Sustainability, transport and design: Reviewing the prospects for safely encouraging eco-driving

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ABSTRACT

Private vehicle use contributes a disproportionately large amount to the degradation of the environment we inhabit. Technological advancement is of course critical to the mitigation of climate change, however alone it will not suffice; we must also see behavioural change. This paper will argue for the application of Ergonomics to the design of private vehicles, particularly low-carbon vehicles (e.g. hybrid and electric), to encourage this behavioural change. A brief review of literature is offered concerning the effect of the design of a technological object on behaviour, the inter-related nature of goals and feedback in guiding performance, the effect on fuel economy of different driving styles, and the various challenges brought by hybrid and electric vehicles, including range anxiety, workload and distraction, complexity, and novelty. This is followed by a discussion on the potential applicability of a particular design framework, namely Ecological Interface Design, to the design of in-vehicle interfaces that encourage energy-conserving driving behaviours whilst minimising distraction and workload, thus ensuring safety.

General Terms

Design, Human Factors

Keywords

Ergonomics, Sustainability, Human Machine Interface, Ecological Interface Design.

1. INTRODUCTION

It has now been largely accepted that anthropometric sources, i.e. humans past and present, are the primary cause of the earth's rising temperature [36]. As a 7 billion strong collective of individuals, we continue to consume more and more resources to satisfy our daily needs. The planet cannot indefinitely support our current level of resource usage let alone projected future consumption rates should prevailing trends continue [37]. The aim

of the current paper is to highlight transport's role in this increasingly important issue and to highlight an opportunity for the mitigation of climate change through the design of technological objects, specifically private road vehicles. A brief review of literature is provided, discussing the importance of the manner in which technology is used and how Ergonomics principles can be applied not only to support safety and usability, but also to encourage reductions in energy usage (and in turn waste production). The role of the private road vehicle will be discussed in relation to the global warming issue, followed by a brief overview of literature concerning the effect of design on behaviour. Finally, an argument is offered for the application of Ecological Interface Design to the design of low-carbon vehicle Human Machine Interfaces (HMI).

2. TRANSPORT AND SUSTAINABILITY

Sustainability does not merely concern our environment's ability to provide resources, but also its capacity to absorb waste. Indeed, it is primarily the emission of carbon dioxide (CO₂; the by-product of using fossil-fuels as an energy source), emitted in volumes that our environmental system does not have the capacity to absorb, that is causing the observed increases in the earth's average temperature [36]. As of 2011, petroleum accounted for 48% of total final energy consumption in the UK [16]. Despite progress in other sectors (e.g. industry, domestic, commercial), transport's CO₂ emissions changed little between 1990 and 2010 [17]. Private road transport plays a particularly significant part, accounting for 54% of all transport's carbon emissions (including those from air, rail, shipping and all private and commercial road transport; [14]). While it is beneficial to encourage people to make fewer journeys (e.g. by encouraging working from home), to improve public transport through investment, and to discourage private car use through punitive measures (e.g. congestion charging), our heavy reliance on private road transport makes it unrealistic to assume these will be sufficient. Private road transport "underpins our way of life" (p.3, [40]), supporting the high level of mobility to which we have been accustomed, with the removal of barriers to modal shift (i.e. getting people from the private car onto public transport) being a highly complex and multi-faceted challenge [66] that will not easily be achieved. It is therefore apparent that if we are to achieve the 80% reduction in CO₂ emissions posited by the UK government (in their 2008 Climate Change Act) necessary to avoid the most serious economic [26, 68] and environmental [36] consequences of climate change, we will have to enact a wide variety of mitigation strategies. The electrification of private road transport and the use of vehicle interface design to encourage energy conservation behaviours in these (and other) vehicles, are two such strategies.

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AutomotiveUI '13, October 28 - 30 2013, Eindhoven, Netherlands
Copyright 2013 ACM 978-1-4503-2478-6/13/10...\$15.00.
<http://dx.doi.org/10.1145/2516540.2516578>.

