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The Impact of Smart Driving Aids on Driving Performance and Driver Distraction

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driver distraction; workload

Abstract

In-vehicle information systems (IVIS) have been shown to increase driver workload and cause distraction, both of which are causal factors for accidents. This simulator study evaluates the impact that two prototype ergonomic designs for a smart driving aid have on workload, distraction and driving performance. Scenario complexity was also manipulated as an independent variable. Results showed that real-time delivery of smart driving information did not increase driver workload or adversely affect driver distraction, while also having the positive effect of decreasing mean driving speed in both the simple and complex driving scenarios. Subjective workload was shown to increase with task difficulty, as well as revealing important differences between the two interface designs. The findings are relevant to the development and implementation of smart driving interface designs in the future.

1. Introduction

1.1 Background

Modern vehicles contain an increasing amount of instrumentation, as a combined consequence of factors including the motivations of vehicle manufacturers, advances in technology and consumer demand. However, this added information available to the driver raises significant ergonomic concerns for driver mental workload, distraction and ultimately driving task performance. Whilst the implementation of legislation designed to reduce driver distraction – namely the banning of hand held mobile phone use (Young et al, 2003) – may help to tackle the symptoms of the problem, a more ergonomic approach would be to treat the cause by focusing on the appropriate design of in-vehicle information systems (IVIS).

Research completed for the ‘100-car naturalistic study’ in the US suggests that driver inattention accounts for almost 80% of crashes and 65% of near crashes (Klauer et al, 2006). Statistics from the UK and US accident databases show that driver distraction (a subset of inattention) accounted for between 2% (Stevens and Minton, 2001; Mosedale et al, 2004) and 8% (Stutts et al, 2001) of accidents respectively. Although these analyses found little evidence of distraction from IVIS systems, this is likely due to the age of the database being interrogated (Stevens and Minton, 2001, used data from 1985 to 1995). Nevertheless, as has been widely reported, there has been an increasing emphasis in recent times on the role that IVIS-related driver distraction plays in the number and severity of road accidents. This issue will only become more apparent with the increased number and sophistication of in-vehicle information systems available (Stevens and Minton, 2001).

Whilst the presence of such secondary tasks can increase the potential risk of an accident or incident, it has been suggested that drivers may have up to 50% spare visual capacity (Hughes and Cole, 1986) during ‘normal’ driving, suggesting that some secondary tasks may be conducted with no subsequent increase in crash risk. Therefore, other contributing factors also have to occur at the same time for this risk to manifest itself (Angell et al, 2006). Contributing factors may include the presence of a junction, urban driving or unexpected events. Such factors 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 IVIS products coming to market, this spare capacity could soon get accounted for, thus creating workload issues if not carefully managed. One such area for new IVIS devices are regarding fuel efficient or safe driving, which combined form the basis for ‘Smart Driving’ (Young et al, 2011).

1.2 IVIS for Smart Driving

Within the European Community, road transport accounts for approximately 15% of greenhouse gas emissions and resulted in 38,875 deaths a year (Eurostat, 2011). As a result of additional legislation and an increase in consumer awareness, motor vehicle manufacturers have started to embrace the ‘eco revolution’. As well as developments in low carbon vehicle technologies, more recently the market has seen a number of ‘green’ IVIS interfaces aimed at encouraging environmentally friendly driving. Meanwhile, safety concerns continue to drive progress with advanced driver assistance systems (ADAS), many of which include an additional interface to the driver. The proliferation of such systems and information overload in the car could pose a potential threat to driver distraction, resulting in the opposite effects to those desired (Young et al, 2011).

