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## Studying the Effects of In-vehicle Information Systems on Driver Visual Behaviour – Implications for Design

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**Abstract** In-vehicle information systems (IVIS) are a common feature in modern vehicles. The interaction of drivers with IVIS when driving must be considered to minimise distraction whilst maintaining the benefits provided. This research investigates the glance behaviours of drivers, assessed from video data, when using two functions – a personal navigation device (study 1) and a green driving advisory device (study 2). The main focus was to establish the number of glances of 2 seconds or more to the IVIS and relate this to driver safety (as stipulated in new guidelines for use of IVIS proposed by NHTSA). In study 1, the percentage of eyes-off-road time for drivers was much greater in the experimental (with device) condition compared to the baseline condition (14.3% compared to 6.7%) but, whilst glances to the personal navigation device accounted for the majority of the increase, there were very few which exceeded 2 seconds. Drivers in study 2 spent on average 4.3% of their time looking at the system, at an average of 0.43 seconds per glance; no glances exceeded 2 seconds. The research showed that ordinary use of IVIS (excluding manual interaction) does not lead to driver visual distraction and therefore the impact on safety is minimal. The results of the study have important design implications for future in-vehicle information systems.

**Keywords** driver distraction, eyes-off-road-time, glance behaviour, green driving advisory system, personal navigation device.

### I. INTRODUCTION

Little is known about the manner in which drivers interact with new technologies in vehicles. Many such technologies are thought to increase the risk of driver distraction since they may increase the likelihood that the driver will take his or her “eyes off the road” during the driving task and hence not focus on the traffic conditions (i.e. become ‘distracted’), thereby increasing the crash-risk. In this study, ‘eyes-off-road’ is defined as any point during driving at which the visual attention is diverted away from the road towards the vehicle interior or mirrors. Hedlund et al. [1] provide a useful definition of distraction as being “a diversion of attention from driving, because the driver is temporarily focusing on an object, person, task or event not related to driving, which reduces the driver’s awareness, decision making ability and/or performance, leading to an increased risk of corrective actions, near-crashes, or crashes”.

Many recent studies have looked at the effect of distraction on crash risk [2-4] although distraction is not a new problem in road safety – it has been around for as long as people have been driving cars [5]. However, there is increasing evidence that it is one of the major contributing factors to car and truck crashes and incidents [2]-[6] and it is likely that the problem will increase as more and more advanced technologies and informatics find their way into vehicles. In response, there has been a recent explosion in research on this topic [7]. Many studies have looked at the overall effects of distraction on crash risk. The National Highway Traffic Safety Administration (NHTSA) [8] in the US estimated that at least 25% of crashes involve some form of distraction whilst other studies indicate that the rate of crash involvement amongst distracted drivers might be as high as 35-50% [9-10]. The former relates to the likelihood of distraction when a crash occurs whereas the latter considers the risk of accidents when distraction is known to have occurred. An important reference is Klauer et al [2] who, using data from the 100-car study, found that whilst short, brief glances away from the forward roadway for the purpose of scanning the driving environment are safe, glances totalling more than 2 seconds for any purpose increase near-crash/crash risk by at least two times. This important research based on video evidence collected from naturalistic driving studies forms the basis of new proposed guidelines generated by NHTSA [11] which include a recommended set of criteria that manufacturers are expected to use to ensure the systems or devices they provide in their vehicles do not distract the driver with tasks not directly relevant to safely operating the vehicle. One of the guidelines states that IVIS manufacturers should ensure that the design of the IVIS should be such that it limits individual off-road glances required for device operation to be no more than 2 seconds in duration which is in accordance with Klauer’s research. This sound evidence-based guideline has been used as a benchmark for some of the analysis described later in this paper. However interestingly, whilst the recommended guidelines are clear about IVIS not causing undue distraction by

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engaging the driver's eyes or hands for more than a very limited duration while driving, some electronic warning system functions such as forward-collision or lane departure alerts would not be subject to the proposed guidelines, since they are intended to warn a driver of a potential crash and are not themselves considered as distracting devices.

Overall, it is intended that the guidelines will be progressively phased in – the proposed Phase I distraction guidelines include recommendations to:

- Reduce complexity and task length required by the device;
- Limit device operation to one hand only (leaving the other hand to remain on the steering wheel to control the vehicle);
- Limit individual off-road glances required for device operation to no more than two seconds in duration.

The last recommendation is particularly relevant to this study since it has been postulated that glances totaling more than 2 seconds for any purpose increase near-crash/crash risk by at least two times that of normal, baseline driving.

