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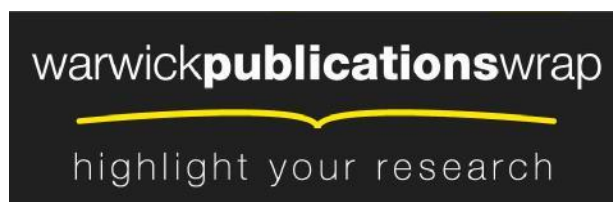
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Chapter 21

Smart Driving Assistance Systems: Designing and Evaluating Ecological and Conventional Displays

Stewart A. Birrell[1] and Mark S. Young[2]

[1] Warwick Manufacturing Group, University of Warwick, UK

[2] Human Centred Design Institute, Brunel University, UK

Abstract

In-vehicle information systems have been shown to increase driver workload and cause distraction; both are causal factors for accidents. This simulator study evaluates the impact that two designs for a smart driving aid and scenario complexity has on workload, distraction and driving performance. Results showed that real-time delivery of smart driving information did not increase driver workload or adversely affect driver distraction, while having the effect of decreasing mean driving speed in both the simple and complex driving scenarios. Important differences were also highlighted between conventional and ecologically designed smart driving interfaces with respect to subjective workload and peripheral detection.

Introduction

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. In-vehicle information systems (IVIS) can distract the driver (see below), and distraction is a causal factor for accidents. Whilst the implementation of legislation designed to reduce driver distraction, namely the banning of hand-held mobile phone use (see 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 systems.

Driver distraction and road accidents

Statistics from some UK and US accident databases show that driver distraction accounts for between 2 per cent (Mosedale et al. 2004, Stevens and Minton 2001) and 8 per cent (Strutts et al. 2001, Wang et al. 1996) of accidents. Although these analyses found limited evidence of distraction from IVIS systems, this is likely due to the type and age of the databases being interrogated. Stevens and Minton 2001 utilised police-reported accident databases from 1985 to 1995. As a reflection of this, only 3 per cent of distraction-related accidents were due to mobile phone use.

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 a secondary task can increase the potential risk of an accident or incident, it is thought that other contributing factors also have to occur concurrently for the 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.

The Foot-LITE project

The Foot-LITEF[1] project aims to develop an integrated, adaptive interface, providing the driver with pertinent and timely feedback and advice on aspects of safe and green driving styles. The system ostensibly comprises two aspects: an in-vehicle human–machine interface (HMI) providing real-time feedback and advice on driving style, coupled with an off-line (post-drive) data logging system which can help to inform transport choices. Whilst there already exist some off-the-shelf, in-car monitoring systems which can provide information on fuel consumption or post-event data recorders (McGehee et al. 2007, Tomer and Lotan 2006, van der Voort et al. 2001), none of these as yet provide detailed feedback to the driver, in real-time, enabling them to refine their behaviour to actually improve driving efficiency and/or safety. Moreover, Foot-LITE also aims to balance feedback on safe driving styles with eco-driving techniques, which may or may not be in conflict (see Young et al. 2011 for a discussion).

Although it might seem counterintuitive to use another potential distraction in an effort to improve safety, the statistics favour this approach. Mosedale et al. (2004) showed that 2 per cent of accidents were a result of driver distraction, whereas over 90 per cent of accidents were a direct result of poor driving or inappropriate driving behaviour. Clearly, though, the biggest challenge with any such system is to encourage positive behaviour change in drivers whilst avoiding the negative effects of driver distraction that the new interface could induce. The solution to this problem lies in the interface design.

Foot-LITE interface designs

In order to achieve the goals of changing driving style while avoiding the 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 HMI designs were conceived, both very different from each other, and both refined through a rapid prototyping study (Young and Birrell 2012) which led to the designs used in this study. Previous work conducted for the project (Birrell et al. 2012) established the principal information elements necessary to increase fuel efficiency and safety. These were correct gear change, and reducing unnecessary acceleration and braking events by planning ahead (related to fuel efficiency); and appropriate headway, lane position and lane deviation (related to safety). Both of the interface designs display these parameters, maintaining information equivalence across each; it is simply the format of presentation that varies.