A UK led project called Foot-LITE aims to bring information on safety and fuel efficiency together on a single, integrated, adaptive interface, providing driver feedback and advice on aspects of safe and green driving styles. The system ostensibly comprises two aspects: an in-vehicle system providing real-time feedback and advice on driving style, coupled with a post-drive, PC based data logging system which aims to encourage longer terms behavioural changes and help inform transport choices. In the current paper, our focus is on the ergonomics of the in-car interface – with the aim of eliciting the desired 'smart' driving behaviours whilst avoiding negative effects such as distraction or overload. In terms of the Foot-LITE project 'Smart' driving is defined as that which is both safe and fuel efficient. A previously completed Cognitive Work Analysis (CWA; Rasmussen et al, 1994; Vicente, 1999) – which defined project constraints and detailed principal information elements which could be presented to the driver – highlighted several behavioural aspects the system would hope to address. These were correct gear change (including the appropriate use of block changes) and maintaining a consistent speed profile facilitated by planning ahead in order to avoid unnecessary acceleration and braking events, both of which relate to fuel efficiency. With respect to safety, maintaining an appropriate headway (distance to you and the car in front), lane position and lane deviation were identified (Birrell et al, 2011).

1.3 Foot-LITE Interface Designs

A rigorous ergonomic methodology has been adopted in order to minimise distraction to the driver as a result of the in-vehicle aspect of the Foot-LITE system. In order to achieve the goals of changing driving style while avoiding negative effects of distraction or increased workload, the in-car interface in particular needs to be designed with the driver's information requirements in mind. Two human machine interface (HMI) designs were conceived, both very different to each other, but both displaying the same information elements as described above (namely gear change and acceleration (eco), and headway and lane deviations (safety)), thus maintaining information equivalence across each – it is simply the format of presentation which varies between the two interface designs.

The first design concept was generated based on principles of Ecological Interface Design principles (EID; Burns and Hajdukiewicz, 2004). Specifically relevant to the Foot-LITE project EID (figure 1[1]) offers to dynamically reflect the driving environment and integrate complex information onto a single, direct perception display (Burns and Hajdukiewicz, 2004). Safety and Eco information on the ecological display – termed in the rest of the paper as 'EID' – is grouped which according with all parameters being shown on the screen at the same time, and changing in real-time depending on the driver's inputs.

Insert Figure 1 here

As an alternative to the EID concept, a more conventional dashboard-type interface (referred to as 'DB'; figure 1) has also been developed according to best practice in the human factors literature (such as the European Statement of Principles on human machine interface for in-vehicle information and communication systems; EC, 2008). Initially based on a vehicle instrument panel layout, the DB interface consists of warning icons (derived from ISO 2575: 2004) and textual information. The basic principles of the design are that only one parameter is shown to the driver at any one time, this being the parameter which was deemed to be the highest priority, the interface then 'scrolls' through the relevant warning icons. The DB design is intended to offer familiarity to drivers being akin to a standard instrument panels,

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

warning messages and icons available in most vehicles. For a more detailed description of the interface designs evaluated in this study please refer to Young and Birrell (2010).

1.4 The current study

Following a rapid prototyping study to refine both designs (see Young and Birrell, 2010), the EID and DB interfaces were subject to more rigorous testing in the Brunel University Driving Simulator. The primary aim of the current study was to assess the impact that these smart driving aids may have on driving performance and driver workload and distraction. Additional aims were to compare the efficacy of the smart driving aids and determine if they do foster the positive, and intended, changes in driving behaviours. The simulator testing represents a filtering stage in the Foot-LITE development process, to select one design to be taken forward to the next stage of user evaluation.

2. Methodology

2.1 Design

The study utilised a 3 (interface design: control, EID and DB) x 2 (driving cycle: Urban and Extra-urban) within-subjects, repeated measures experimental design. The control condition was to record baseline driving performance with no smart driving advice offered. The order of conditions were counterbalanced across participants (see Procedure, below, for further details) to negate order effects.