Many in-vehicle Information and Communication Technologies (ICT) are now available on portable navigators and smartphones and the market penetration of these is increasing exponentially [12]. Nevertheless no standards exist which are directly related to the use of such devices in vehicles and there is little published knowledge about their overall impact on driver behaviour and safety. In 2008, a series of pan-European Field Operational Tests (FOTs) designed to collectively assess the impact of functions provided by "nomadic devices" (such as personal navigation devices) on the driving task were initiated. A Field Operational Test (FOT) is a relatively new concept in the field of transport safety research. The Field Operational Test Support Action (FESTA) handbook [13] defines FOTs as "*studies undertaken to evaluate a function or functions under normal operating conditions in environments typically encountered by the host vehicle(s) using quasi-experimental methods*". Essentially a FOT involves an extensive field-testing program which aims to assess the efficiency, quality, robustness and acceptance of ICT solutions for smarter, safer, cleaner and more comfortable transport and travel. Such ICT technologies include, for example, navigation and traffic information systems, advanced driver assistance systems and co-operative vehicle-highway systems.

The programme for field testing of nomadic devices was conducted in 8 EU Member States. The United Kingdom operated 2 different test sites in the midlands of England and each test site tested different devices. One test site hosted at Loughborough in the East Midlands of England tested a personal navigation device (study 1) whilst a second test site hosted at Nuneaton in the West Midlands of England (study 2) tested a green driving advisory system. The studies were conducted independently of each other and there were variations in the approach to the analyses. These are highlighted in the results section for each study.

The objective of this study and current paper was to evaluate the effects that driving with an IVIS has on glance behaviours during normal real-world driving scenarios in comparison to a control condition. The specific research question addressed was 'Does the device cause distraction?' and this was addressed by the hypothesis 'The duration and/or number of glances to defined areas of the driver's visual scene changes' whilst also determining the number of glances in excess of 2 seconds.

## II. METHODS

### ***Participants and Data Capture***

Participants for study 1 were novice users of a personal navigation device (PND) who had little experience with such devices. A total of 78 participants were recruited from the test-site locality and all completed a long-term Field Operational Test (L-FOT) which lasted for a period of nine months. However, from the 78 participants, a smaller sample of participants (n=10) were selected to participate in a Detailed Field Operational Test (D-FOT) involving enhanced data acquisition. The participants (6 male, 4 female) had an average age of 42 (S.D. = 12.9) and were selected purely on a willingness-to-participate basis.

Participants for study 2 were novice users of a prototype green driving advisory device who had little experience with such a device. In total 40 participants completed trials for this FOT. Data were excluded for over half of the participants as selection was made on the quality of the video footage for both the baseline and experimental condition trials. In total, data were analysed at an in-depth level for 15 participants (10 male and 5 female). All trials were conducted in daylight which was a constraint of the Data Acquisition System (which required good lighting to operate effectively).

Participants received a financial incentive for taking part in the studies. These were in the form of a one-off payment for each D-FOT and staggered payments throughout the L-FOT.

### ***Device Tested***

Study 1 tested a Blom Ndrive G800 device. The NDrive G800 is a personal navigation solution based on GPS technology. It provides navigation through visual and voice instructions, which includes names of roads and locations, door-to-door navigation and detailed information about points of interest.

Study 2 tested the Foot-LITE device. Foot-LITE is a Smart' driving system which incorporates Green Driving Support (GDS) with safety features of Lane Departure Warning (LDW) and Forward Collision Warning (FCW). Foot-LITE provides the driver with feedback and information on Smart driving behaviours in the vehicle in real time via an integrated visual interface presented on a Smartphone. The Smart driving advice offered is based on numerous internal parameters, with data being collected via an adapted lane departure warning camera and On-Board Device (OBD) II port, as well as accelerometer and Global Positioning System (GPS). In the tests conducted in the study, information was collected on the driver interaction with a display on the Human-Machine Interface (HMI) which provided feedback on aspects such as levels of acceleration/deceleration, lane positioning and departure warning, headway and gear change advice.

### ***Experimental Design***

A "within-subjects" experimental design was used for both studies. The participants completed a 'baseline' drive at the outset of the study during which data capture was performed. In study 1, the subjects were specifically requested to drive a prescribed route of approximately 25 kilometres and were directed by an experimenter who was present in the front passenger seat. The route contained a combination of urban/rural/mixed road types and a total of 27 junctions. Following this initial drive, these subjects returned to completing the L-FOT and were given a personal navigation device to use on a daily basis. After approximately 8 months (verified through subjective data collection via questionnaire), the same 10 subjects were requested to perform the same drive but using the navigation device to guide them around the route (the condition phase). The experimenter was also present during this drive but did not give navigation instructions during the second drive.

In study 2, all subjects only participated in the detailed experimental FOT and were asked to drive a prescribed route first without using the Foot-LITE device (baseline) and then some days later, with the Foot-LITE device (condition).

### ***Data Collection and Processing***

In both studies the subjects were asked to drive a vehicle fitted with a RaceTechnology D2 data-logger which captured data on GPS and several vehicle parameters. Vehicle data capture included information on position, speed, accelerations and vehicle operations and was recorded by an on-board GPS-based data logger. All data were recorded at 100Hz and synchronised automatically with the video data.

