spent glancing away from the roadway of 12 s or less. If a task does not meet the acceptance criteria, the NHTSA Guidelines recommend that in-vehicle devices be designed so that the task cannot be performed by the driver while driving.

1.2. Aims and objectives

The aim of this study and current paper was to evaluate the effects that on-road driving with a smart driving system has on glance behaviours over an extended period of time in real-world driving scenarios verses a control condition. The analysis will adopt a 'holistic' methodology rather than being 'event driven', by this we mean analysing a longer section of roadway rather than a specific period of time surrounding IVIS activity or complex driving situations (such as approaching junctions or overtaking). This offers the advantage of understanding IVIS use during comparatively normal or routine driving conditions, allowing us to make a better assessment of visual allocation. In addition the analysis of glance behaviours when using in-vehicle systems during a specific 'task' is well represented with the literature (see Dingus, Antin, Hulse, & Wierwille, 1989; Engstrom, Johansson, & Ostlund, 2005; Horrey & Wickens, 2007; Kaber, Liang, Rogers, & Gangakhedkar, 2012; Renge, 1980; Rockwell, 1988; Victor, Harbluk, & Engstrom, 2005; and summarised by Green & Shah, 2004). However, the impact of IVIS on normal driving is less well known, and hence addressed in this paper. Therefore data presented in this paper can be used as a reference for normal and extended periods of driving by future research to evaluate the use of IVIS.

Obviously placing an additional information source in the vehicle will attract the drivers' attention – particularly a highly visual display that changes in real-time as being evaluated here – this is clear from the literature cited above. What is unknown is whether this re-allocation of visual resource is taken from driving critical procedures such as glances to the mirrors, instrument panel or the road ahead, or from any 'spare' visual capacity (c.f Green & Shah, 2004; Hughes & Cole, 1986).

2. Methodology

2.1. The foot-LITE smart driving aid

This current study utilised a smart driving system developed for a UK project called Foot-LITE.[1] The system developed aims to bring information on safety and fuel efficiency together on a single, integrated, adaptive interface. Foot-LITE provides the driver with feedback and information on smart driving behaviours in the vehicle, in real-time via a visual interface presented on a Smartphone (HTC HD2). 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 camera, the vehicles On-Board Diagnostics (OBDII) port, as well as 3-axis accelerometer and a Global Positioning Satellite (GPS) module.

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[1] See foot-lite.net.
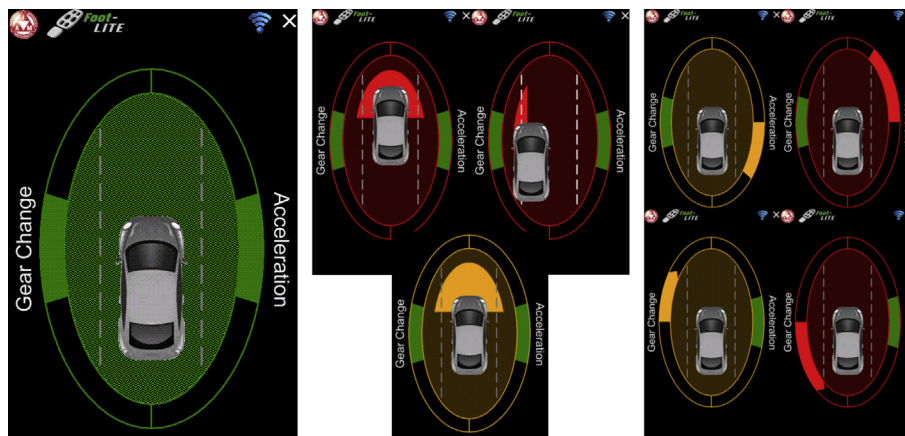
Fig. 1. Example screenshots from the Foot-LITE Smart driving advisor. Only one 'oval' is ever presented on the IVIS at any one time, but all aspects depicted can change in real-time and in combination. Picture 1 (left) – default green display. Picture 2 (centre) – top-left to bottom – headway warning, lane deviation warning, headway caution. Picture 3 (right) – top-left to bottom-right – braking caution, acceleration warning, change up caution, change down warning. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The Foot-LITE human–machine interface (HMI) concept (Fig. 1[2]) was developed based on principles of Ecological Interface Design (EID; Burns & Hajdukiewicz, 2004). Specifically relevant to the Foot-LITE project, 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 shown on the screen at the same time, 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 throughout the Foot-LITE project until the version, shown in Fig. 1, was released for on-road trials. The ergonomic development and evaluation of the HMI has been reported in previous papers (see Birrell & Young, 2011; Birrell, Young, Jenkins, & Stanton, 2012).