In addition to the two interface options (EID and DB, detailed in the introduction) two different driving scenarios were developed for this study. These were an ‘Urban’ and ‘Extra-Urban’ scenario, both based on the New European Drive Cycle (NEDC) against which standard emissions data are tested. Both driving scenarios consisted of four 3 m wide driving lanes (two for the driver's direction of traffic and two for approaching traffic), and were a fixed distance in length, thus taking approximately five minutes each to complete when driving at the appropriate speeds. The urban cycle consisted of driving in a city environment with no barrier between the two directions of traffic, at a speed limit of 30 mph. A series of eight traffic light controlled intersections were placed at specific locations, either with or without pedestrian crossings. The second driving scenario was an extra-urban cycle consisting of a dual carriageway with varying speed limits. Within the extra-urban cycle, the driving environment changed from a more urban setting (with shops, offices, bus stops, petrol stations etc. and a barrier separating the two directions of traffic) within the 40 mph section of the scenario, to a rural setting for the final higher speed sections of the scenario (60 and 70 mph). This scenario was free from stop signs and traffic lights; however, other traffic of varying speeds was placed in the nearside (left hand lane for the UK scenario) for the driver to negotiate. In order to limit a learning effect of repeating the driving scenarios, two different versions of each were created. Both were based on the same physical road infrastructure, but traffic light sequences (in the urban cycle) and traffic frequency (extra-urban) were randomised, but amount of traffic and number of red/green light passed remained consistent.

2.2 Dependent Variables

Dependent variables included objective and subjective metrics of driving performance, driver distraction and workload. Numerous objective parameters of primary task (i.e., driving) performance were assessed for this study, including mean values over the entire driving scenario for speed, acceleration, deceleration and time headway. In addition to these mean data, percentage of journey time spent in excessive acceleration, braking and headway was also recorded. ‘Excessive’ in the context of this study was defined when a predetermined threshold – as recommended by guidelines set out by the Institute of Advanced Motorists, and adapted by algorithms completed by Ricardo Ltd (both partners on the Foot-LITE project) – was exceeded. For example excessive headway was based on driving standards guideline of maintaining a two second gap to the car in front. When this threshold was exceeded a ‘red’ warning was triggered to be displayed. In the control condition no smart driving feedback was presented to the driver, however the raw data were still collected and analysed. Finally, the percentage of time speeding and time taken to complete the driving scenario were also recorded.

To infer driver distraction, a secondary visual task was adopted – the Peripheral Detection Task (PDT). The PDT is popularly used to objectively assess workload during driving, and has been shown to be sensitive to changes in driver workload as well as distraction caused by the use of IVIS (Harms and Pattern, 2003; Jahn et al, 2005). The basic premise of the PDT is that during times of increased driving mental workload, the driver will reduce the time spent looking in the peripheries of their vision. This includes the peripheries of their forward vision as well as scanning and monitoring of instrument panels and mirrors (Harbluk et al, 2007; Recarte and Nunes, 2000). Deterioration in PDT performance, represented by either an increase in response time or decrease in correct responses, would infer that the smart driving aids were adversely affecting driver attention.

The PDT used for this study was a standardised task within the driving simulator software, consisting of changing symbols which appear in the top left and right of the drivers’ forward peripheral vision. At 10 predefined times throughout the driving scenario, these symbols changed from their default shape, of a red diamond, to a red triangle. The driver’s task was to respond as soon as they noticed the change by pressing a button on the steering wheel corresponding to which symbol had changed. Response time and accuracy of response were measured; if no response is made within 10 seconds, a ‘miss’ is recorded and the symbol reverts to its default. Again to limit the learning effect, the time and location of PDT events were randomised for each driving scenario and interface condition.

The Driver Activity Load Index (DALI; Pauzie and Forzy, 1996) was used to rate participants’ subjective ratings of driving performance and workload. DALI is heavily based on the NASA Task Load Index (TLX; Hart and Staveland, 1988) and evaluates workload specifically during the driving task. It is less frequently used than the TLX, but more tailored for the evaluation of IVIS (e.g., Pauzie, 2009; Tretten et al, 2009), with ratings for six factors (global attention demand, visual demand, auditory demand, stress, temporal demand and interference), each scored from zero to five (low to high). A mean value is then calculated for all six factors, resulting in the DALI rating.