Video data were captured at both test sites using 4 configurable video channels. Two of the video channels captured contextual data from the road environment including the road ahead and the road behind the vehicle. The other two cameras were focused on the participant primarily to capture visual behaviour but they also provided an opportunity to record other aspects of driver manual interaction with the system and other vehicle controls.

### ***Data Processing***

Data were processed at both test sites using a combination of software applications including MATLAB, SPSS, SQL and basic DOS scripts.

In study 1, data were captured for all 10 participants for all of the journeys undertaken. However, because the objective of the study was to examine changes in visual behaviour that may be evident with use of a PND, the video data were 'clipped' such that only footage of driving manoeuvres through the 10 most complex junctions e.g. traffic volume and junction complexity including signalisation and presence of other road-users, were included. The rationale for this was that these were the locations on the route where the driver would be most reliant on the device for successful negotiation through the junction but also were the locations where mental workload and visual demand on the driver elicited by the PND would be at an absolute maximum given that the driver was reliant on the instructions and cues, both auditory and visual, given by the PND.

In study 2 the route was chosen to include sections of motorway, and urban and inter-urban driving environments so that the interaction with the green driving function could be assessed in these different

driving environments. A total of three 8-minute periods of driving were selected for each driver, one period for each road environment.

### Data Analysis

Visual behaviour was coded using a ‘data reduction’ approach and coding taxonomy of visual behaviour similar to that used in the 100-car study [2]. This included the PND or the Foot-LITE device during the experimental condition. A comparison was then made of the number of glances and glance durations to each of the selected locations within and external to the vehicle in the baseline and experimental conditions. The coding system and method for data reduction employed varied between the two studies; the details are included under the results for each study.

## III. RESULTS

### Study 1 (Personal navigation device)

The data collected in study 1 have been analysed using an independent t-test for statistical significance between the two driving trials (Baseline, no navigation device and Condition, with navigation device) at the 5% level.

The video data were examined frame by frame for 10 junctions and coded according to whether the driver was attentive to the road ahead (forward) or to elsewhere (other). Glances to the navigation device were identified separately. The analysis concentrates on the number and duration of glances that were away from the road ahead in order to answer the hypothesis outlined in the Introduction.

Addressing the hypotheses ‘The number of glances changes’, Figure 1 illustrates the increase in number of glances between baseline and condition trials. Statistically significant differences ( $t=8.235$ ,  $d.f. = 8$ ,  $p<0.001$ ) are found between the two conditions for all participants with the average increase equating to 37.5 additional glances per participant (the largest increase being 58 additional glances). This is approximately a 100% increase in number of glances between baseline and condition trials.

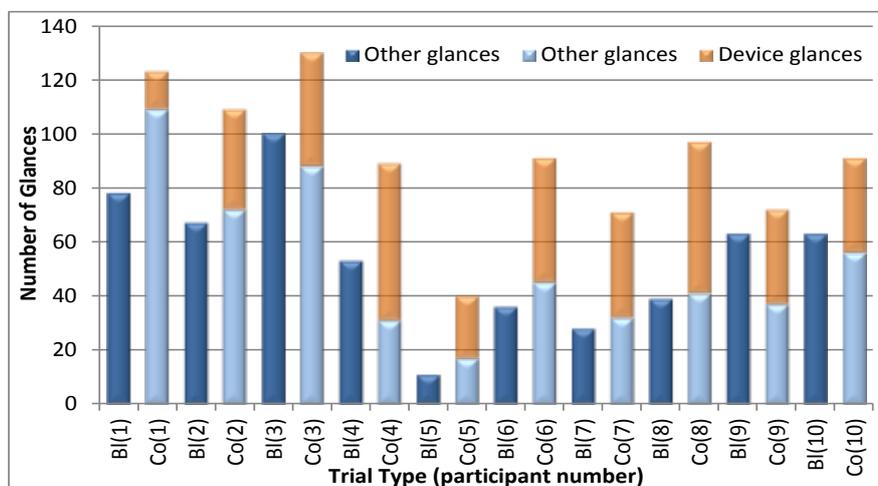


Figure 1. Number and location of glances across all junctions by baseline (BL) and condition (CO) trial type  
Personal navigation device

The number of glances for all junctions and by experimental condition shows that the increase is predominantly due to glances to the device (Figure 1). Despite some localised differences, the average number of ‘other’ glances between baseline (BL) and condition (CO) trials remained relatively close at 53.8 glances and 52.8 glances, respectively. The number of additional device glances instigated by the effect of the condition trial ranged between 14 and 58 (average 38.5). The increase in the number of glances between baseline and condition is 100% attributable to the device in 4 participants and 80% or greater in 5 others; only 1 case shows a lower increase with 31% of additional glances attributable to the device.

The average duration of glances made during the baseline and condition trials was 0.6 seconds and 0.71 seconds, respectively (Figure 2) and this difference was statistically significant ( $t=3.25$ ,  $d.f. = 8$ ,  $p<0.01$ ). The increase in duration ranged from 0.01 seconds to 0.25 seconds (average 0.11 seconds increase).