3. THE IMPORTANCE OF USAGE

Though technological advancement is of course critical to the mitigation of climate change, it is not the only challenge; we must also see behavioural change [68]. A promising means for encouraging this change is through the careful design of products. Consider this; consumers' behaviour is shaped by the product they are using, with the product being designed with a particular activity in mind [64]. With technological objects, it is often the use phase (as opposed to the manufacturing or disposal phase) that incurs the greatest environmental impact [52]. This is particularly noticeable in road vehicles; life-cycle analyses suggest that 76% of CO₂ emissions and 80-90% of energy use can be attributed to the burning of fuel in an internal combustion engine [57]. Though hybrid and electric vehicles incur greater manufacturing costs and lower use costs, more than half of the global warming potential still arises from vehicle usage [30]. Hence the challenge is to design the vehicle's interface such that certain behaviours are encouraged (i.e. conservative driving styles) and others are discouraged (i.e. aggressive, fuel intensive driving styles).

3.1 Design, persuasion and feedback

Before going on to discuss HMI design specific to road vehicles it is worthwhile to outline some design philosophies more generally. As aforementioned, a user's behaviour is shaped by the product they are using, with the product being designed with a particular use, or method of use in mind [64]. It is important to bear in mind that technology design not only needs to be, but inherently *is* persuasive, in that it persuades the user to behave with the product in a certain way, i.e. it guides the interaction process. Fogg [24] described this in terms of intention on the part of the creator; a machine can have no intention of its own, hence it is those that create the machine that do so with an intention to affect human behaviour and/or attitudes [23]. Explicitly recognising the intention to influence behaviour inherent in design is a key feature of Lockton and colleagues' [51, 53] Design With Intent method. Here they describe the careful design of an object's operation sequence such that the user's choices and the consequences of those choices are brought to conscious attention. The simple example offered by Lockton *et al.* [51] is that of the two-button toilet flush, used to bring water usage to the attention of the user.

Guiding (or indeed restricting) the interaction sequence is one way to elicit certain behaviours, however it is also possible to affect behaviour through the activation of goals and the provision of information. Rather than simply guiding the behaviour itself, the aim here is to affect users' knowledge, beliefs, attitudes and intentions, the determinants of behaviour [2, 22]. These methods of affecting behaviour gain support from Abrahamse *et al.* [1] in their review of household energy use intervention strategies; here it was found that interventions aimed at the determinants of behaviour were the most successful in encouraging energy conservation. Feedback is an example of such an intervention.

Feedback, that is to say information regarding the consequences of action, has long been recognised as having a significant impact on performance (e.g. [3, 8]). It has, however, been suggested that feedback alone is not a sufficient condition for effective performance. Locke and colleagues [45–49] argued that an individual's goals interact with feedback to steer behaviour insofar as goals and intentions mediate the effect of feedback. That is not to say that a user's goal must already be activated before receiving feedback in order for performance to be effective; the feedback itself may prompt goal activation [41]. The Feedback Intervention Theory postulates that feedback can direct

an individual's attention (consciously or otherwise) to a specific goal [41]. In the theory, goals are described in terms of the levels of behaviour to which they apply. For example, an individual may have a high-level goal of wanting to be 'eco-friendly', regardless of their current activity. An example of a low-level goal would be that of wanting to save fuel when driving; it is task-specific. To affect task-specific behaviour (e.g. driving style), task specific goals must be activated (e.g. to save fuel whilst driving). Furthermore, a goal can only be reached if appropriate feedback is provided such that the individual knows where they stand in relation to that specific goal [50]. Therefore feedback, if designed successfully, can both activate the goals pertinent to the task, and can inform the user of the consequences of their behaviour, thus guiding performance [54].

3.2 Energy use in vehicles

To take advantage of the effect of feedback on energy-use behaviour has been the goal of number of researchers in the driving domain. Though this has become increasingly popular in recent years (in line with public knowledge of climate change), it has been long recognised that the style with which a person drives can have a significant impact on fuel economy. In 1979 Leonard Evans found that when asked to drive economically in a real world setting (i.e. reducing acceleration levels and driving 'gently') participants could reduce fuel consumption by 14% [20]. Similarly, Walters and Laker [74] found that participants used 15% less fuel when asked to drive 'economically' around a test track. Both of these studies only used the activation of goals; neither employed any feedback mechanism whatsoever. Research on feedback in vehicles performed around the same time did not, however, find such beneficial effects; in 1976 Hinton and colleagues (cited in [71]) reviewed a number of fuel efficiency support tools (brought out mainly in response to the oil crisis of the early 1970s), finding only insignificant fuel savings across devices.