The first interface design was generated based on the principles of ecological interface design (EID; Burns and Hajdukiewicz 2004), following the completion of a cognitive work analysis (as

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    1   See www.foot-lite.net.

reported by Birrell et al. 2012). EID is an approach to interface design that was introduced specifically for complex socio-technical, real-time and dynamic systems. It has been applied successfully within a number of work environments, including process control, nuclear, petrochemical, military and aviation domains (Burns and Hajdukiewicz 2004), and in a more theoretical manner within vehicle interface design (Jenkins et al. 2007, Seppelt and Lee 2007). 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 (Figure 21.1). Hence all of the safety and eco-related parameters are shown on the screen at the same time, with all parameters changing in real-time depending on the driver's inputs.[2]
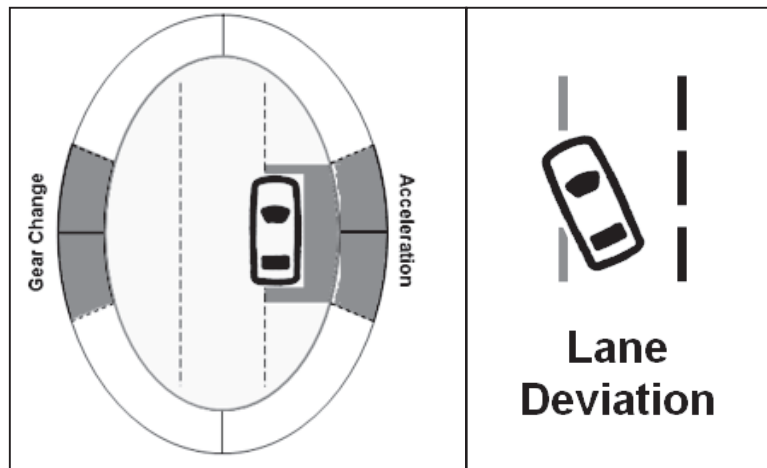

Figure 21.1   EID (left) and DB (right) interface designs; both are displaying the warning for lane deviation. The EID interface groups safety parameters inside the oval and eco-parameters in the outer oval, while the DB only displays the highest priority parameter

As an alternative to the EID concept, a more conventional dashboard-type interface (DB) has also been developed according to best practice in the human factors literature (Figure 21.1). Initially this was based on a vehicle instrument panel layout; the DB interface consists of a series of warning icons with corresponding 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 standard instrument panels, warning messages and icons available in most vehicles.

The principal differences between the two displays are that the DB interface displays only the highest priority driving parameter at any one time – whether this is safety (headway or lane deviation) or eco-related (gear change and acceleration) – whereas the EID interface displays all parameters all the time. Other differences are that DB information is based on iconography and

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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.

textual information, with EID focusing on the location, size and colour of "blocks" to convey the information presented (Figure 21.1). Additionally with the EID display eco-driving information is spatially linked (i.e. changing up a gear is usually associated with acceleration events, and conversely braking with gear changes down), with safety parameters semantically mapped (see Sanderson et al. 2003), as the movement of the virtual car on the display represents the on-behaviour and performance of the driver in the real-world (i.e. when the virtual car moves out of the lane to the left on the display, this indicates that the vehicle in the real-world has deviated to the left). Safety and eco-information on the EID is also grouped, which – according to Sanderson et al. (2003) – allows relations and constraints to be easily perceived.

The aims of the study presented in this chapter were initially to assess the impact that smart driving aids may have on driving performance and driver distraction. Beyond this, we tried to establish if any differences were observed between the two interface designs developed for the project. To achieve these aims a driving simulator study was conducted.