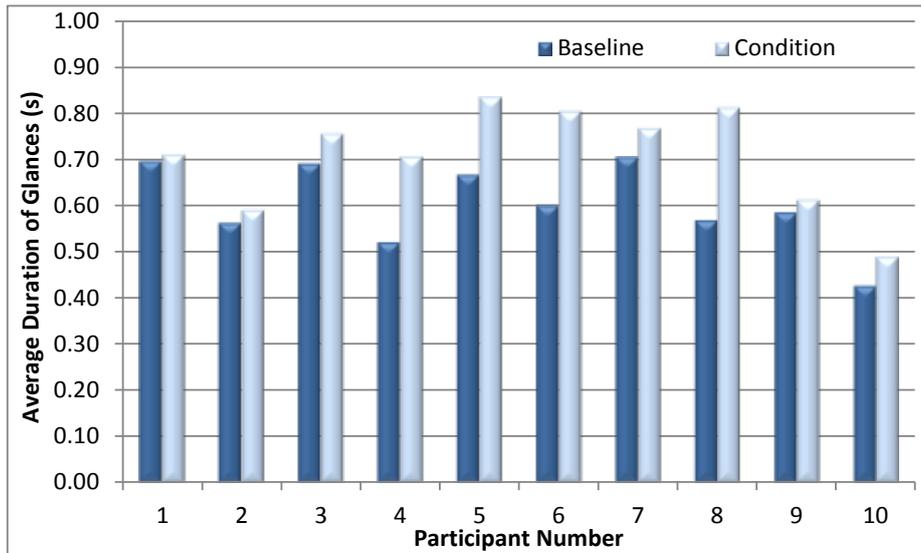


Figure 2. Average duration of glances across all junctions for baseline and condition trial type Personal Navigation Device

Glances to the test device during the condition trials were generally the longest glances compared to all other locations for both the baseline and condition trial (Figure 3). However, the difference in average duration of glances between baseline and experimental condition (not including the device) was not significant ( $t= 1.89$ ,  $d.f. = 8$ ,  $p=n.s.$ ) but the difference in glance duration between the baseline and the experimental condition (specifically average duration of glances to the device) was statistically significant ( $t= 4.71$ ,  $d.f. = 8$ ,  $p<0.01$ ). The average glance duration to the test device was 0.76 seconds compared to the average ‘other’ durations of 0.60 seconds and 0.65 seconds for baseline and condition, respectively. The greatest increase in glance duration to the device compared to an average of ‘other’ was 0.31 seconds, the average increase being 0.13 seconds.

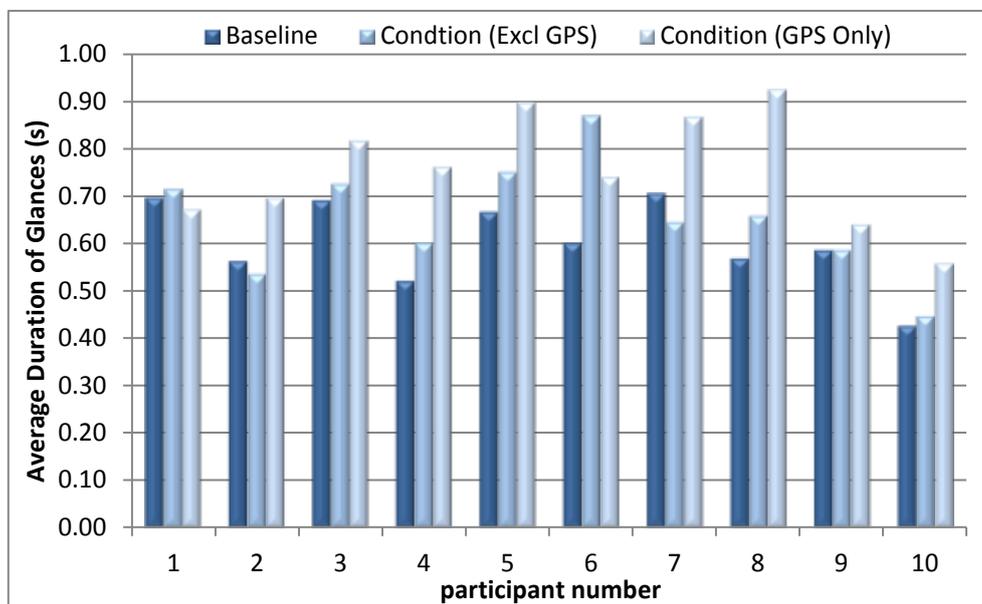


Figure 3. Average duration of glances across all junctions by glance location and trial type Personal navigation device

The majority of glance durations occurred between 0.4 seconds and 1 second (Figure 4). Glances of longer durations, particularly those over 2 seconds, did not feature significantly with only small differences between the baseline (BL) and condition (CO) phases (2 glances and 3 glances, respectively).