2.3 Apparatus

2.3.1 Driving Simulator

The Brunel University Driving Simulator (BUDS) was used for this study. BUDS is a fixed-base, fully interactive immersive simulator based on a 2006 Jaguar S-Type full vehicle body. The driving simulator software is provided by STISim (Systems Technology Inc, Hawthorne, CA; Build 2.08.04), which has state-of-the-art graphics hardware enabling a real-time, fully-textured, anti-aliased, 3-D graphical scene of the projected virtual world. The images are projected via three Toshiba TDP-T95 digital projectors onto three 2.4 m x 2.0 m (viewable area) screens at a resolution of 1280 x 1084 pixels, thus giving the forward facing scene plus the left and right peripheral scenes. In total from the driver's seat the projection covers a 150° horizontal and 45° vertical field of view. Simulated images of the dashboard instrumentation as well as rear view and side mirrors are projected onto the viewing screens. The simulator is controlled by a Logitech multimedia driving unit (G25 Racing Wheel) consisting of steering wheel, gear lever and pedal block (including clutch pedal), fitted in the car as a UK-standard right-hand drive vehicle. The Logitech driving unit allows for simulation of manual or automatic transmission, with manual being used in the present study. The frame rate and data capture rate throughout the study were fixed at 30 Hz.

2.3.2 In-Vehicle Human Machine Interface

To present the two interface designs to the driver, a 7" colour screen (Dicoll Ltd Model W07T740-OFA3) was placed in the vehicle. This was located on the centre console to the left of the steering wheel to enable ease of viewing without blocking the driver's view of the road ahead. The interface presentation was fully integrated with the simulator software, such that it provided actual feedback on the drive in real-time.

2.4 Participants

Twenty-five participants (14 female, 11 male) with an average age of 35.2 years (SD = 8.7) completed the study, none of whom had no prior knowledge or involvement in the Foot-LITE project. Inclusion criteria for participation were that they drove regularly on UK roads and at least 5,000 miles per year, they had at least three years driving experience and held a full EU licence, and had normal or corrected-to-normal vision.

2.5 Procedure

Each driving scenario (urban and extra-urban) was completed for each of the interfaces (EID and DB) as well as for the baseline, totalling six experimental conditions. Before the experimental conditions were conducted participants were given a five-minute practice drive (consisting of a mixed driving route, encompassing city and dual carriageway, including negotiating intersections) in the simulator to get used to the controls and the PDT. In an effort to minimise the possibility of order effects influencing the outcomes of the study, the order of which the experimental conditions were completed was counterbalanced. This was with the exception of the baseline conditions (i.e., without any feedback) which were always completed first in order to reference participants' driving behaviours without them being exposed to the smart driving rules. The remaining conditions (2 x interface, 2 x driving scenario) were then counterbalanced.

After the control conditions, but before the interface conditions were completed, participants were given an introduction to the two interface designs. This briefing was considered very important as it ensured that participants evaluated the scenarios and interfaces with some knowledge of what the displays were trying to convey. Far from contaminating the study, it was felt that such briefings were essential in obtaining meaningful data, and was realistic in covering the kind of information which might otherwise be found in an instruction manual or supporting documentation for the Foot-LITE product. At the end of each experimental condition participants completed the DALI questionnaire, as it focuses on interaction with the smart driving aid it was not completed following the baseline conditions.

2.6 Data Analysis

Raw data (collected at 30 Hz) was processed in MS Excel, then aggregated across all participants for each parameter to enable comparisons of mean data. Outlying data points (as determined by SPSS) were reviewed for measurement artefact or erroneous data, but were not removed unless obvious errors or trends were identified. Statistical significance of the subjective measures of driver workload (DALI) and was assessed using Friedman and Wilcoxon Signed Rank tests, while the driving data were assessed using two MANOVAs and related Bonferroni corrected pairwise comparisons, one for urban and one for extra-urban driving. Statistical significance was accepted at $p<0.05$ and conducted using SPSS 15.0 for Windows.