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

- *Headway:* A visual representation of time headway was presented to the driver as a cautionary threshold (shown as amber in Fig. 1, picture 2) when the driver was less than 2 s to the car in front, and a warning threshold (red) when below 1.5 s. When the driver was greater than 2 s, 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.
- *Lane departure warning:* A red warning was given to the driver when they deviated from their lane (Fig. 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 when having actually left their lane. There was no cautionary advice for lane departure warning.
- *Gear change advice:* The bottom half of picture 3 in Fig. 1 shows the gear change advice offered to the driver, with the amber arrows suggesting either a single gear change up or down in a sequential manner. Red arrows indicate gear either a block change (2nd to 4th gears for example) is preferable, or a single shift if high power demand are needed. Once the driver changes to the recommended gear this section of the HMI will revert to the green default.
- *Acceleration and braking:* As presented in the top half of picture 3 in Fig. 1 braking and acceleration advice is offered to the driver in order to limit excessive acceleration, and also to try and encourage a smoother speed profile. Again cautionary (amber) and excessive (red) warnings are given.

2.2. Driving scenario

The driving scenario adopted for this study was a fixed driving route in the Leicestershire area (central England), it was 40.1 miles (or 64.5 km) in length and took approximately 1 h and 15 min to complete. The scenario encompassed three clearly defined sections of roadway which included only one type of road category – 'Motorway', 'Urban' or 'Inter-Urban' (Fig. 2). To ensure comparisons could be made between each of the sections of roadway 3, 8 min 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 analysis were based on fixed GPS points relating to 8 min of the benchmarking run, therefore each participant completed the same distance and encountered the same traffic situations, but total driving time may vary slightly depending on self-selected

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[2] 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.
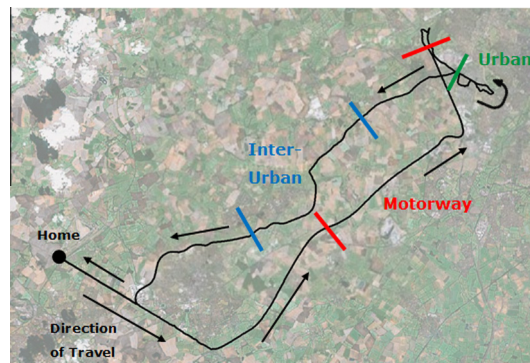
Fig. 2. Driving scenario adopted.

driving speeds, traffic densities etc. This resulted in an average driving time analysed for all participants of 23.2 min (SD = 0.63 min) in the control condition and 22.8 min (0.78) in the experimental condition.

The motorway (i.e. freeway, autobahn etc.) section consisted of 3 or 4 lanes with the merging of two motorways approximately halfway through this section; the speed limit was 70 mph ($\approx$113 kph). The urban section of roadway was completed on unregistered, residential single carriageway and one-way roads. The speed limit was 30 mph ($\approx$48 kph), with numerous traffic light controlled intersections, roundabouts and *T*-junctions included within this section. The inter-urban section linked two conurbations, with speed limits of 50 and 60 mph ($\approx$80 and 97 kph). The main carriageway was all one lane in width with multiple lanes at intersections and roundabouts; this section of roadway selected for analysis could also be classified as rural.

In all driving conditions participants were given route guidance instructions verbally by the experimenter, who accompanied all participants at all times during the driving scenario and 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 guidance 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'.

2.3. Experimental equipment

Driver glance behaviour was recorded using 4 cameras installed inside the vehicle (Fig. 3). Data were collected using the Race Technology Video4 hardware in conjunction with a GPS data logger (also supplied by Race Technology; DL1 Mk3). The first camera captured high definition video and was attached to the Smartphone holder and positioned to record the face of the driver. This made it easier to identify when the participant was looking at the smart driving IVIS. The three remaining cameras were standard definition and placed to record the forward and rearward facing driving scene, as well as one positioned to record Smartphone activity. All three were attached to the windows via suction cups.

All participants drove the same instrumented vehicle throughout the study; this was a UK right-hand drive 2006 Ford Focus Zetec, 1.6L diesel with manual transmission. The data loggers were fitted under the passenger seat, with associated cabling concealed as much as possible. The Smartphone which runs the Foot-LITE application was installed via a phone holder attached with a suction cup to the windscreen (Fig. 3).
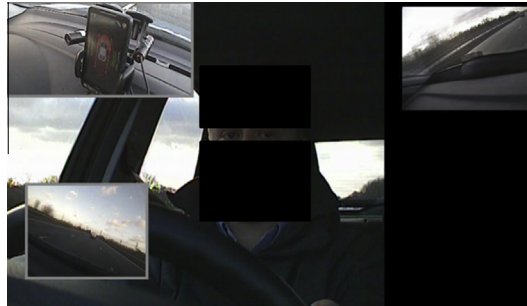
2.4. Participants