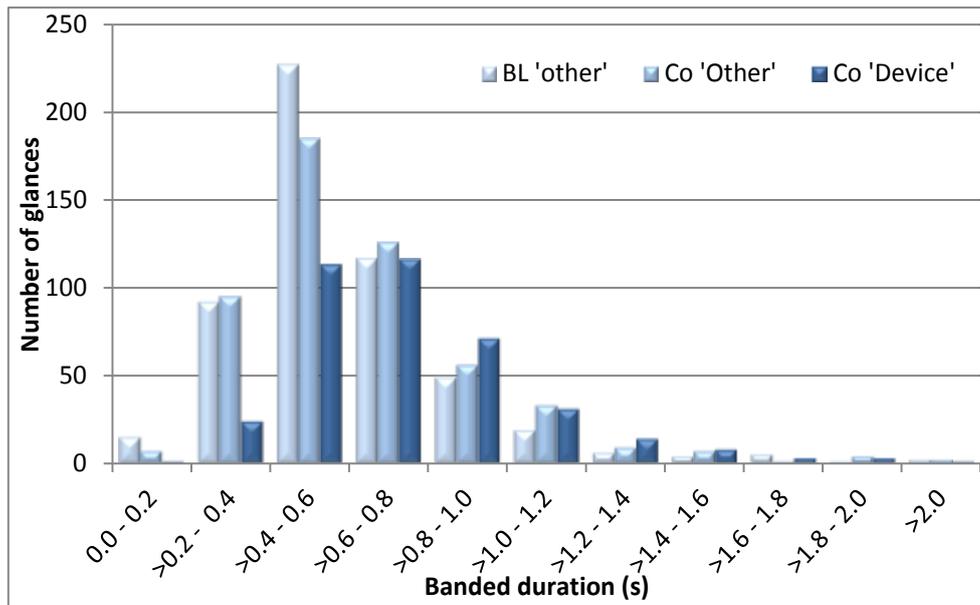


Figure 4. Number of glances to test device and 'other' locations by glance duration – All trials  
Personal navigation device

A slight increase in longer glances over 0.8 seconds was observed when comparing proportions of all 'other' glances (from baseline and condition trials) with device glances (Figure 4). An increase in shorter glances was also evident in the 'other' sample while very long glances (>1.6 seconds) remained consistent. There was no significant difference in the number of 2-second glances between the baseline and conditions trials.

### Study 2 – Green Driving Advisory Device

The data collected in study 2 have been analysed using an independent t-test and an independent F-test for statistical significance at the 5% level.

The video data in study 2 were reduced to record the glance duration to specific areas in the driver's fields of vision as follows:

- IVIS – the foot-LITE Smart driving system
- Mirrors – left and right wing mirrors, rear-view mirror
- Driving Equipment – or vehicle controls (e.g. instrument panel, gear stick, handbrake etc.)
- Road: Centre – centre of the roadway, which may not always be straight ahead if, for example, going round corners
- Road: Off-Centre – looking at the road but not centrally; includes side roads, oncoming traffic, traffic signs or non-specific road glances
- Other – glances other than those specified above (e.g. glances to the experimenter, non-driving related in-vehicle equipment etc.)

In order to reduce the video data for the analysis purpose, three 8-minute segments of data were coded. Each segment related to a different road environment: motorway, urban and inter-urban. Thus, 24 minutes of data were analysed for each participant.

Considering the research question related to the number of glances, the total number of glances (in absolute form) made to any of the locations by the participants was recorded at 1103.3 (S.D. = 130.3) glances in the control condition versus 1128.7 (S.D. = 110.9) in the experimental condition. Figure 5 below shows the average number of glances made to all locations for each roadway section and there is very little variation.