Methodology

Experimental tools

Driving simulator
The Brunel University Driving Simulator (BUDS) was used for this study. BUDS is a fixed-based immersive simulator with a 2006 Jaguar S-Type as the donor car. The driving simulator software is provided by STISim (Systems Technology Inc., Hawthorne, CA; Build 2.08.04), where the images are projected via three digital projectors onto three 2.5 m × 2.1 m (viewable area) screens, providing the forward facing scene plus the left and right peripheral scenes. 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 consisting of steering wheel, gear lever and pedal block (including clutch pedal), fitted in the donor car as a UK-standard right-hand drive, manual transmission vehicle. The frame rate and data capture rate throughout the study were fixed at 30 Hz.

In-vehicle human–machine interface
As the main aim of this study was to evaluate the potential effects on driver distraction and driving performance as a result of using a smart driving aid, an in-vehicle HMI was needed to present this information to the driver. To achieve this, a 7" colour screen 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 drivers' view of the road ahead. The screen was linked via cable to an additional PC which drove the HMI, and this PC in turn received a data stream from the simulator machines to feed the HMI. The HMI thus gave real-time feedback via either the EID or DB interfaces as described above.

Experimental design

A three (interface design: baseline, EID and DB) × two (driving cycle: urban and extra-urban) within-subjects experimental design was utilised for this study. Dependent variables included objective and subjective metrics of driving performance and driver distraction and workload.

Driving scenarios

Two different types of driving scenario were developed for this study, both based on the New European Drive Cycle (NEDC) against which standard emissions data are tested. The first scenario was an urban cycle which consisted of driving in a city environment with two 3 m wide lanes (including a 1.5 m wide lane for parked traffic on the left of the two driving lanes). The same setup was used for oncoming traffic on the right-hand side of the road, with no barrier between the two directions of traffic. A series of eight traffic-light-controlled intersections were placed at specific locations, either with or without pedestrian crossings. The speed limit throughout was 30 mph. The scenario was 2.5 km from start to finish and took approximately five minutes to complete. In order to limit a learning effect of repeating the scenario, two different versions were created. Both were based on the same physical road infrastructure (i.e. intersection locations and road layout), but traffic light sequences and divided attention events (see next section) were changed.

The second driving scenario was an extra-urban cycle consisting of a dual carriageway with varying speed limits. The road again consisted of two 3 m wide lanes on each side of the carriageway. In an effort to mirror the NEDC this scenario was again approximately five minutes long with the first three minutes at a speed limit of 40 mph, followed by one minute of driving at a speed limit of 60 mph, finishing with approximately one minute of national speed limit (i.e., 70 mph). Within the extra-urban cycle, the driving environment changed from a more urban setting (with shops, offices, bus stops, petrol stations etc., set back off the main road, 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. This scenario was free from stop signs and traffic lights; however, other traffic of varying speeds was placed in the nearside (or left-hand lane) for the driver to negotiate. The scenario was 6.3 km in length and took approximately five minutes to complete.

Secondary task

In order to gain a measure of driver distraction, a secondary visual task was adopted – the peripheral detection task (PDT). The PDT is popularly used to objectively assess workload during driving, as well as to evaluate distraction and workload caused by IVIS (Harms and Pattern 2003, Jahn et al. 2005). PDT has been shown to be a reliable measure of driver workload and is particularly suited to simulator testing. 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 periphery 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).

The STISim software provides the PDT events, comprising red symbols near the top corners of the central screen. When in the driving seat these symbols appear in the top left and right of the drivers' peripheral vision. At ten pre-defined positions 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 corresponding button on the steering wheel. The STISim software automatically recorded the response time and whether or not it was a correct response. If no response was made within a set period of time, a "miss" is recorded, and the symbol reverts to its default. To limit the learning effect two different sets of divided attention events were written for each driving cycle.

Measures of driving performance

Objective parameters of primary (i.e. driving) task performance were recorded automatically by the simulator software. For the purposes of this chapter this means driving speed and lane position

over the entire run were evaluated. In addition, PDT variables of mean response time and number of correct response were also recorded.