Data presented in this paper is a subset of that collected as part of a larger Detailed Field Operational Trial (or DFOT) completed for the TeleFOT project. TeleFOT is an EU funded project with wide reaching aims to investigate the use of nomadic devices (e.g. Satnavs, Smartphones etc.) in vehicles, assessing their effectiveness, safety as well as overall user perceptions. For this specific DFOT a total of 40 participants were recruited, all of whom were employees 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, to satisfy this numerous criteria had to be met including: being over 21 years of age; having held their licence for greater than one year; and not having over 6 points on their licence or having been disqualified from driving for certain offences. Also only participants were selected who did not have a working knowledge of the project. Fifteen participants (10 male and 5 female; Table 1) were selected from the original 40 to be included in this analysis. This selection was based on those with the highest quality of raw video data collected in both the control and experimental conditions, and also if the Foot-LITE system was working effectively throughout the entire route. Details regarding the performance effects of the Foot-LITE Smart driving system on driving behaviours are presented separately (see Birrell, Fowkes, & Jennings, 2013); in this current paper the focus is on the effect of the IVIS on driver glance behaviours.

Table 1
Study participant demographics.

	n	Age (yrs)		Driving experience (yrs)	
		Mean	SD	Mean	SD
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

Fig. 3. Camera locations taken from an example of video used for analysis.

2.5. 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. The order of which the participants completed the conditions were counterbalanced, this was to ensure an equal gender split (i.e. half the males and females completed the smart driving experimental condition first) as well as to overcome some scheduling issues.

When participants arrived to take part in the study for their first condition they were given a verbal and written explanation of the TeleFOT project and also 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 drivers 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 15 min of the journey was excluded (Fig. 2: 'Home' to start of 'Motorway') to ensure the drivers were comfortable with the vehicle controls.

Before 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. As explained previously the first 15 min of each driving trial was for vehicle familiarisation; in the experimental condition participants were also given further guidance on the smart driving interface as each event appeared on the screen. In both conditions participants were simply instructed to drive as they would do normally; however, in the experimental condition they were encouraged to visually interact with the smart driving IVIS, but only when they deemed it safe to do so.

2.6. Data analysis and dependent variables

In-vehicle cameras collected raw video files which could be played-back at various speeds (including frame-by-frame) within Race Technology's bespoke analysis software (Analysis v8); this also synchronised the video data with the GPS and accelerometer logger data collected. Pilot video analysis trials revealed that frame-by-frame video analysis was immensely time consuming; with a single 5 min reference period of video analysis for one participant taking up to 2 h to accurately process and code. As no automated analysis of raw video was available (to the authors' knowledge) an alternative method was needed. For this particular study an innovative method to analyse the raw video data was established which used the JWatcher[3] software. JWatcher is a freeware tool originally developed as an observational recording program 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:

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[3] http://www.jwatcher.ucla.edu.

- IVIS – the Foot-LITE Smart driving system.
- Mirrors – left and right wing mirrors, rear-view mirror (initially coded separately).
- Driving equipment – or vehicle controls (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 from centre to off-centre.
- *Road:* off-centre – looking out of the windscreen (but not centrally) or side windows (but not mirrors).
- 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 very start of the transition (or movement of the eye away from its fixed location), through to when it is fixed on its new location (dwell time), and ending just before the next transition begins. For real-time video analysis this poses a significant problem, as we do not know where the driver is going to fixate (i.e. look at) when they start the first transition. For this reason we used a slightly adapted definition of glance duration, 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 with a keystroke and activating the JWatcher time recording for glance duration. The key to this method was accurately and reliably defining the start of each glance fixation.

To further ensure accuracy of the video processing methodology intra and inter-analyst variation was assessed against the 5 min reference period mentioned previously, with results being compared to the frame-by-frame analysis. Initially analyst variations did occur, specifically with glances to the mirrors and experimenter. With limited guidance present in the literature as to what constitutes a glance to a specific location when driving, the authors established their own rules based on extensive practical experience handling the pilot data. Whilst it is appreciated that each driver is different and not every glance will be correctly identified, the comparison with the frame-by-frame analysis ensured reliability and repeatability was maximised, essential given the critical nature of the video coding to the study. Examples of the rules are shown below:

- Glances to the 'Rear View Mirror' involve only movement of the eyes <u>OR</u> significant head movements, not both. Also glances would be in a general upwards direction and not laterally.
- Glances to the 'Examiner' were defined as sideways (or lateral) glances involving movement of the eyes <u>AND</u> head, and would typically be shorter in duration.
- Glances to the 'Left Wing Mirror' were generally easy to define as they involve clear head <u>AND</u> eye movements across and down, dwell times would typically be longer in duration.
- Glances to the 'Right Wing Mirror' could be either only significant movement of the eyes <u>OR</u> head. These are different to 'Road: Off-Centre' as they will be looking in a downwards direction rather than just laterally.
- Glances to 'IVIS' are easily defined as the driver facing camera was placed next to the Smartphone, and glances were straight into the camera.