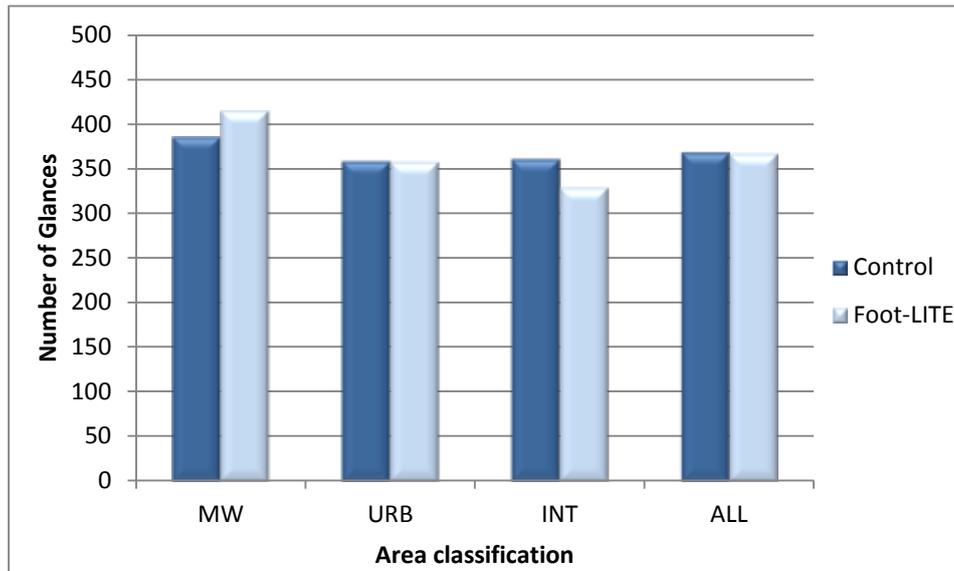


Figure 5. Total number of glances made for each area class and combined for control condition and Foot-LITE device - Green Driving Advisory Device in Motorway (MW), Urban (URB), Inter-urban (INT) and All Roads

Certainly there are slightly more glances made during motorway driving (MW) with the device active. However, this is not true for urban driving (URB) or inter-urban roads (INT) where there is no change and fewer glances, respectively. An average for all road types shows this clearly with 368 glances made in the control condition and 367 made during condition (Foot-LITE) driving. Statistical analyses of these data using a student's t-test were conducted. Overall the numbers of glances made in the control condition did not differ significantly compared to the numbers of glances made in the experimental condition. Furthermore, when the data were analysed according to individual road types (i.e. motorway, urban and inter-urban), there was also no difference in the numbers of glances made in the control and experimental conditions.

Using a multivariate analysis of variance (MANOVA), Figure 6 below shows that the introduction of the Foot-LITE system resulted in a significant reduction ( $F_{(1,29)} = 12.8, p < 0.01$ ) in the percentage of glances to 'Road Off-centre'. This is thought to arise from compensation for glances to the system, which accounted for some 11.4% of the glances in the experimental condition. No other significant differences were observed.

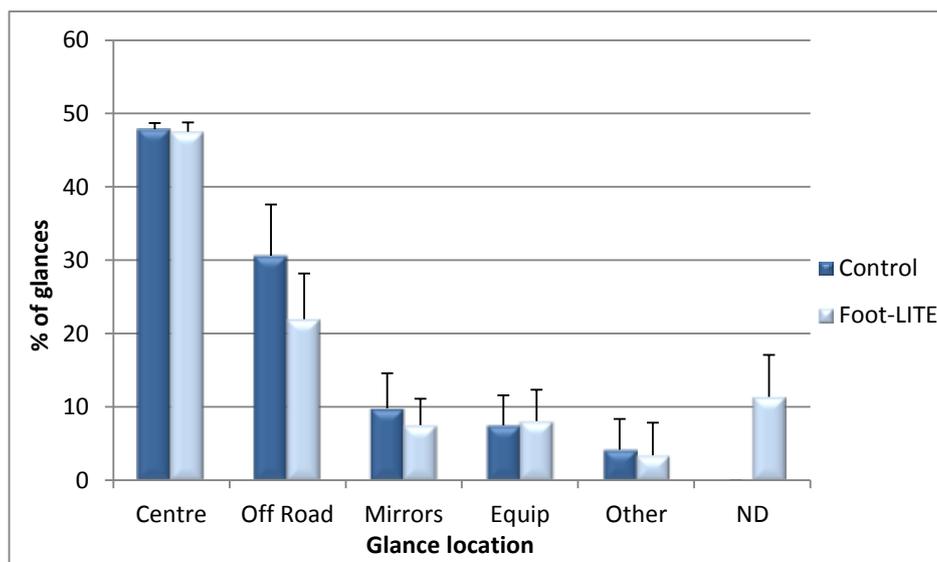


Figure 6. Mean percentage of glances to each location in the control (no device) and experimental (device present) conditions. Error bars represent standard deviations of the mean data – Green Driving Advisory Device

In respect of the duration of the glances, the mean glance durations to various locations in the vehicle are shown in Table 1 below. The average glance duration to the mirrors and driving equipment (displays) was around 0.5 to 0.6 seconds. No significant changes to mean glance duration was detected as a result of using the device on condition (Foot-LITE) trials. Mean glance duration to the Foot-LITE device was recorded as 0.43 seconds (SD=0.08) compared to glances to driving equipment (0.61 seconds) or mirrors (0.49 seconds).

