Ecological IVIS Design: Using EID to develop a novel in-vehicle information system

New in-vehicle information systems (IVIS) are emerging which purport to encourage more environmentally friendly, or 'green' driving. Meanwhile, wider concerns about road safety and in-car distractions remain. The 'Foot-LITE' project is an effort to balance these issues, aimed at achieving safer and greener driving through real-time driving information, presented via an in-vehicle interface which facilitates the desired behaviours while avoiding negative consequences. One way of achieving this is to use ecological interface design (EID) techniques. This paper presents part of the formative human-centred design process for developing the in-car display through a series of rapid prototyping studies comparing EID against conventional interface design principles. We focus primarily on the visual display, although some development of an ecological auditory display is also presented. The results of feedback from potential users as well as subject matter experts are discussed with respect to implications for future interface design in this field.

Statement of relevance: The design development process for an in-vehicle EID is presented, which more often than not is seen as a 'missing link' in ergonomics as very few papers describe the link between analysis and design. Lessons can be learned for the general theoretical EID process, as well as for the specific application of IVIS displays.

Keywords: cognitive work analysis; eco-driving; ecological interface design; in-vehicle information systems, road safety

Introduction

Over the past decade the environmental cost of road transport has become a key issue for government, car manufacturers and consumers (Young et al., 2008), accounting for 19% of the European Union's greenhouse gas emissions (EEA, 2007). One way in which driving can become more environmentally friendly (or 'greener') is by adopting 'eco-driving' behaviours, since CO_2 emissions and fuel use are directly linked. European studies suggest that eco-driving can reduce fuel consumption and emissions by between 5 and 15% (af Wahlberg, 2002; 2007; Waters and Laker, 1980; van der Voort et al., 2001). A number of vehicle manufacturers are capitalising on this trend by offering in-vehicle information systems (IVIS) which provide eco-driving feedback to the driver.

However, road safety remains a key policy issue alongside the environmental concerns (e.g., PACTS, 2007), and the introduction of additional IVIS feedback could have a negative impact on driver distraction (cf. Donmez et al., 2007; Regan et al., 2009), with research completed for the '100-car naturalistic study' in the US suggesting that driver inattention accounts for almost 80% of crashes and 65% of near crashes (Klauer et al., 2006). 'Foot-LITE' is a UK project, aiming to develop a system which encourages both safer and more environmentally friendly driving, and thus meeting both of these policy objectives. The system ostensibly comprises two features: an in-vehicle interface providing real-time feedback on vehicle control, coupled with a complementary pre- and post-drive web-based application which would download and interpret journey data to support longer term behavioural changes and inform transport choices. The work presented here is part of a package focused on the ergonomics of the system, with particular emphasis on the in-vehicle human machine interface (HMI), which will present information to the user while they are driving. A key objective of the system, as with any in-car HMI, is to encourage desired behaviours (in this case, safer and greener driving) while avoiding any negative effects of overload or distraction (cf. Harbluk et al., 2007). One way of achieving this would be to apply principles of ecological interface design (EID; Burns and Hajdukiewicz, 2004; Vicente, 2002).

EID is an approach to interface design that was introduced specifically for complex socio-technical, real-time, and dynamic systems. Based on a paradigm of ecological psychology (cf. Gibson, 1979), it exploits the precept that we directly perceive invariants in the world, rather than indirectly through mental representations – meaning that, for interface design, we must study what is actually in the world (Hoff, 2004). EID has been applied successfully within a number of work environments, including process control, nuclear, petrochemical, military and aviation domains (Burns and Hajdukiewicz, 2004; Jamieson & Vicente, 2001). By presenting environmental constraints in a graphical format for direct perception, performance is improved and workload is reduced over conventional displays which require the user to integrate information in their heads (Davidsson et al., 2009; Hajdukiewicz and Vicente, 2004; Hoff, 2004; Sanderson et al., 2003). Vicente and Rasmussen (1992, p. 589) suggest that an 'EID interface should not contribute to the difficulty of the task, and at the same time, it should support the entire range of activities that operators will be faced with.' Thus it has been argued that interfaces designed following the EID framework will reduce mental workload when dealing with unfamiliar or unanticipated events (Vicente, 1999b). EID therefore offers potential for meeting the IVIS requirement of improving performance at no cost to workload. Within the scientific literature a handful of studies have used EID for vehicle design, for instance a lateral collision warning system (Jenkins et al., 2007), lane change manoeuvres (Lee et al., 2006; Stoner et al., 2003), intelligent transport systems (Salmon et al., 2007) and adaptive cruise control (Seppelt and Lee, 2007).