Since the accurate recording of glances was defined through the pilot analysis and the definition of the rules above, numerous other parameters could be defined from this. JWatcher recorded keystroke (or glance) data in text files that were imported into MS Excel for processing and parameter calculation. Results presented in this study are for all three roadway sections combined, i.e. the entire 24 min of the driving scenario. Statistical testing was conducted using SPSS 16.0 for Windows, with a MANOVA being used to evaluate potential differences between the control and experimental conditions, significance was accepted at $p < 0.05$. Dependent variables defined for this study are:

- Glance frequency – absolute and percentage of glances to a certain location.
- Glance duration – average, maximum and percentage of time spent at each location, and number of glances greater than 2 s.
- Glance transitions – percentage of glances to/from each location.

3. Results

The changes in glance behaviours when using a smart driving IVIS were assessed in this paper; the main interesting results are summarised in the following tables.

3.1. Glance frequency

The mean number of glances (in absolute form) made to any of the locations by participants was recorded at 1103.3 (SD = 130.3) glances in the control condition verses 1118.6 (110.3) in the experimental condition (Fig. 4). Fig. 4 also shows that approximately 15 more individual glances were made in total in the experimental condition when driving on the motorway. A similar number of glances were made in both conditions during urban and inter-urban driving.

The rest of the analysis presented will refer to combined results for the entire journey, separate statistical analysis was not conducted on individual roadway categories. Regarding the breakdown of glances to each recorded location for the entire
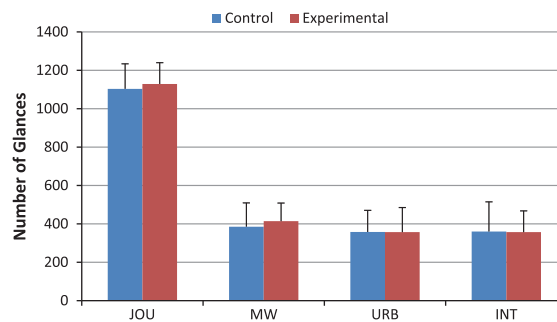
Fig. 4. Mean number of glances made to each location for the entire driving scenario, as well as each individual roadway section. Error bars represent standard deviation of the mean data.

journey, Fig. 5 shows that the introduction of the Smart diving in-vehicle system 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 11.3% (or 126.4 out of 1118.6) of the glances for the entire journey in the experimental condition. No other significant differences with respect to glance frequency were observed.

3.2. Glance duration

Mean single glance duration is shown in Table 2, with times of around 0.5–0.6 s 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 s (SD = 0.08). Maximum glance durations were again similar for both conditions, with times to areas other than the road being consistently around 1.3–1.4 s (Table 2). Interestingly the maximum glance duration to the IVIS was the lowest recorded (although not significantly) at 1.28 s.

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, 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 (Fig. 6).

The final glance duration parameter is the number of glances greater than 2 s. Results show that there were no single glances to the IVIS that were longer than 2 s made by any of the 15 participants for the 24 min of driving analysed. In fact very few glances were greater than 2 s (other than to the road), with only 1 glance to the mirrors, 3 to the driving equipment, and two others in the experimental condition.

3.3. Glance transitions

Table 3 shows that in the control condition 53.2% of glances were between the road centre and off-centre, this reduced to 37.0% in the experimental condition, a significant decrease ($F_{(1,29)}$ = 9.02, $p < 0.05$) in the number of transitions by 16.2%, again to compensate for the introduction of the IVIS in the experimental condition. As with both glance frequencies and durations a small reduction was also seen with respect to interactions with the mirrors, although as before this difference was not statistically significant.

4. Discussion

4.1. Glance frequency

The main outcome relating to glance frequency with this current study was that the total number of glances made was similar for both the control and experimental condition, at approximately 1100. Therefore the glances made to the in-vehicle smart driving system during the experimental condition must have, to some extent, been reallocated from a different location rather than simply increasing the absolute number of glances made. What we clearly would not want to see is a reduced number of glances to the main roadway ahead, or to driving relevant in-vehicle tasks such as speed monitoring or checking mirrors.