3. Results

3.1 Primary Task Performance

Mean driving speed returned a significant main effect between the three experimental conditions in both the urban ($F_{(2,68)} = 3.11$, $p<0.05$) and extra-urban ($F_{(2,68)} = 4.31$, $p<0.05$) driving scenarios. In addition to these main effects, pairwise comparisons revealed that when driving with either interface design (EID or DB) in urban driving, mean driving speed was significantly ($p<0.05$) lower than that of the baseline condition (figure 2). However, for extra-urban driving this difference was only significant when considering the EID compared to baseline (figure 2). Another speed related parameter was the percentage of time spent travelling over the speed limit, where a significant main effect was observed for both urban ($F_{(2,68)} = 2.30$, $p<0.05$) and extra-urban ($F_{(2,68)} = 3.63$, $p<0.05$) driving. Pairwise comparisons revealed both EID and DB to be significantly ($p<0.05$) lower than baseline in urban driving, and again only EID to be lower than baseline in extra-urban driving (figure 3).

Insert Figure 2 and 3 here

Mean acceleration showed a significant main effect ($F_{(2,68)} = 3.96$, $p<0.05$) within urban driving. Figure 5 shows that this decrease was as a result of smart driving feedback from either interface; however, the difference was only significant ($p<0.05$) with the pairwise comparisons between the DB and baseline conditions. There was also a trend ($p\approx0.1$) for a decrease with smart driving feedback in the extra-urban driving scenario (figure 4).

Insert Figure 4 here

The percentage of time that the participants spent in excessive acceleration (indicated by a red warning being displayed on the smart driving advisors) also elicited a main effect ($F_{(2,68)} = 3.45$, $p<0.05$) between the conditions in urban driving. Figure 5 shows that whilst both interface designs resulted in a decrease, this again was only significant between the DB and baseline conditions. No differences were observed with extra-urban driving.

Insert Figure 5 here

When considering mean and excessive deceleration parameters in urban driving, only excessive deceleration differed significantly between the conditions ($F_{(2,68)} = 4.17$, $p<0.05$). As with acceleration, this difference was only significant between the DB and baseline conditions (figure 5). In the extra-urban driving cycle no deceleration parameters differed between experimental conditions.

Neither mean nor excessive headway (time spent under two seconds) parameters revealed a significant difference between experimental conditions or driving scenario. Despite this, figure 6 reveals that the reduction in percentage of time that drivers spent at excessively low headways when using either of the smart driving aids did approach significance (*p*=0.060) for the main effect. This difference was not deemed significant most likely as a result of the large deviations within the data, shown by the error bars. Finally the time taken to complete the run was recorded with no differences being observed for either driving scenario.

Insert Figure 6 here

3.2 Peripheral Detection Task Performance

Results for PDT performance showed that the interface conditions (EID and DB) resulted in faster mean response times (of approximately 0.6 seconds) to the PDT when compared to the baseline condition in the urban cycle, although surprisingly the analyses found this difference to be non-significant (*p*=0.097). However, a significant main effect was observed for the number of correct responses to the PDT ($F_{(2,68)} = 3.97$, $p<0.05$). The EID condition resulted in the greatest number of correct responses, averaging 9.5 (out of 10 divided attention events), with pairwise comparisons revealed that this difference was significant ($p<0.05$) when compared to the baseline condition in urban driving (figure 7). Mean response time and number of correct responses to the PDT were very similar between all three experimental conditions in the extra-urban scenario, with no significant main effects or pairwise comparisons being observed.

Insert Figure 7 here

3.3 Subjective Measures

On the DALI rating scales, participants rated the EID interface as presenting significantly lower workload ($Z = -1.99$, $p<0.05$) than the DB interface design when driving the urban setting (table 1). No difference was observed during the extra-urban scenario. As expected and was implicit in the study design, urban driving was rated as significantly lower workload ($p<0.05$) than the extra-urban route (table 1).