Whilst the ergonomics literature presents several papers detailing the basis for EID (namely cognitive work analysis – CWA; Vicente, 1999a; Birrell et al., 2008), and an increasing number proffering their actual EID displays, there remains something of a gulf between the development and the execution of EID as part of the wider human-centred design process (though for exceptions see Jamieson, 2003, and Sanderson et al., 2003). Moreover, it is imperative that this process includes a justification for the EID approach over conventional interface designs, particularly within a safety-critical context such as driving. In the rest of this paper, we explain the interim phase of the design process through a series of rapid prototyping studies aimed at developing an EID concept for Foot-LITE, and testing this against an alternative concept based on conventional interface design principles. We focus here mostly on the development of the in-car visual interface, although later in the paper we do also discuss similar efforts for the auditory interface.

EID visual display – design development

In keeping with the design process for ecological interface design (summarised by Sanderson et al., 2003), our starting point was to focus on the information requirements of the driver using cognitive work analysis – specifically, the abstraction hierarchy (AH; Rasmussen, 1985). The AH can be used to establish what type of information should be displayed, as well as where, when and how it should be presented, and finally how to integrate pieces of information which need to be associated (Lintern et al. 2004). An AH completed previously for the Foot-LITE project (Birrell et al., 2008) suggested several aspects of safe and eco-driving that should be represented on the display, such as headway, lane deviation and cornering speed for safety, complemented by engine speeds and acceleration forces for eco-driving. As implied above, EID offers to dynamically reflect the driving environment and integrate this complex information onto a single, direct perception display.

Another key concept upon which EID is based, is the skills-rule-knowledge taxonomy (Rasmussen, 1983) – components of which are largely identifiable from the AH. It has been suggested that safe and green driving depends on support at all three of these levels (Davidsson et al., 2009), but most in-vehicle information system displays only provide (and, arguably, *should* only provide) skill- and rule-based driver information. Sanderson et al. (2003) noted that the interface should support cognitive work at the most appropriate level of cognitive control. Moreover, Christoffersen et al. (1998) implied that whilst an EID can foster knowledge-based processing, this is only if users engage with the interface and reflect on its feedback. Given the concerns for driver distraction and overload (Regan et al., 2009), we suggest that the appropriate levels for in-vehicle feedback should be restricted to skill- and rule-based information, since knowledge-based processing is effortful and attention-demanding (Rasmussen, 1983). Mapping these levels onto models of vehicle control (e.g., Ranney, 1994), the IVIS display should show tactical and operational elements of driving. The flexibility of the Foot-LITE concept allows for strategic information (knowledge-based processing) to be presented off-board via the web-based application. Thus, it was decided that only low-level manoeuvring and vehicle control elements (consistent with the output of the AH) are to be presented on the in-vehicle interface.

Sanderson et al. (2003) describe that, as a skill-based information design principle, the interface should directly guide users' actions – as well as their understanding of how such actions move them towards their goal (Davidsson et al., 2009). Highly skilled drivers, with expertise in safe and green driving styles, are presumed here to pick up on direct cues in the environment (such as engine note, kinaesthetic feedback or advance visual information) to modify their behaviour. At the skill-based level, this will occur largely unconsciously, but most average drivers are likely to process only a small proportion of this richness of information in the real world (cf. Hoff, 2004). Thus the Foot-LITE EID attempts to make explicit the cues used by skilled drivers, by providing real-time, continuous feedback on these skill-based elements of vehicle control. Although there is an argument for retaining some processing in the head for longer-term retention of skills (i.e., holding back some information from the display), this approach is not suitable for safety-critical situations which require a fast response (Patrick and Morgan, 2010) – such as driving. Meanwhile, at the rule-based level, there should be consistent one-to-one mapping between the environmental constraints and the perceptual information in the interface (Sanderson et al., 2003). In our interpretation, such information is presented by discrete, 'pop-up' messages in tandem with the continuous, skill-based display. For instance, gear change information is implicit in the engine speed bar on the eco-driving ring, and is reinforced by more tactically-oriented messages such as 'change up sooner' – and both positive reinforcement as well as corrective messages are given. Positive encouragement was a significant outcome from the CWA analysis completed at the beginning of the project (Birrell et al., 2008), and is considered to be an important learning tool in facilitating desired behaviours.