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, in a visual behaviour context, 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. Some obvious exceptions exist within off-road glances, such as those to
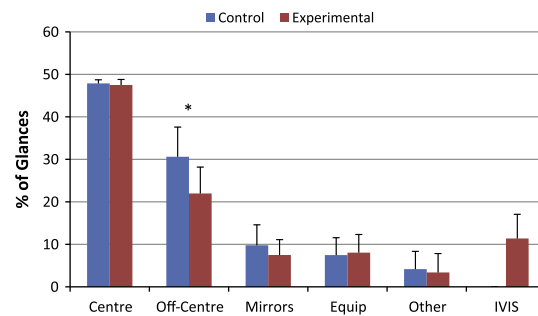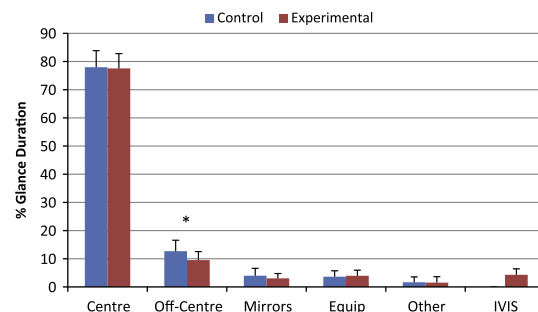
Fig. 5. Mean percentage of glances to each location in the control and experimental conditions. Errors bars represent standard deviation of the mean data. Asterisks (∗) indicates a significant difference ($p < 0.05$) between the conditions.

Table 2
Mean glance frequency and duration results for all participants combined from each of the three roadway sections for both Control and Experimental conditions.

	% of Glances		Ave. glance duration (s)		% Total glance duration		Max. glance duration (s)		N of glances >2 s	
	Con.	Exp.	Con.	Exp.	Con.	Exp.	Con.	Exp.	Con.	Exp.
Centre	47.87	47.60	2.32	2.20	77.98	77.49	19.58	18.41	158.4	155.7
Off road	30.61	22.10	0.54	0.53	12.70	9.52	4.65	5.25	5.53	5.00
Mirrors	9.78	7.47	0.49	0.50	3.99	2.96	1.39	1.38	0.13	0.07
Equip	7.47	8.14	0.62	0.61	3.63	4.03	1.30	1.37	0.07	0.20
Other	4.17	3.28	0.46	0.64	1.67	1.51	1.06	1.70	0.00	0.13
IVIS	NA	11.31	NA	0.43	NA	4.31	NA	1.28	NA	0.00

Fig. 6. Mean percentage of glance duration to each location in the control and experimental conditions. Errors bars represent standard deviation of the data. Asterisks (∗) indicates a significant difference ($p < 0.05$) between the conditions.

high sided vehicles during overtaking on a motorway, or to side roads and pedestrians in the urban environment. Nevertheless, the authors suggest, based on an understanding of the relevant literature and anecdotal evidence from the study participants, that a large proportion of glances within this category could be considered not safety or operationally critical to the driving task. However, a more detailed glance analysis is needed to fully substantiate this. The primary difference is that glances to the forward roadway and mirrors are essential for safe driving, as they are defined within the NHTSA risk ratio calculations (Klauer, Dingus, Neale, Sudweeks, & Ramset, 2006).

Results presented in Fig. 5 show that glances to the IVIS were predominantly (and statistically significantly) reallocated from the off-road glances with a reduction from 30.6% of glances made in the control condition to 22.1% in the experimental condition. No other significant interactions were observed. As described above this study is proposing that these would account for the 'spare' glances, and would have limited detrimental effect on driving safety. It is worth noting that Table 2 shows even in the experimental condition off-road glances still accounted for 22% of the total glances made, so those driving task related off-road glances would still likely be accounted for within this category. What is shown even more definitively is that 'Road: Centre' glances did not alter at all with the introduction of the smart driving IVIS, with the percentage of glances to this category being almost identical at 47.9% versus 47.6% for the control and experimental conditions respectively.

Research has suggested that when driving under higher mental workloads driver vision tends to focus on the forward facing view, and less on the peripheries (Harbluk, Noy, Trbovich, & Eizenman, 2007). Results from the current study could be interpreted as the smart driving IVIS leading to a reduction in the number of glances to the peripheries (as classified

as Road: Off Centre) as a result of an increased in mental workload caused by the system. However, this effect is not fully borne out in the results when we consider the reallocation of glances to the IVIS (again in the peripheries of vision) as described above, but is a potential outcome worth noting.

A comparison between previous studies investigating the effects of IVIS on glance behaviour is possible by assessing the number of glances per minute to the in-vehicle system; with the current study this was 5.54 glances per minute to the Foot-LITE Smart driving system. Lansdown (2000) showed that 2.06 glances per minute were made to the in-car entertainment system during a radio turning task and 4.94 glances per minute when interacting with a congestion warning device. Green, Hoekstra, Williams, Wen, and George (1993) showed a difference between older and younger drivers when using a Satnav system at an average of 7.1 and 7.5 glances per minute respectively. This suggests that using the smart driving IVIS in this study required less visual interaction than using a Satnav but more than when adjusting an in-car entertainment system. Given the relative complexity of the information presented on the IVIS evaluated in this study, namely real-time feedback on headway and lane deviation feedback as well as gear change and acceleration advice, this could be considered a positive outcome for the EID principles adopted for the HMI design.