Subjective measures of driving workload were assessed using two different questionnaires; these were the NASA-Task Load Index (TLX; Hart and Staveland 1988) and the Driver Activity Load Index (DALI; Pauzie and Forzy 1996). TLX is a widely accepted standard subjective workload measure and is considered to be very sensitive and reliable in comparison to other ratings scales (Hill et al. 1992). It has also been used extensively in driving-elated research (Horberry et al. 2006, Harbluk et al. 2007, Harms and Pattern 2003, Stanton and Young 2005). The questionnaire asks participants to rate their perceived workload on six subscales: mental demand, physical demand, temporal demand, performance, effort and frustration. DALI is heavily based on the TLX and evaluates workload specifically during the driving task. It is less frequently used but more tailored for the evaluation of IVIS, 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.

Participants

Twenty-five participants (14 female, 11 male) with an average age of 35.2 years (SD = 8.7) completed the study. Inclusion criteria for participation were that they drove regularly and at least 6,000 miles per year, had at least four years' driving experience with a full UK licence, and had normal or corrected-to-normal vision. Participants were recruited from Brunel University and all had no prior knowledge or involvement in the Foot-LITE project. Participants were paid a nominal fee for their involvement in the study. All participants experienced all conditions of the study in a within-subjects design.

Procedure

Each drive cycle was completed for each of the interfaces and the baseline condition; this totalled six experimental runs. In addition, participants were given a five-minute practice run in the simulator to get used to the controls and the PDT before the experimental trials began. The baseline conditions (i.e. without any HMI feedback) were always completed first in order to satisfy additional aims of the study – to evaluate participants' driving pre- and post-feedback – although the present chapter does not report this performance data. However, the order in which driving cycles (urban or extra urban) were completed was also randomised, meaning that participants either completed the baseline urban or extra-urban as their first experimental condition. The remaining HMI conditions were fully randomised in terms of both HMI design and driving cycle.

Before the interface conditions were completed, participants were given an introduction to the two HMI designs. This briefing was considered very important as it ensured that participants evaluated the scenarios and HMIs with some knowledge of what the displays were trying to convey. Rather than contaminating the study, it was felt that such briefings were essential in obtaining meaningful data, and were realistic in merely covering the kind of information which might be found in an instruction manual or supporting documentation for the Foot-LITE product.

At the end of each condition the participants were asked to complete the subjective questionnaires. The DALI questionnaire was only completed following the HMI experimental conditions, as it focuses on interference from the smart driving aid, which was obviously not relevant for the baseline condition. The TLX questionnaire was completed after all conditions.

Data analysis

The subjective measures of driving performance (TLX and DALI) were assessed using Friedman and Wilcoxon Signed Rank tests, while the driving data were assessed using an ANOVA and related pairwise comparisons. Statistical testing was conducted using SPSS 15.1 for Windows and significance was accepted at $p<0.05$.

Results

The analyses identified differences between the three experimental conditions (baseline, EID and DB) as well as interactions within the driving cycles. The following section details results from the study, with Table 21.1 summarising the mean data.

Table 21.1 **Mean data for primary task performance, secondary task and subjective measures (respectively) for all three experimental conditions and both driving scenarios; standard deviation in parentheses**

	Urban			Extra-urban		
	Base	**EID**	**DB**	**Base**	**EID**	**DB**
Speed (mph)	18.8 (2.6)	17.1 (2.7)	16.9 (3.3)	46.8 (4.5)	41.8 (6.5)	43.5 (6.6)
Lane (ft)	17.7 (2.7)	18.5 (1.7)	18.1 (1.8)	14.7 (2.4)	15.2 (1.8)	14.8 (2.0)
Response time (s)	3.60 (1.6)	2.94 (1.2)	2.99 (1.3)	2.56 (1.4)	2.38 (1.2)	2.48 (1.3)
Correct response (n)	8.63 (1.0)	9.54 (1.0)	9.33 (1.1)	9.42 (1.0)	9.67 (1.0)	9.58 (1.1)
TLX	51.5 (22.7)	46.8 (21.8)	48.6 (21.6)	37.7 (22.9)	38.0 (21.8)	37.1 (19.7)
DALI	–	2.45 (1.3)	2.74 (1.3)	–	2.21 (1.2)	2.17 (1.2)