Figure 1 shows a prototype of the EID interface developed for the current study. The principal aspects of the interface are based on Gibson and Crooks (1938) ecological notion of the 'field of safe travel', which was noted as '…a spatial field but it is not fixed in physical space. The car is moving and the field moves with the car through space.' (p. 456). On the EID display, the inner oval directly illustrates the driver's field of safe travel in the real-world, as the representation of the car moves within the shape and warnings are given if headway decreases or for lane departures. Thus the boundaries of the oval represent the limits of the field of safe travel. The outer ring presents the parameters associated with eco-driving performance, such as engine speed and acceleration; these are essentially bars moving up or down with acceleration / engine speed, with the optimum level in the middle of the bar. All of these parameters were identified from the AH, and reflect the continuous, skill-based vehicle control elements of driving. In both safety and eco-driving cases, the driver's goal is to maintain the car within a ‘Green Zone’ of performance, to optimise each set of parameters.

Insert Figure 1 about here

As an integrated graphical interface, this concept meets the requirements for an ecological display by being high in temporality and spatiality properties (Hoff, 2004). Furthermore, the skill-based components are ‘semantically mapped’ (Sanderson et al., 2003) – the relations between, and constraints on behaviour and performance are directly represented on the display. “Good semantic mapping means that system states (normal and abnormal), relations and constraints can be easily perceived” (Sanderson et al., 2003; p. 152). The grouping of both safety and eco-driving elements around a ‘green zone’ of optimal performance clearly identifies the constraints on desired performance, and suggests to drivers which actions ought to be taken to maintain such.

As an alternative to the EID concept, a more conventional dashboard-type interface (DB) has also been developed according to best practice interface design guidelines 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). Based on a vehicle instrument panel layout, the DB interface consists of bar charts, warning icons (derived from ISO 2575: 2004), pop-ups and textual information (see figure 2). The basic principles of the design are that driving information is grouped (as with the EID), with the eco-driving parameters all being presented in the left hand circle, while safety-related information is shown in the circle on the right. The main centre circle has a smart driving meter situated at its crest, with additional driving related information or predefined Smart driving tips presented underneath. The DB design is intended to offer familiarity to drivers, being akin to standard instrument panels available in most vehicles. We do not go into detail here on the development of the DB interface, since the focus of the present paper is on EID. Rather, the DB is merely presented as a foil to the EID for the subsequent rapid prototyping study, in a similar manner to the landmark study by Christoffersen et al. (1998). Suffice to say here that it was purposefully designed to impart exactly the same information as the EID, since ultimately the interfaces developed here will be tested more thoroughly using simulated driving data. The data feeding the displays will be equivalent across each interface option, and thus it is merely the representation of the data that differs. Whilst it could be argued that the representation itself imparts information to the user (especially in the configural relationships between variables on the EID), in our view this is what may set the interfaces apart – and, indeed, what we are testing.

Insert Figure 2 about here

Rapid prototyping study

In keeping with a human-centred design process to the project, both the ecological interface design and dashboard concepts were presented to potential users for their evaluation and consideration. In order to make an early human factors assessment of the two designs, static rapid prototypes of each were produced using standard desktop software.

Two iterative studies were conducted as part of this rapid prototyping phase, both aimed at specifying information requirements for the interface as well as gathering objective and subjective data on the efficacy of the designs. Study 1 was a questionnaire to determine users' views on specific elements of the presentation as well as choice of the 'pop-up' icons for rule-based information. This was followed by Study 2, a desktop presentation study of a variety of driving scenarios on each interface for user evaluation.