4.2. Glance duration

Comparing the mean single glance duration results obtained in this study to other research conducted reveals comparable durations for glances to the analogue speedometer at between 0.4 and 0.7 s (Bhise, Forbes, & Farber, 1986 taken from Wierwille & Tijerina, 1998) and 0.62 s (Dingus et al., 1989). Average glance duration to the driving equipment (including speedometer and gear lever) with the current study was 0.62 and 0.61 s in the control and experimental condition respectively, which is comparable to the studies above and adds further credence to the accuracy and reliability of the method adopted to assess glance behaviour used here. Mean single glance durations to the mirrors in this current study (including left and right wing mirrors and rear-view) are generally a little lower than those reported in the literature at 0.5 s in both conditions compared to 1.0 s (Wierwille & Tijerina, 1998), and 1.1 s (Rockwell, 1988). However, this may be a result of the method to calculate the parameter. The above studies calculate eyes-off-road time which may well have included both transitions from the road to the mirror and then back again, unlike the current study which only included the single transition. Also, no specific driving manoeuvre or task was completed in this study, meaning mirror checking (particularly the rear-view) could predominately be considered a monitoring task which generally results in shorter glance durations (Kaber et al., 2012). Results from Lansdown (2000) showed mean single glance durations to the rear-view mirror to be 0.53 s, which is closer to the numbers found in this study.

Mean single glance duration to the Smart driving IVIS was 0.43 s, with Fig. 7 showing approximately 75% of the glances being between 0.2 and 0.6 s. Comparisons with previous research show that mean glance durations to a satellite navigation (or route guidance) system have been shown to be between 1.06 and 1.45 s (Dingus et al., 1989), approximately 1 second (Green et al., 1993), and 0.76 s (Morris, Reed, Welsh, Brown, & Birrell, 2013); glances to in car entertainment of 0.88 s (Lansdown, 2000), between 0.8 and 1.1 s (Dingus et al., 1989), and 0.6 s (menu navigation; Metz, Schomig, & Kruger, 2011); a surrogate in-vehicle task (arrow identification) between 1 and 1.5 s (Victor et al., 2005) and 0.73 to 0.94 s (Horrey & Wickens, 2007) depending on complexity; and finally 1.1 s when using a congestion warning system (Lansdown, 2000). What is clear from the results presented above is that mean single glance durations to an IVIS vary given the specific task and study, but in general times are around 0.8–1.1 s which is considerable greater than the 0.43 s in the current study.

This finding could be considered a positive outcome for the Foot-LITE Smart driving system, as whilst the number of glances to the system was comparatively high (compared to the mirrors and driving equipment) the durations were short. This according to Wierwille's prescriptive model, where shorter more frequent glances will be intermixed with periods with eyes-on-road, will preserve driving safety (Wierwille, 1993). Being able to perceive the information from the smart driving aid quickly and easily was very much implicit in the design of the HMI (see Young & Birrell, 2012). With graphical representations of environmental constraints for safety parameters and semantically mapped eco parameters, it would appear from this study that these criteria have been met.
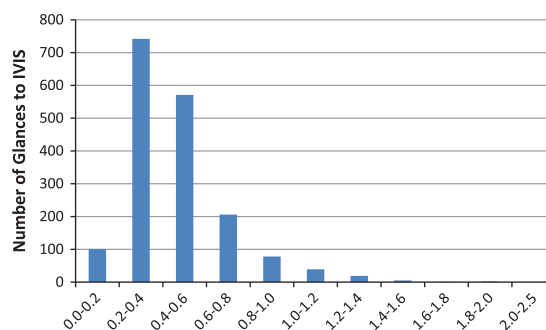

Fig. 7. Distribution of the glance durations to IVIS during the experimental condition.

No significant differences were observed with respect to mean single glance duration between any of the locations or conditions measured in this study (with the exception of the expected longer glances to the road compared to other categories; Table 2). It is however relevant to note that the longer than normal in-vehicle glances (i.e. maximum glance durations) are important as these may have a greater safety implication (c.f. Horrey & Wickens, 2007).