Primary task performance

Mean driving speed returned a significant main effect between the three interface conditions in both urban ($F_{(2,68)} = 3.11$, $p<0.05$) and extra-urban ($F_{(2,68)} = 4.31$, $p<0.05$) driving cycles. In addition to these main effects, pairwise comparisons revealed that, when driving with either interface design (EID or DB), mean driving speed was significantly ($p<0.05$) lower than that of the baseline condition with urban driving (Figure 21.2). However, this difference was only significant when considering the EID compared to baseline in extra-urban driving. Mean lane position did not differ between any of the conditions in either driving cycles.
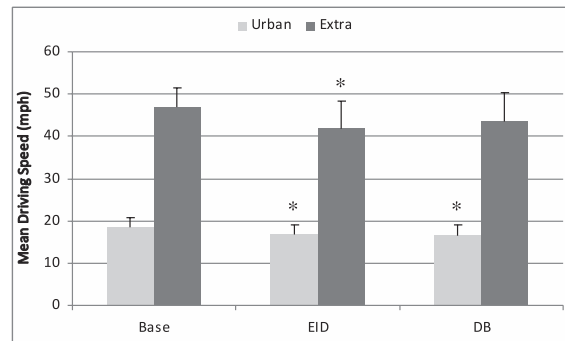
Figure 21.2   Mean driving speed for each experimental condition in the urban and extra-urban driving cycles. Asterisk indicates significant difference (*p*<0.05) to baseline conditions. Error bars represent standard deviation of the data

Secondary task performance

Measures of secondary task performance in this study were the number of correct responses and mean response time on the PDT. No significant differences were observed with mean response time in the extra-urban cycle (Table 21.1). However, a significant main effect was observed for the number of correct responses to the PDT ($F_{(2,68)}$ = 4.20, *p*<0.05) in the urban cycle. The EID condition resulted in the greatest number of correct responses, averaging 9.5 (out of 10 divided attention events). Pairwise comparisons revealed that this difference was significant (*p*<0.05) when compared to baseline condition. Table 21.1 also shows the mean response time and number of correct responses to the PDT were all very similar between all three experimental conditions in the extra-urban cycle, with no significant main effects or pairwise comparisons being observed.

Subjective measures

Two separate questionnaires were used to measure subjective workload of the driver for each condition. The NASA-TLX was completed following all scenarios (baseline and interface), with DALI being completed only after the interface conditions for both driving cycles.

NASA-TLX
When considering the urban driving cycle, results from the TLX questionnaire showed no significant differences between the conditions, despite Figure 21.3 indicating participants rated the baseline condition slightly higher in workload than when using the smart driving aids, at 51.5 against 46.8 and 48.6 for EID and DB, respectively. TLX ratings for the extra-urban cycle also showed no differences between any conditions. As may have been expected given the set up of the driving scenarios, the extra-urban cycle was rated significantly lower for workload (*p*<0.05) compared to urban (Figure 21.3).