Study 1: User requirements questionnaire

A user requirements questionnaire was designed to elicit and refine the information requirements to be represented on both the ecological interface design and dashboard interfaces. The questionnaire was completed by 15 'user' participants (nine female, mean age 40.1 years), all of whom were regular, experienced drivers, as well as 11 subject matter experts (SMEs; primarily males aged 25-59) from the Foot-LITE project consortium. The questionnaire was split into two sections. The first focused on determining the type and format of information that should be presented on the Foot-LITE in-vehicle interface. For instance, one design decision which called for clarification was the orientation of the 'acceleration' bar of the EID outer ring – should positive accelerations be towards the top of the graph, mapping on forward movement and engine speed, or should braking be towards the top, reflecting the momentum or g-forces involved in the motion? Without exception, the users and the SMEs opted for a consistent mapping of movement and engine speed (i.e., acceleration 'increases' the bar and it moves up). It is perhaps unsurprising, given the novelty of the EID interface for users, that most of their feedback pertained to this rather than the DB display.

Similar differences in opinion emerged when considering the priorities of information content on the display. For example, the SMEs rated having a gearshift indicator as the most important information to be displayed in the vehicle, whereas users ranked this 13th out of 20. However, in terms of format of presentation, both the users and the SMEs agreed that information should be presented in an instantaneous format (i.e., actual moment-to-moment data). A simple generic representation of headway information (i.e., safe, dangerous etc.) was also favoured by both the user and SME groups.

The second section of the questionnaire asked participants to rank, in order of preference, a selection of icons which represented different aspects of green and safe driving which would be used for the DB interface as well as the pop-ups. These icons were derived from reviewing other standardised icons which are already present in current vehicles (i.e. adaptive cruise control, gear shift indicators etc.), following International Standards Organisation guidelines for in-vehicle icons (e.g., ISO 15008:2003; ISO 11429: 1996), and other icons generated specifically for the present research. The parameters to be presented on the interface (i.e., headway, acceleration forces etc.) were all listed along with four different icon options for each. The preferred icons for each driving parameter were aggregated across respondents to determine which icons would be used in study 2.

As well as rating their preferences, the respondents gave some useful feedback about icon design. Key points from these comments related to advice on cornering speeds and representation of gearshift information. Icons for cornering speed received a mixed response. With further probing it transpired that participants did not want to receive such information while actually driving the corner (as was intended), as this could be distracting. Meanwhile, responses from SMEs and users differed for the gearshift indicators. A simple numerical gear icon was preferred by users over a more elaborate image of a gear ‘gate’ pattern. On the other hand, SMEs preferred the gate, but since they also rated the simpler icon a close second, the latter option was chosen to take forward.

Taken together, the results of the questionnaire enabled us to refine the prototype displays in accordance with user and SME feedback. In essence, the nature of the information presented has not changed, since this is determined by the aforementioned abstraction hierarchy output and skill-rule-knowledge requirements. The components of safe and eco-driving are still represented, and skill-based vehicle control feedback is provided via the continuous display, while rule-based tactical information is given as pop-up messages. Nevertheless, the exact format of presentation has been adjusted according to user preferences – most notably in the acceleration bar of the eco-driving display on the EID, as well as in the specific choice of pop-up icons for both interfaces. The second stage of rapid prototyping takes the full visual display forward for user evaluation against the DB option.

Study 2: Desktop evaluation

The principal aim of the desktop study was to evaluate users' subjective responses to the two candidate designs for the human-machine interface. A series of five driving scenarios was conceived covering various aspects of safe and/or eco-driving, with static exemplars for each version of the HMI constructed to represent these scenarios. Both positive (i.e., desirable) and negative (undesirable) situations were represented. It is important to note again that the scenarios and the associated HMI representations were carefully designed such that the information presented across each interface (EID and DB) remained the same – it is merely the format of presentation which was varied and evaluated. The scenarios were designed to represent likely situations which may occur during normal driving, with each interface presenting comparable information.

A new sample of ten 'user' participants (six female; mean age 43.8 years), separate from the questionnaire study, were shown the scenarios for both HMI options in a counterbalanced repeated-measures design. No experts were used for this stage of the evaluation. A minimum of ten participants was needed for the study in accordance with SAE Recommended Practice J2364, which suggests that for early development phases when using a mock-up or computer simulation, static task time averaged over ten participants should be less than 15 seconds (Green, 1999). Participants were given a brief introduction to the Foot-LITE project and the aims of the study, and were informed of the basic principles of each interface design (EID and DB). The static interface scenarios were then individually presented on a laptop PC; following this participants offered a brief discussion on their understanding of the scenario and any behavioural changes they would make to their driving as a result. Dependent variables covered performance measures of response times and accuracy in interpreting the scenarios. Qualitative analyses of participants' descriptions of the displayed scenarios were used to infer the accuracy of their understanding. In addition, participants were asked to complete the System Usability Scale (SUS; Brooke, 1996) as a quantitative reflection of their subjective opinions on usability for each HMI design.