Insert Table 1 Here

4. Discussion

4.1 Primary Task Performance

This study revealed a decrease in mean driving speed and time spent speeding when being in receipt of in-vehicle smart driving feedback (figures 2 and 3). This can be considered to be a positive effect, as it has been linked to a decrease in the number and severity of road traffic accidents (Haworth and Symmons, 2001; Taylor et al, 2002; Aarts and van Schagen, 2006), as well as increases in fuel economy (Haworth and Symmons, 2001). Moreover, such a speed reduction is also wholly consistent with the aims of Foot-LITE, since the presence of a smart driving aid may have encouraged participants to reduce speed, or stay within the posted speed limits in an effort to facilitate safe and fuel efficient behaviour. This was despite the smart driving advisors not actually providing specific speed-related information, drivers may have associated smart driving with conscientiousness about speed – and this appeared to be particularly pronounced for the EID display. However, a decrease in driving speed has also been observed when drivers are engaged in a mobile phone conversation while driving (Alm and Nilsson, 1990; Haigney et al, 2000). This is considered to be a compensatory behaviour in an attempt to reduce workload, as well as increasing perceived safety margins (Haigney et al, 2000), and so could be indicative of increased distraction. That the EID showed wider effects on speed could, then, be indicative of increased workload due to the novelty and complexity of the display – although this is not borne out by the workload and distraction data. Indeed, the PDT data seems to indicate that the EID is less distracting (see further discussion on the PDT below), and so we would tend to conclude that the overall reduction in driving speed should have a positive safety impact.

The acceleration parameters measured in this study showed the greatest sensitivity to changes as a result of the smart driving aids, particularly in urban driving and specifically with the DB interface (figures 4 and 5). One of the golden rules of smart driving is to avoid excessive acceleration events (Young et al, 2011), thereby reducing high engine loads and maintaining a smooth driving style. A reduction in acceleration rates has been shown to be beneficial to both fuel economy and emissions (El-Shawarby et al, 2005; Ericsson et al, 2001; Waters and Laker, 1980), as well as the risk of accidents (af Wahlberg, 2006). A reduction in excessive acceleration values were observed with in-vehicle feedback both in the urban. Despite the relatively consistent speeds adopted for the extra-urban scenario, a trend was still observed ($p \approx 0.1$) for mean acceleration to be lower with smart driving feedback (figure 5), suggesting that even when low levels of acceleration are required at higher driving speeds a reduction in mean values can be achieved through smart driving feedback.

With respect to deceleration (aka braking) parameters, the key effects were observed in the urban scenario, where there were more opportunities to adjust deceleration behaviour since this scenario was characterised by eight traffic light controlled intersections. Some traffic lights were set as an ‘amber light dilemma’ where participants could either select to brake heavily (causing an unavoidable excessive deceleration event to occur) or drive through the lights. It is worth noting that no participants stated that they were encouraged not to stop at the lights to avoid the excessive deceleration warning message being shown. A reduction in excessive deceleration events (as observed in both interface conditions, but only significant with respect to DB compared to the baseline) may indicate that participants were planning ahead, noting the changes in traffic light sequences and slowing down in plenty of time. This approach would maintain a more consistent speed profile – which, as we have seen, increases fuel economy – as well as having obvious implications for safety (in the risk of rear-end collisions) when heavy braking events are avoided.

Findings from this study suggest that neither mean headway nor percentage time spent under two seconds differed significantly in either driving scenario between any experimental conditions. However a trend for a difference was observed with respect to excessive headway, with figure 6 showing that driving with smart driving feedback did result in a decrease in time spent driving closer than two seconds. This can be attributed to one of two things, either that either participants did not know that they were driving too close to the car in front in the baseline condition – as they had no headway feedback – or that participants felt compelled to increase headway in order to maintain aspects of smart driving as directed by the in-vehicle feedback. Research has suggested that headway can follow the same trends as observed with driving speed when IVIS are used – in other words, drivers will increase headway in order to increase perceived safety margins (Strayer and Drews, 2004. Additional research has suggested that this phenomenon may only occur during steady-state activities (such as car following), and that during tactical control manoeuvres (such as overtaking or lane changing) under cognitive load participants did not adapt their driving to increase headway (Horrey and Simons, 2007). The research outlined above leaves the likely effect of IVIS on headway unclear, but what can be universally accepted is that increases in headway are a desirable and positive outcome for smart driving feedback.