DALI
DALI is more IVIS specific, with questions focusing on visual demand and interference of systems, in addition to some more standard ratings as covered in the TLX questionnaire. Results from this study show that participants rated the EID interface significantly lower in workload (Z = –1.99, *p*<0.05) than the DB interface design when driving the urban cycle. No difference was observed
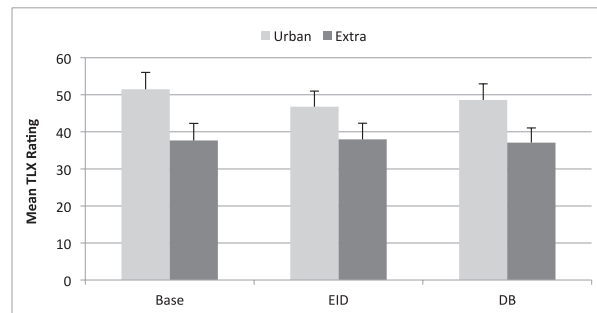
Figure 21.3   Mean NASA-TLX rating for each experimental condition for both urban and extra-urban scenarios. Error bars represent standard error

when comparing the two interfaces during the extra-urban cycle (Figure 21.4). As with the TLX ratings, urban driving was rated at a significantly higher workload ($p<0.05$) than the extra-urban route.
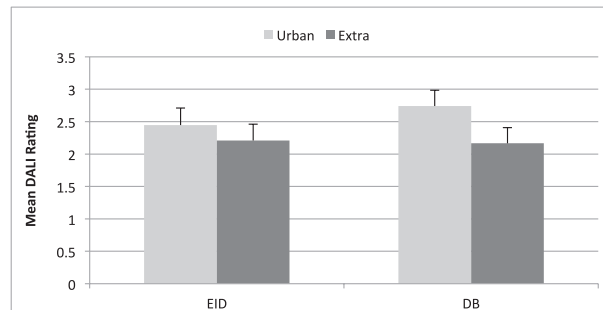

Figure 21.4   Mean DALI rating given by participants for each experimental condition for both urban and extra-urban scenarios. Asterisk indicates significant ($p<0.05$) difference between EID and DB condition. Error bars represent standard error discussion

Primary task performance

When considering the effect of the smart driving aids on driving performance, this study found that mean driving speed was significantly reduced across both urban and extra-urban driving scenarios when using either of the HMI options. A decrease in driving speed is generally a positive result, as it has been linked to a decrease in the number and severity of accidents (Haworth and Symmons 2001, Taylor et al. 2002, Aarts and van Schagen 2006), as well as increases in fuel economy. However, a decrease in driving speed has also been observed when drivers are engaged in a mobile phone conversation while driving (Haigney et al. 2000). This is considered to be a compensatory behaviour in an attempt to reduce workload, as well as to increase perceived safety margins (Haigney et al. 2000), and so could be indicative of increased distraction. However, given the improvements in PDT performance observed when using the smart driving advisors, and a lack of a difference in TLX ratings, it is suggested that the more positive explanations for the reduction in driving speed – which are wholly consistent with the aims of Foot-LITE – are more likely; namely, that the presence of in-vehicle feedback may have encouraged participants

to reduce speed in an effort to facilitate safe and efficient driving. Additionally, the absence of any differences in mean lane position could be interpreted positively (as an absence of distraction) or negatively (no positive effects of the smart driving aids). Given that both interfaces provided specific advice on lane discipline, further analyses of the data are necessary to determine whether baseline performance was already at ceiling.

Secondary task performance

PDT performance, both in number of correct responses and in mean response times, 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). Deterioration in PDT performance, represented by either an increase in response time or decrease in correct responses, would indicate that the smart driving aids were adversely affecting driver attention. Results for the extra-urban driving scenario showed that no differences were observed between the baseline conditions and either of the smart driving aid conditions. Thus 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. This may be indicative of the lower levels of subjective workload and general "ease" of the extra-urban driving scenario.

Meanwhile, an interesting and unexpected finding was observed when considering PDT performance in the urban environment. The number of correct responses actually increased with the EID interface when compared to the baseline condition. This finding may be a result of the experimental design adopted for this study, as the baseline condition was always completed first (in line with ancillary aims of the study not reported here). The improvements in performance on the latterly completed EID condition may then be a simple practice effect in the simulator. However, if this were the case, then you may expect the same pattern to have been observed in the extra-urban cycle (as again the baseline condition was completed before any smart driving feedback was given), which it was not. Furthermore, since peripheral detection events were randomized, there is unlikely to be a learning effect for event timings or locations between conditions, coupled with the practice runs completed by all participants.