Results and discussion

Absolute response time, irrespective of whether the response was correct, was on average 0.4s faster for the EID than the DB interface (8.0s vs. 8.4s respectively), although a Wilcoxon test revealed that this difference was not statistically significant

(Z = -0.56; p = 0.58). It is notable that in each case, the response times recorded here are well within the 15 second rule for static task completion as suggested by Green (1999) and as part of SAE Recommended Practice J2365, thus implying safe use of either of these in-vehicle HMIs while driving. It is worth emphasising that participants were viewing the interface options for the first time during the tests, with only a very brief introduction explaining the displays. Nevertheless, both interfaces showed some degree of a learning effect, in that response times reduced for the scenarios presented later in the evaluation. Further observations on the data for specific scenarios suggested in particular that participants responded well to the positive encouragement given by the EID, as response times and standard deviations were low.

Accuracy of participants' responses to the scenarios was coarsely classified into 'fully correct', 'partially correct' (i.e., some elements of safe and/or eco-driving were not correctly identified), or 'incorrect'. Approximately one-third more participants correctly identified the scenario with the EID interface compared to the DB display. At the same time, more participants incorrectly identified the scenario with EID. Thus more participants only partially identified the scenario with the DB compared to EID. With more fully correct responses on the EID, the results suggest that this interface allows both the safety and fuel economy aspects of the design to be more clearly identified. However, it is a notable concern that five participants could not identify correctly any aspect of the interface, with all of these incidents occurring on the very first slide presented to the participants. Furthermore, when reviewing the transcripts, a common finding emerged that users were either slow to grasp or misunderstood the EID interface particularly with respect to headway. The implication from these results is that there is a steeper learning curve with the EID and suggests the need for a detailed explanation or 'tour' of the interface before use in an actual driving situation evaluation. However, it was also clear from their subjective responses that participants made a direct link between acceleration and fuel consumption with the EID, suggesting that it can support effective action and users' understanding of how these actions move them toward their goals (cf. Davidsson et al., 2009).

Subjective usability ratings, assessed via SUS, revealed that the DB design was rated higher than the EID (74.1 vs. 67.8 respectively), but a Wilcoxon test also revealed that this difference was not significant ($Z = -0.65$; $p = 0.61$). As well as assessing the overall mean ratings, responses to the individual questions on the SUS questionnaire were also analysed. Results suggest that participants rated EID as being more complex but more consistent compared to the DB design. We believe that both these factors are effects of the integrated nature of the EID presentation, which aims to combine information onto a single, direct perception display. It is again worth noting that participants were relatively naive to both interfaces in this study, and the EID in particular is an unfamiliar style of presentation for drivers. Our findings echo those of others (e.g., Jamieson et al., 2003) who have found initial resistance to EID displays when compared to traditional interfaces. Anecdotal reports from the study suggest that although the EID takes some getting used to, it can surpass the DB once the initial learning curve is complete. Participants noted that a potential limitation with the DB interface was its requirement to look in two separate places, hold this information in memory and then integrate the information in order to interpret it. As befits the ecological approach, the EID integrates all the information on the display, relieving the user of such demands. Furthermore, participants subjectively responded favourably to the positive reinforcement elements of the EID, and this was reflected in their objective performance data for both speed and accuracy.

EID auditory display – development and testing

Up to now, we have been discussing purely the visual component of the interface designs. However, similar work has been undertaken to develop an auditory display for the interfaces as well. Wickens (1984) suggests that because driving is a visually demanding task, the auditory modality is ideal for delivering effective warnings. The presentation of redundant information via the auditory field is therefore an effort to reduce driver visual workload and manage mental demand during higher (visual) workload situations (cf. Edworthy and Stanton, 1995).