The NHTSA guidelines on in-vehicle electronic devices suggest that using an in-vehicle system should not result in glances away from the roadway for greater than 2 s (NHTSA, 2012). Whilst the Smart driving system used in the study was not specifically designed to limit visual interaction, attention was paid in the design process to limiting workload on the driver (both visual and cognitive). Results from this current study show that when using the Foot-LITE Smart driving system in our mixed route driving scenario, no single glances were made to the IVIS which were longer than 2 s by any of the 15 participants for the 24 min of driving analysed. This finding is fundamental, and whilst it cannot be concluded that the IVIS evaluated in this study does not cause any form of distraction to the driver, it does suggests that it complies with the proposed NHTSA guidelines. Even adhering to the more conservative recommendations by Horrey and Wickens (2007) – which suggests a correlation between in-vehicle glances of longer than 1.6 s to the likelihood of a collision – only 3 of 1830 glances (0.16%) to the IVIS were over this threshold (Fig. 7). In addition, the average maximum glance duration to the IVIS for all participants was 1.28 s and was the shortest (not significant) of all the locations analysed.

Table 2 shows that the percentage of total glance duration (mean for all participants) towards the centre of the road was almost identical in the control verses experimental condition, at 77.98% and 77.49% respectively. This suggests clear differences between the smart driving IVIS evaluated in this study and other IVIS. Victor et al. (2005) reported the percentage of time with eyes on the road centre to be between approximately 70% and 85% for baseline driving on motorway and rural roads. This decreased significantly when completing a surrogate in-vehicle task of varying complexity to between 55% and 65% of eyes on road centre for a simple visual task to between 35% and 55% for a complex visual task. Data from the 100-car naturalistic driving study presented by Klauer (2005) suggest that on average the percentage of time with eyes off forward roadway (excluding mirror glances) was approximately 18% for baseline driving (taken from 5000 5 s baseline epochs), this increased to approximately 26% when being involved in a near crash, and to 37% when involved in an actual crash. Again Table 2 shows that using the same criteria as the 100-car naturalistic study the mean time with eyes off forward roadway in this current study was 18.0% in the control condition and 19.5% in the experimental IVIS condition. From the comparisons presented above, and with the 100-car naturalistic driving study using the total time eyes off forward roadway as their principal measure to determine risk ratios of being involved in an incident or accident (Klauer et al., 2006), we can infer that using the Foot-LITE Smart driving system would not increase the risk of being involved in a road traffic accident or incident.
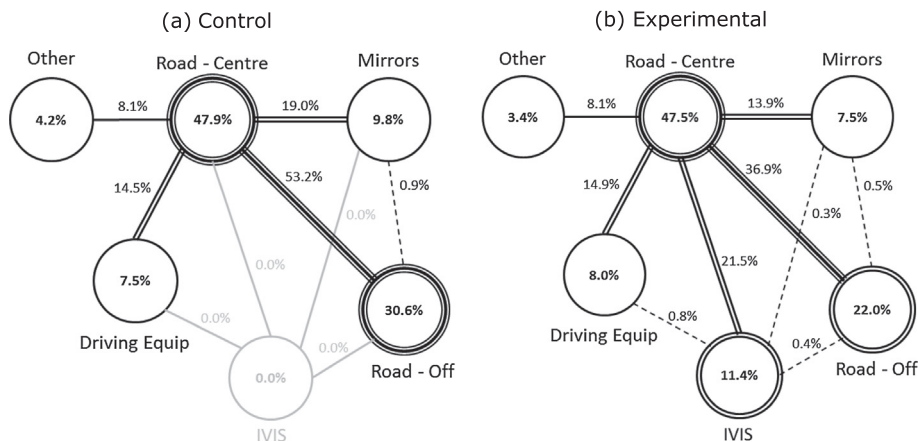
4.3. Glance transitions

As one would probably expect the vast majority of glances either originated from, or ended at the centre of the road; with these accounting for approximately 95% of all glance transitions (Table 3). In the experimental condition glances to the IVIS accounted for over a fifth of total transitions, showing significant interaction with the system during its use. An interesting finding was that in the experimental condition there were an average of 11 more glances to the driving equipment per participant than in the control, and could suggest an increase in interaction with other 'information' displays in the vehicle. Conversely, in the experimental condition glance transitions involving the mirrors reduced by 5.4% compared to the control condition (Table 3). Although these differences were not statistically significant, this final finding requires further investigation.

All the data presented thus far reveals some interesting findings regarding glance behaviours with the use of an in-vehicle smart driving aid, however summarising these results into one easily digestible format is difficult. For the purpose of this study a method was developed, termed Glance Transition Decomposition Analysis, adapted from work by Antin, Dingus, Hulse, and Wierwille (1990) who produced a probability diagram showing the percentage of total glance duration and transitions between the locations. Fig. 8 shows the data from this current study, with the circles representing the percentage of total number of glances to each location and lines linking the circles indicating the percentage of glance transitions between the two locations. The number of the lines either around the circles or of the linking lines indicates the percentage of glances either at or between each of the glance location categories.