The authors propose that the improvements in PDT performance with the EID interface (and to a lesser, non-significant, extent with DB) are as a result of the changes in driving behaviour that smart driving is trying to effect – namely, planning ahead, maintaining a consistent speed profile and adhering to posted speed limits. As already reported, the smart driving aids resulted in a decrease in mean driving speed over the entire scenario of between 10 and 12 per cent when compared to the baseline condition. Such a decrease in driving speed may allow the driver more time to adapt to upcoming events (such as change in traffic light, car pulling out etc.), which may ultimately be reflected 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.

Subjective measures

TLX

In the urban cycle no significant differences in TLX ratings were observed between any of the conditions. Even an assessment of the individual TLX sub-scales did not reveal interesting findings within the urban cycle, other than that the highest rated factors across all experimental conditions were "mental demand" and "effort"; both of these were significantly higher (p<0.05) than "physical demand", which received the lowest rating. Likewise, the mean ratings for TLX data from the extra-urban scenario for all three experimental conditions were very similar.

Despite the absence of differences between the interface conditions, the TLX questionnaire did reveal differences between the drive cycles. As one might expect, and was implicit in the scenario and experimental design, participants rated the urban cycle at a significantly higher workload (p<0.05) than the extra-urban cycle by around 25 per cent. Jahn et al. (2005) reported similar findings to the current study, in that TLX ratings were significantly higher for a complex navigation task (using a satellite navigation system) compared to a simple navigation task. However, subjective workload ratings did not differ for the two displays they evaluated (one small, one large). Other studies have also shown TLX ratings to differ significantly with increasing task complexity (Horberry et al. 2006, Harbluk et al. 2007). On the whole, then, the TLX data suggest that the EID and DB interfaces are comparable in terms of subjective workload.

DALI

DALI, on the other hand, did reveal significant differences between the two interface options. DALI is based on the TLX but slightly shifts the focus of the questionnaire to be more driving-specific and relevant to IVIS, with the inclusion of factors such as visual demand and interference. Given this focus, DALI was only completed following the smart driving feedback conditions and not the baseline condition. As with the TLX ratings, no differences were observed between the conditions in the extra-urban driving scenario, with mean data again being very similar. However, when the data for the urban environment were analysed, the EID was rated significantly lower in workload demand compared to the DB display (Figure 21.4). The difference in the mean data equated to around a 12 per cent reduction for the EID display. This difference was more marked when considering the factor of global attention demand, which was 17 per cent higher in the DB condition. Previous research has shown differences with DALI ratings when using a mobile phone while driving (Pauzie and Pachiaudi 1997); with the load index being significantly higher for auditory and interference factors when engaged in a mobile phone conversation.

In the presence of significant primary task demands during the urban scenario, it can be safely assumed that lower workload ratings for the EID interface suggest an improved 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.

TLX or DALI?

Although not a specific aim of this current study, an issue has been identified which will be of interest to driving researchers conducting future IVIS research. This was that TLX did not identify differences between subjective workload during driving between any of the experimental conditions adopted for this current study, either between the DB and EID interfaces or smart driving aid versus baseline. However, differences were observed with task complexity (simple, extra-urban or complex, urban driving scenario), a similar result to that seen by Jahn et al. (2005). Reasons

for the lack of observable difference with TLX may be due to the nature of the questions asked. For example, physical workload was rated very low in this current study, and standard deviations revealed very little difference between participants, and also between conditions. Task performance and effort may also be less relevant when using a repeated measures study design, as the same driving task is completed each time but with differing feedback devices. Therefore, unless a device resulted in the participants being so distracted that they actually crashed the car, a differentiation in driving performance may be difficult to establish between representative conditions. Conversely, important factors for IVIS evaluation, such as auditory demand and interference, were present with DALI but not TLX. This may allow more subtle design differences between interfaces to be taken into consideration when subjectively rating a driving system. In addition, as shown by this study, DALI was also sensitive to differing task complexity.