For this project, audio options were developed for each real-time (i.e., skill-based) driving parameter. The rationale for addressing only the skill-based information is based on the assumption that the auditory modality is limited in terms of the amount and complexity of data it can transmit; thus the low-level vehicle control elements lend themselves to auditory feedback. Furthermore, auditory warnings are considered where the speed of response is a key variable (Edworthy and Stanton, 1995), as is the case with the skill-based, vehicle control information. Such information which Foot-LITE delivers to the driver includes gear change, acceleration and braking information (related to eco-driving), and headway and lane deviation information (related to safety). For each of these driving parameters three audio options were created: auditory icons, earcons and speech icons.

Auditory icons have been defined as naturally occurring sounds that can convey information about system events by analogy with everyday events (Gaver, 1986; 1989). An everyday example of an auditory icon is in the ‘recycle bin’ metaphor on desktop PCs, which gives a sound like the scrunching of paper when it is emptied. In the driving domain these may include sounds such as sirens, horns, engine noise or rumble strips. These are not abstract sounds (as with warning tones and earcons), but are designed to convey ecological information which should be familiar to the driver for a specific event. Gaver (1986) suggests that the more a representation's form depends on its meaning, the easier it should be to learn. From the perspective of the present paper, then, auditory icons are the closest to an ecological interface. The auditory icons created for the Foot-LITE interface included a sound of rumble strips for lane deviation, a sonar Doppler for headway (similar to that used for parking sensors), an over-revving engine for gear change, and the skidding of tyres for excessive braking.

Earcons, on the other hand, are abstract, synthetic tones that can be used in structured combinations to designate a particular meaning (e.g., Brewster et al., 1993). However, the link between earcons and their meanings does not exist naturally and must be learned (Graham, 1999). An example of an earcon, again from desktop PCs, is the alert that plays when you receive an email. This sound has no direct representation to receiving mail (an auditory icon of this might be a letterbox flapping), but in regular computer users has a strong learned relation to check their email. Earcons are the most common type of auditory warning used by vehicle manufacturers, and to a large extent we have followed their lead with the design of those used for the present study. For instance, a range of beeps were used to signify compromised headway and lane deviation, with increasing frequency to denote urgency for these safety-critical messages (cf. Hellier et al., 1993). Earcons for eco-driving included two-tone chimes for gear change (mid-high for change up; mid-low for change down), and a set of three high or low pitched chimes for excessive acceleration or braking respectively.

Finally, speech icons in our case comprised a synthetic voice verbalising a maximum of two units of information (or three words) relating to the specific driving parameter presented. Due to their nature, speech (or verbal) messages do not need to be learned and no inference is required; however, speech signals (even when only one or two words in length) take a relatively long time to present (Patterson, 1982) and require a significant period to interpret (Graham, 1999). It also follows that speech messages can only be fully interpreted when the message verbalisation is nearly complete. The speech icons selected for this study included statements such as ‘too close’ (for headway), ‘out of lane’ (for lane deviation), ‘change up’ or ‘change down’ (for gear change), and ‘heavy braking’ and ‘excessive acceleration’.

As with the visual display options, a desktop rapid prototyping study was conducted to evaluate the different audio options, which will ultimately be used to complement the real-time visual display. A series of static slides from the visual scenarios discussed earlier was shown to a further 20 different ‘user’ participants (12 female; mean age 40.11 years) via a PC presentation. Each slide included three hyperlinked boxes, one for each auditory interface type relating to that scenario (e.g., if the scenario was lane deviation, then there would be a clickable box to play a rumble strip, an earcon beep, and the ‘out of lane’ speech warning). Participants were allowed to click on these boxes as they pleased, in order to rate the sounds from most to least appropriate, using a methodology adapted from that proposed by Edworthy and Stanton (1995). Efforts were made to control for the loudness and duration of the sounds, in accordance with guidance from Edworthy and Stanton (1995). However, following the lead of Graham (1999), other sound attributes (such as pitch) were not controlled for as this may have compromised the differences between the different audio options. Furthermore, since this was a rapid prototyping study, the audio options presented were not finalised or refined sound files, and participants were instructed to simply rate the appropriateness of the warnings rather than their quality.