	% of glances		Ave glance duration (s)		% total glance duration		Max glance duration (s)		Glances > 2s (n)	
	Control	F-LITE	Control	F-LITE	Control	F-LITE	Control	F-LITE	Control	F-LITE
Centre	47.87	47.5	2.32	2.2	77.98	77.56	19.58	18.41	158.4	156.3
Off road	30.61	21.97	0.54	0.53	12.7	9.52	4.65	5.25	5.53	5.0
Mirrors	9.78	7.49	0.49	0.49	3.99	3.04	1.39	1.38	0.13	0.07
Equipment	7.47	8.04	0.62	0.61	3.63	3.98	1.3	1.3	0.07	0.2
Other	4.17	3.38	0.46	0.64	1.67	1.53	1.06	1.06	0.0	0.13
Foot-LITE	NA	11.37	NA	0.43	NA	4.32	NA	1.28	NA	0.0

Table 1. Mean number of glances and glance durations for all participants combined from each of 3 roadway sections in control and experimental conditions - Green Driving Advisory Device

With few changes being observed in average or maximum glance durations, it would be expected that the percentage of total glances to each location would follow similar trends to glance frequencies – that is, in order to ‘allocate’ visual resource to the Foot-LITE device during the experimental condition, there would be a corresponding reduction in the percentage of glance durations off-centre when compared to the control condition. This was observed in the analysis using a MANOVA with the reduction being significant ( $F_{(1,29)} = 6.25, p < 0.05$ ) and with no other interactions occurring (Figure 7).

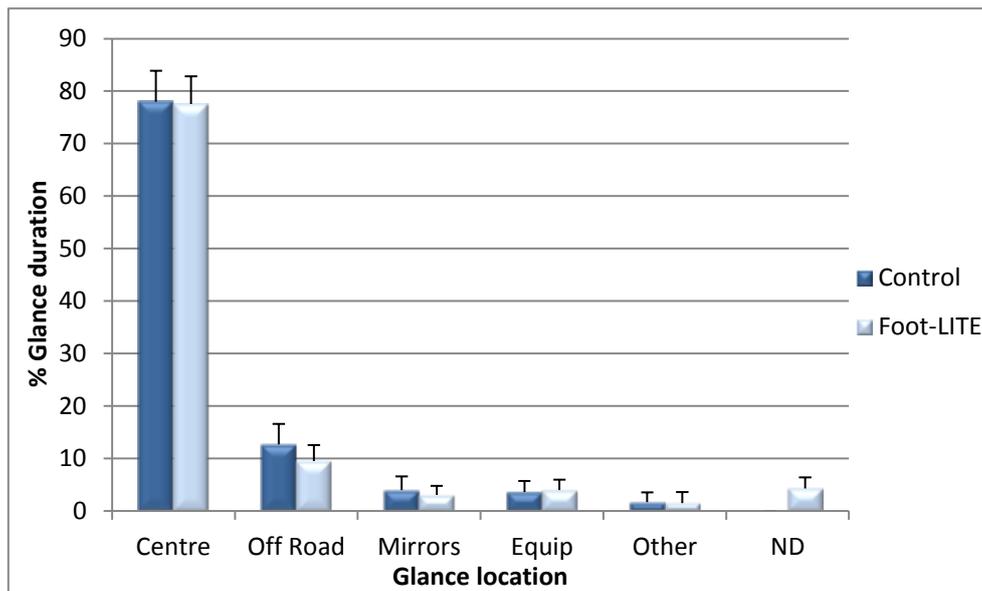


Figure 7. Mean percentage of glance durations to each location in the control and experimental conditions (Error bars represent the standard deviation of the data) - Green Driving Advisory Device

The final parameter examined was the number of glances greater than 2 seconds (Figure 8). Maximum glance durations to locations other than ‘centre’ (off road, mirrors, driving equipment, other and device) were consistently around 1.3 to 1.4 seconds’ duration. No change to maximum glance duration was observed as a result of using the device on condition trials. The maximum glance duration recorded for the device was 1.3 seconds.

No glance of greater than 2 seconds was made to the device by any of the participants during the 21 minutes of the driving scenario selected for this analysis. Six glances exceeded the 2-second threshold and were recorded to the driving equipment (x3), other (x2) and once to the mirrors. 75% of all glances made during the Foot-LITE trial were between 0.2 and 0.6 seconds, considerably below the 2-second threshold.