There are, however, negative aspects to adopting DALI; whereas TLX is a widely accepted standard subjective workload measure and is considered to be very sensitive and reliable in comparison to other ratings scales (Hill et al. 1992), DALI is less frequently used and validated, especially when considering the available peer-reviewed scientific literature. Another issue which needs raising is that, with the inclusion of such driving-related factors (interference and auditory demand) within DALI, it may not be suitable to use in a "control" condition where no feedback is given and only normal driving is assessed. This means that changes from a baseline to when using IVIS may be difficult to assess. In addition the comparison of driving to other tasks (such as completing a computerised cognitive assignment) cannot be achieved as it can with TLX. As a result the authors recommend the use of the DALI subjective workload questionnaire over TLX when assessing different HMI designs in either a driving simulator or naturalistic driving, or the effect of IVIS in differing complexities of driving scenarios.

Ecological or conventional smart driving interfaces?

This chapter has presented an evaluation of two very different smart driving HMIs: one, an ecological display, which aims to dynamically map the real-world driving situation without using icons or text based messages, but instead relying on the colour and location of blocks of information to transmit driving-related parameters to the driver; and the second, a conventional display, which is more instantly recognisable and descriptive in nature. Both interface concepts have their pros and cons, and inevitably people will prefer the information display of one over the other. However, the scientific evidence presented in this chapter suggests that the ecologically designed EID display resulted in significantly lower subjective workload when driving in an urban environment, and also improvements in peripheral object detection over the conventional DB display. The authors suggest that this observed difference is as a result of the ability of participants to quickly and accurately perceive what information is being transmitted via the EID display. Text messages take time to read and icons – no matter how well they have been designed – have to be interpreted by the driver. This may result in an increase in processing time over a more directly perceptible display.

Ecological interface design was developed specifically for complex socio-technical, real-time, and dynamic systems (Burns and Hajdukiewicz 2004). It was deemed appropriate for the Foot-LITE project, as two distinct categories of driving information are being presented to the driver (namely safety and ecological) with two real-time parameters for each category (headway and lane deviation, and gear change and acceleration respectively). The necessity to integrate this information, in the authors' opinion, warranted the ecological approach. Whilst EID was deemed appropriate for this project, it may not be suitable for all in-vehicle interface designs; specifically, those that are presenting relatively simple information or a limited number of driving parameters. In

addition, it does not lend itself inherently to the presentation of numerical data but rather graphical representations. However, when it is necessary to present complex and dynamic information requirements, an ecological approach to in-vehicle interface design would be recommended by the authors.

Summary and conclusions

Concern has been expressed in the literature that the use of IVIS can cause driver distraction and be detrimental to driving performance. Moreover, the proliferation of such systems on the market, or coming to market, means that such issues will continue to dominate research and policy. One way that distraction and workload can be minimised is by good ergonomic design and rigorous testing of in-car interfaces. Ecologically designed interfaces may form an appropriate tool to help minimise driver workload and distraction in complex driving scenarios.

Foot-LITE aims to give real-time, pertinent and tailored smart driving advice to the driver in the vehicle. Whilst this system will obviously result in another information display for the driver to interact with, the objectives of the project are to minimise any potential driver distraction through the development and testing of an ergonomically designed interface display. The study reported in this chapter is part of that process, and demonstrated that the delivery of smart driving information did not increase driver workload (as measured by TLX); and nor did it adversely affect driver distraction (assessed with the PDT). It resulted in a significant decrease in mean driving speed in both urban and extra-urban driving environments. If the positive effects of Foot-LITE are borne out through the further testing and development planned in the rest of the project, it could show that IVIS systems do not necessarily have to increase workload or distraction if they are designed appropriately. Positive and helpful information may actually improve driving performance while minimising workload and distraction.

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