Results and Discussion

Participants' responses were coded such that the audio rated as the most appropriate was given a numerical value of 3, with the least appropriate given 1 – thus the higher the mean rating the better perceived the audio. Descriptive statistics are presented in Table 1; no inferential analyses were conducted on this limited dataset. However, we can observe some trends from the data. In general, speech was preferred for conveying eco-driving information, with auditory icons rated the least appropriate. However, for safety parameters, auditory icons were generally rated most appropriate, with earcons the least.

Insert Table 1 about here

Previous research suggests a general tendency towards speech icons over earcons and auditory icons amongst users (e.g., Jones and Furner, 1989; Lucas, 1995), reflecting the trend for eco-driving information in the current study. However, Jones and Furner (1989) make the point that the selection of audio representations should not be based on preference alone. Participants who had received an explanation of the auditory icons showed improved accuracy and response time, indicating a strong propensity towards learnability for both auditory icons and earcons (Lucas, 1995).

A key benefit of auditory over speech icons is that the information conveyed can be processed more effectively, especially at times of high workload (Bliss and Kilpatrick, 2000). Graham (1999) assessed the use of auditory icons against more conventional warnings for a vehicle collision avoidance system, and found that the auditory icon warning produced significantly faster braking reaction times, thus favouring the use of auditory icons for this safety-critical application. Furthermore, the fact that speech messages can only really be fully understood when the message is nearly complete, may slow down reaction times in emergency situations (Graham, 1999). However, it must be acknowledged that speech icons are generally preferred by users and show greater response accuracy to non-speech icons (e.g. auditory icons or earcons).

Our conclusions from this study suggest that the audio options to be taken forward to the next phase of more rigorous testing should include one verbal and one non-verbal icon for each of the safety and eco-driving parameters. Given that auditory icons were preferred for safety, and in conjunction with the theoretical advantages put forward in the literature, these will constitute the non-verbal icons for safety-related parameters. The opposite preference for eco-driving parameters means that earcons will be chosen as the non-verbal icon in this area – although it would appear likely that speech icons will continue to attract users' preferences. Nevertheless, as Jones and Furner (1989) pointed out, we cannot design on users' preferences alone, and the next stage of testing will be directed at evaluating the effects of these displays on drivers' performance in a simulator.

Summary and conclusions

A visual human-machine interface for a new in-vehicle information system has been developed according to ecological interface design principles. We have attempted to describe our course through the interim phase of the human-centred design process, from analysis through design development to early human factors assessment, which more often than not otherwise remains hidden in the literature. Results from the user requirements questionnaire suggested what format participants wanted the relevant information to be presented in. These responses were used to develop the two candidate HMI designs taken forward into the desktop evaluation study. Although the visual EID offers a range of potential benefits in theory, there was little to choose between the EID and traditional dashboard option based on the preliminary assessment from users. Nevertheless, with extended use the advantages (or otherwise) of EID may become more apparent (e.g., Christoffersen et al., 1998). Participants also made clearer links between their driving style and changes to fuel economy with the EID interface, ratifying the integrated and direct perception nature of this design. The subjective responses given by the participants form a good basis for potential iteration of both interfaces.

Similarly, a selection of audio options were developed for the interface, based on auditory icons, earcons, or speech icons, and these were subjected to user evaluation in a separate desktop study. Users preferred auditory icons for safe driving feedback, and speech icons for eco-driving advice. It is our feeling that auditory icons, which best align with principles of EID, would be most suited to the ecological visual display, especially for safety-related driving parameters. Meanwhile, earcons or speech icons might be better for presenting eco-driving information.

As a rapid prototyping evaluation of proposed interface designs for the Foot-LITE HMI, the current study has served its purpose. It was intended as a filtering stage between background analysis and more detailed interface evaluation, and as such makes no claims about the robustness of its scientific method. The sample sizes are small, and the inferential statistics are consequently limited in their analysis. What we have done is perform a preliminary evaluation of a series of visual and auditory interface options, refining and narrowing these down for further development and testing. However, these conclusions have been largely based on users' preferences and some rudimentary performance evaluations with static visual concepts. Further work is necessary to validate the designs, using dynamic versions in actual driving scenarios, against the original criteria of improving driver performance while avoiding distraction. Final decisions on the designs will be based on driver performance and workload, in addition to subjective responses. The next stage of the research is therefore to develop dynamic versions of the displays, and take them forward for more rigorous performance testing in the Brunel University Driving Simulator (preliminary results of which are available in Birrell and Young, 2009). In the meantime, we hope that the current paper sheds some light on the design development process for other applications of ecological interface design.