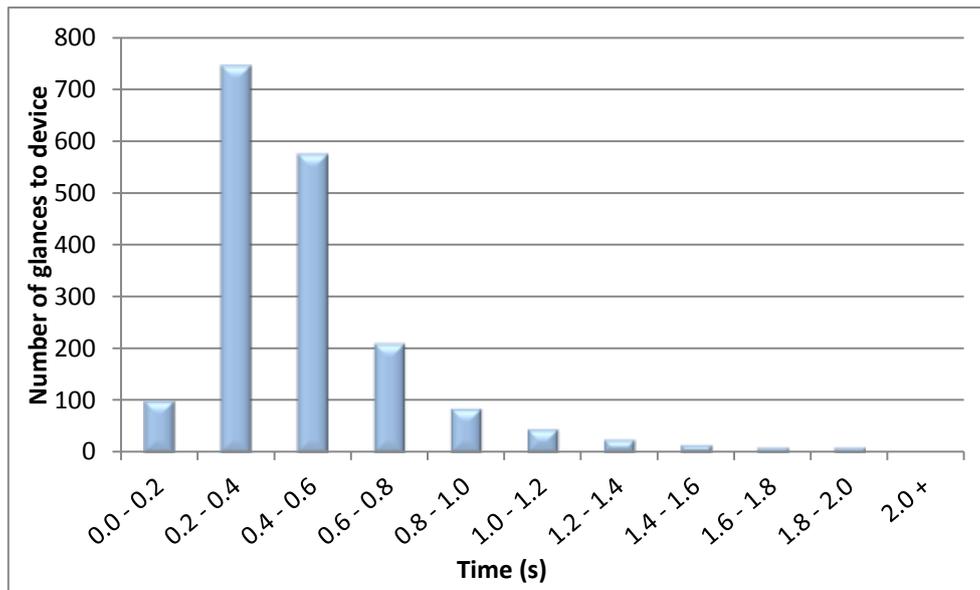


Figure 8. Number of glances to Foot-LITE device by banded glance duration

#### IV. DISCUSSION

In this study, the results of the FOTs for the Navigation Device showed that the device led to an increase in both the percentage of eyes-off-road time and the average glance duration. In some respects, a change in visual behavior is to be expected since the Navigation Device provides information, both auditory and visual, which is designed to be processed by the driver in order to significantly facilitate the driving task. However, it is necessary to examine whether this change in visual behavior is detrimental to safety by distracting the driver from focusing fully on the driving task.

One could argue that any additional eyes-off-road time beyond that required to safely operate the vehicle in accordance, for example, with the rules laid out for the driving test (rear view mirror, side mirror checks etc.) is intuitively negative in terms of safety. However, as introduced previously, relationships have been suggested between the length of glances away from the road and the risk of accident involvement although these relationships also need to be contextualised with vehicle speed and complexity of road environment which also influence crash risk.

In study 1, the percentage of eyes-off-road time for drivers was much greater in the experimental (with device) condition compared to the baseline condition (14.3% compared to 6.7%). However, further analysis of the glance behaviour shows that whilst glances to the personal navigation device account for the majority of the increase in eyes-off-road time (in accordance with intuitive expectations), when the durations of the glances are analysed, there are very few which are 2 seconds or more in duration; the average glance is 0.76 seconds which compared with average duration of glances to other target areas of 0.6 seconds, well below the proposed NHTSA guidelines.

In study 2, the main outcome was that the total number of glances made was similar for each condition, at approximately 1100. Therefore, glances to the in-vehicle Smart driving system during the experimental condition must have been reallocated from a different location. Mean glance duration to the Foot-LITE device was 0.43 seconds, with approximately 75% of the glances being between 0.2 and 0.6 seconds, also well below the NHTSA proposed guidelines.

Although there were a few glances over 2 seconds in either FOT, these occurred both to the navigation and equally to other areas of the visual scene. The 2-second guide is a rough rule of double risk which needs to be contextualised further with vehicle speed and complexity of road environment which influence crash risk.

It is difficult to compare the results of the Navigation tests with the Foot-LITE tests. For example, the HMIs are different as is the response expected from the driver with the Foot-LITE. HMI is associated with a simple driver response (speed up, slow down etc.) whereas navigation requires more cognitive processing to interpret

the information provided in order to make an appropriate response. Other devices with a diversity of HMIs may provide wider ranging and perhaps different results. Furthermore, the market is evolving quickly and even moved on during the life of the project. There is now more widespread use of smart-phone applications to provide functions, an example of a change in HMI. Hence, although the results of this study are useful on the assumption that they could be more widely extrapolated to the general traffic context, there is a need to keep evaluating how the changing HMIs affect driver distraction. However, comparing this with other research which has investigated the effects of using an IVIS on glance behaviours shows that time recorded with Foot-LITE was considerably less in comparison. Other studies of mean glance durations to personal navigation devices have been shown to be between 1.06 and 1.45 seconds [14] and approximately 1 second [15] whilst glances to in-car entertainment were found to be 0.88 seconds [16] and between 0.8 and 1.1 seconds [14].

Small sample size particularly was an issue in this study and further studies should aim to use larger samples where possible as well as automating the data analysis process. It should also be remembered that in both FOTs, it was only possible to examine segments of the drive to address the Distraction question. For a more comprehensive evaluation, it would have been necessary to examine on a frame-by-frame basis all of the video data for all of the individual drivers in all of the tests. However, with the available resources and project duration, it was only possible to analyse the video data for a sample of participants for which visual behaviour data were available. For these drivers, it was also only possible to select certain segments of the route driven. Whilst every effort was made to ensure that the segments (road junctions) that were chosen were both the most demanding in a visual and cognitive workload sense and where reliance on the nomadic device was high (and hence whether the risk of distraction was thought to be at its maximum), the fact remains that the sample size is small overall and nothing can be learned regarding the driving during other segments of the route. Although an initial attempt was made to overcome this dilemma by automating the visual data collection process (using eye-tracking equipment), this was not successful as it became apparent that eye-tracking equipment, which works extremely well in carefully controlled laboratory environments, does not work well in situations where the environment is very variable and changes rapidly (due to differential lighting).

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