Results from the current study show that on the whole, the smart driving aids had positive effects on driving performance (in terms of speed, excessive acceleration and deceleration) yet at no expense to journey time which remained unchanged for both urban and extra urban driving. This satisfies the goal that smart driving feedback should elicit positive changes to driving behaviour without impacting on journey time. However, so far the choice between the ecologically designed interface (EID) and the conventional DB displays is equivocal, since the former had a greater effect on speed, while the latter more reliably affected acceleration and braking.

4.2 Peripheral Detection Task Performance

It would appear from the results that the presence of a smart driving aid giving real-time, pertinent and timely advice to the driver did not result in an increase in driver distraction for extra-urban driving. Meanwhile, an interesting and unexpected finding was observed when considering PDT performance in the urban environment. Performance with respect to the number of correct responses significantly improved over the baseline condition when participants drove with the EID interface (figure 7). This finding may be a result of the experimental design adopted for this study, as the baseline condition was always completed first, so it may then be a simple practice effect in the simulator. However, if this was the case, then the same pattern should have been observed in the extra-urban cycle – but instead there are no differences on the PDT. Furthermore, since peripheral detection events were randomised there is unlikely to be a learning effect for event timings or locations between conditions, in addition PDT was also active, and fully explained in the practice trial at the beginning of the study.

The authors would favour the conclusion that the improvements observed in PDT performance with smart driving feedback is a result of the changes in driving behaviour that smart driving is trying to effect. Namely an associated reduction in speed, which in turn may free up attentional resources for the PDT, and this, is only evident in the urban scenario where workload was otherwise high. This is further supported by the notion that speed related parameters were significantly improved when using the EID interface over baseline and DB, which also correlates to a significant increase in PDT performance. Another possible factor may be that participants were more attuned to visually scanning their driving environment as a direct result of having a visual display in the vehicle itself. Research has shown that when driving under higher mental workloads (as the urban cycle was compared to the extra-urban), driver vision tends to focus on the forward facing view and less on the peripheries (Harbluk et al, 2007). The presence of the smart driving interfaces may have encouraged drivers to maintain wider visual scanning patterns inside and outside the car, facilitated by the observed decrease in driving speed, and thus increasing recognition of the peripheral detection events.

4.3 Subjective Measures

DALI results indicated around a 12% reduction in workload for the EID display in the urban scenario, when compared to the DB display (figure 8). This difference was more marked when considering the factor of global attention demand, which was significantly ($p<0.05$) less demanding in the EID interface, with a rating of around 17% less compared to the DB condition (table 1). In the presence of significant primary task demands during the urban scenario, it can be assumed that lower workload ratings for the EID interface suggest a preferable design. It is our interpretation that the dynamic and integrated EID design for real-time smart driving feedback produced the decrease in driver workload when compared to the more conventional, piecemeal icon and warning based display that was the DB. Research conducted by Vashitz and colleagues (2008) evaluated two different IVIS for tunnel driving safety, and showed a subjective preference for a ‘high’ versus a ‘low’ information display, with participants suggesting a preference due to ‘... absence of vital information in the low-information display, which appears in the high-information display’ (Vashitz et al, 2008, pp. 71).

5. Summary and Conclusions

This study demonstrated that the delivery of smart driving information did not increase driver workload (as measured by DALI), nor did it adversely affect driver distraction (assessed with PDT). Furthermore, improvements in desired driving behaviours were observed, in the form of reduced speeds and excessive acceleration and braking events. Moreover, negative effects on driving performance such as reductions in headway or increase in journey time were not seen when using the smart driving aids.

In terms of driving performance, where EID had a wider effect on speed whereas acceleration and braking was more widely influenced by the DB, there was little to choose between the EID and DB interface options. However, in terms of driver mental workload and distraction, the EID appeared to have more benefits, with better attention to peripheral stimuli and reduced subjective workload, both in the urban scenario.

Further testing and development is planned within the Foot-LITE project, including on-road studies. If the positive effects of these interfaces are borne out through such tests, it could show that IVIS systems do not necessarily have to increase workload or distraction, if they are designed appropriately and using an ergonomic design process. Positive and helpful information, such as that given to the driver by Foot-LITE, may actually improve driving performance while reducing workload and distraction.

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