Acknowledgements

Foot-LITE is sponsored by the TSB, DfT and EPSRC under the Future Intelligent Transport Systems initiative. The Foot-LITE consortium is comprised of: MIRA, TRW Conekt, Auto-txt, HW Communications, Ricardo, Zettlex, Hampshire County Council, Institute of Advanced Motorists, Transport for London, Southampton University, Newcastle University and Brunel University. The authors are grateful to the two anonymous reviewers who provided useful feedback in improving our original manuscript.

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Table 1: Mean ratings given for each audio option within each real-time driving parameter.

Eco Parameter		Mean	SD	Safety Parameter		Mean	SD
Change Up	Auditory	1.45	0.69	**Lane Deviation**	Auditory	2.25	0.91
	Earcon	1.89	0.74		Earcon	1.90	0.79
	Speech	2.63	0.60		Speech	1.85	0.75
Change Down	Auditory	1.40	0.68	**Headway**	Auditory	2.37	0.83
	Earcon	1.95	0.71		Earcon	1.55	0.76
	Speech	2.58	0.69		Speech	2.11	0.74
Accel'n	Auditory	1.50	0.76	**Lane Instability**	Auditory	1.75	0.85
	Earcon	2.00	0.79		Earcon	1.84	0.76
	Speech	2.53	0.61		Speech	2.37	0.76
Braking	Auditory	1.55	0.76				
	Earcon	1.89	0.81				
	Speech	2.53	0.61				

List of Figure captions

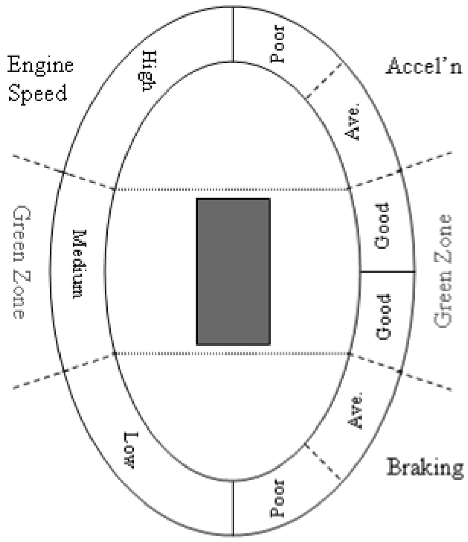

Figure 1: Prototype EID interface.

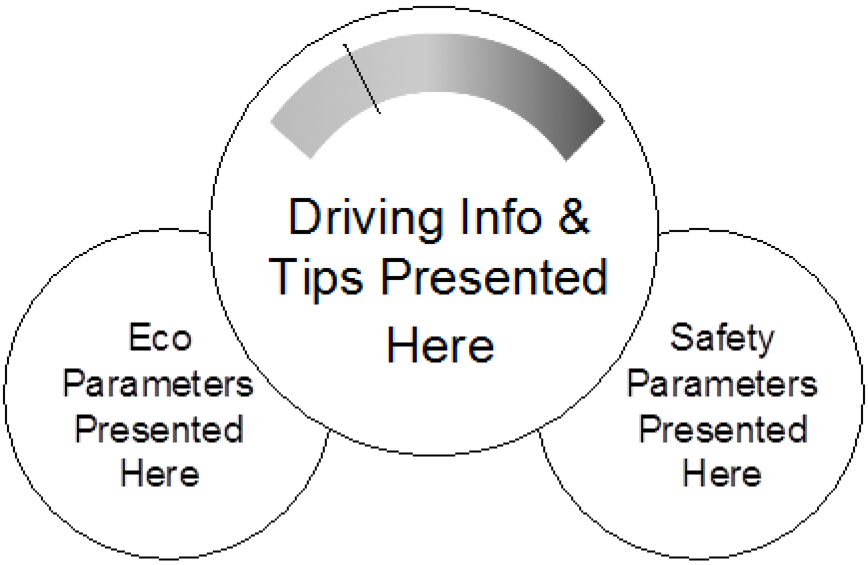

Figure 2: Prototype DB interface.