Table 3
Mean percentage of glance transitions either made from or to each location (e.g. either from Centre to Mirrors or Mirrors to Centre) in both the Control and Experimental conditions.

Transitions to/from		Con.	Exp.
Centre	Mirrors	19.0	13.6
Centre	Off	53.2	37.0
Centre	Equip	14.5	15.1
Centre	Other	8.1	6.5
Centre	IVIS	NA	21.8
Centre	Any	94.7	94.0
Any	Any	5.3	6.0

Fig. 8. Glance transition decomposition analysis for (a) control and (b) experimental conditions using data from the current study. Single line (—) <10%; double line (=) 10–25%; triple line (≡) >25%.
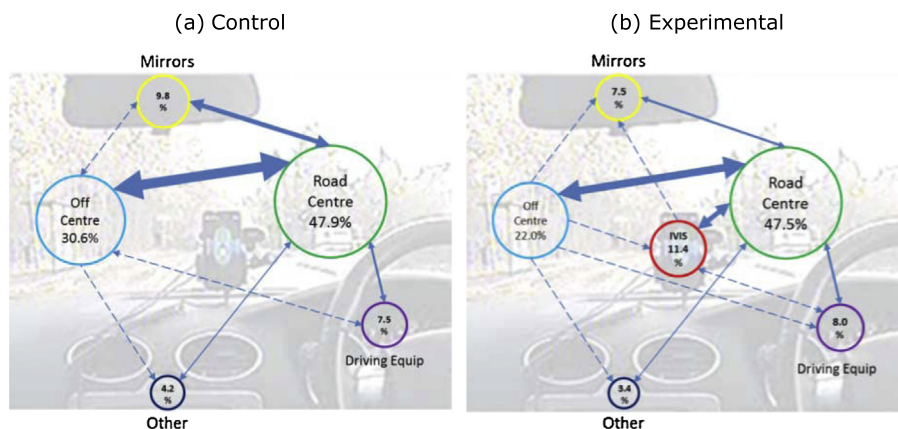
Fig. 9. Glance transition decomposition analysis for (a) control and (b) experimental conditions using data from the current study.

An alternative method for presenting the data is shown in Fig. 9. Here values and figures are superimposed onto an actual view of the driving scene from the current study. The area of the circle is proportional to percentage of glances, and the thickness of the connecting lines proportional to the number of transitions between locations. Both figures emphasise the interaction that takes place with the IVIS, with 21.8% of glances going from the road centre to the smart driving aid and numerous smaller interactions with the mirrors, driving equipment and off centre.

5. Conclusions

Comparing 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 and maximum glance durations and also the number of glances per minute. Using an in-car entertainment system 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, Breyer, Farber, Freyer, & Limbacher, 2009). One aspect from this current study which may warrant further research was the effect that using an IVIS had on mirror use. As can be seen in Fig. 5 the percentage of glances to the mirrors did reduce, although not significantly ($p = 0.152$). This was subsequently reflected in the percentage of the drive looking at the mirrors and also the number of transitions. This reduction could be interpreted in two ways, either the visual load demanded by the IVIS led to a reduction in glances to the mirrors, which is an obvious safety concern. Another argument could be made regarding perceived verses actual safety margins when using the Foot-LITE system. Drivers may have felt less inclined to check mirrors as they had a perceived safety net of the Foot-LITE system giving them feedback relating to the vehicles position on the road. Secondly, there was an increase when using Foot-LITE of actual safety margins, namely a significant increase in mean headway and a reduction in the time spent travelling closer than 1.5 s to the car in

front (Birrell et al., 2013). Both of these factors may have led to the drivers' perceived need to check the mirrors reduce, and certainly is a consideration for future research.

Findings presented in this paper show that using an in-vehicle smart driving aid during real-world driving scenarios resulted in the drivers spending an average of 4.3% of their time looking at the system, at an average of 0.43 s per glance, with no glances of greater than 2 s, and accounting for 11.3% of the total glances made. Given the results, the authors propose that the allocation of visual resource towards the IVIS could be considered to be taken from 'spare' glances, resulting in limited safety implications during real-world, on-road use. Importantly glances to the mirrors, driving equipment and at the centre of the road did not reduce with the introduction of the IVIS. With the 100-car naturalistic driving study suggesting that very simple secondary tasks do not appear to have a crash risk that is greater than normal driving (Klauer et al., 2006), this study concludes that an ergonomically designed in-vehicle interface, utilising ecological interface design principles, presenting both safety and eco-driving information to the driver via an integrated and adaptive interface does not have to lead to visual distraction, and the subsequent compromise in driving safety.

Acknowledgements

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