The lack of positive effect on fuel economy of the tools reviewed by Hinton *et al.* highlights the fact that it is not merely the presence of feedback that is important, but the design of that feedback. The tools reviewed were deemed inaccurate, untimely, often contradictory and ultimately unclear [71]. Moreover the tools were often considered distracting and were hence largely ignored. Partly in response to these shortcomings, van Der Voort and colleagues [71] investigated a prototype fuel-efficiency support tool that was designed to support speed choice, acceleration, deceleration, and gear choice (factors most associated with fuel economy [33]). Though simply asking participants to drive economically resulted in a 9% fuel use reduction (i.e., goal activation only), those participants with the eco-feedback tool achieved an additional 7% fuel saving (i.e. goal activation plus feedback). In a purely urban simulated environment this additional fuel saving rose to 14% [71].

The intrinsic motivation to save fuel whilst driving will of course vary between drivers and between situations, however the incentive to do so may be consistently higher in electric and hybrid vehicles due to the issue of range anxiety [39]. Drivers of electric vehicles may be inherently more motivated to drive in an economical fashion than those driving traditional internal combustion engine vehicles in order to avoid the negative emotions (i.e. range anxiety) associated with a vehicle of restricted range and limited infrastructural support [39]. Considering driving style can affect energy consumption rates by as much as 30% in electric vehicles [9] an efficiency support tool

to help drivers make the most out of their energy reserves is likely to have significant positive effects.

One study to assess such a tool was that of Kim *et al.* [39]. This research assessed the use of a power flow gauge in a simulated electric vehicle, finding that those drivers with the feedback presented milder, more stable accelerator pedal usage and lower energy consumption than those without energy use feedback. It is also possible to encourage economical driving by simply presenting the number of potential driving miles remaining in the battery; such a concept was investigated by Everett *et al.* [21]. This study found that having the miles-remaining display present encouraged participants to drive more economically.

4. SAFETY AND USABILITY

The design of a fuel efficiency support tool is not only important in terms of its efficacy in encouraging economical driving styles, but in terms of its usability, particularly with regards to safety. Hence an informative, aesthetically pleasing tool with which individuals are engaged and enjoy using may help to encourage efficient, environmentally-friendly driving styles, may not necessarily be appropriate for use in vehicles on the road.

The practice of Hypermiling (see www.hypermiler.co.uk) provides an interesting example of where a range of behaviours that have a significantly positive effect on energy conservation are not necessarily advisable due to safety reasons. While over-inflating tyres, turning off the engine and coasting downhill, or drafting as close as possible to the vehicle in front to make use of the slipstream, may be beneficial activities for reducing fuel consumption, they present a trade-off in terms of road safety [5, 35]. The driving task is highly complex, comprising over 1600 separate tasks [73]. Being the safety critical domain it is, the addition of more information to an already complex array of in-car systems should be very carefully considered if we are to avoid increasing workload and distraction, both of which are causal factors for accidents [10, 61]. People have limited cognitive resources and as such, if the non-driving task demands increase (such as can happen when required to attend to an additional 'eco' display), attentional resources for other tasks decrease [75], resulting in the possibility that the concurrent feedback will interfere with on-going task performance, a principle that has been demonstrated both within and outside of the driving domain [4, 15, 65]. Furthermore, Groeger [28] describes driving as a goal-directed task, with multiple goals (e.g. speed, safety, economy) active simultaneously that at any point in time may be in conflict with each other. Highlighting the importance of economy goals may have detrimental effects on performance in other aspects of driving, for example safety.

Despite the possibility of conflict arising in the driving task, safe driving and economical driving do have significant overlaps [77]. Aggressive driving is seen as both dangerous [77] and uneconomical [19] due to characteristically high acceleration and deceleration rates and high engine speed and power demands. It is possible then to encourage both safe and economical driving through supporting ecodriving; Hedges and Moss [32] showed that after supplying eco-training to Parcelforce van drivers accident rates dropped by 40% and fuel efficiency increased by 50%, and Haworth and Symmons [31] demonstrated 35% reduction in accident rates alongside reduction in fuel consumption (11%) and emissions (up to 50%) following similar training. Despite these safety / efficiency overlaps, both of these studies represent instances of pre-task information, rather than on-

line feedback, hence safety with regards to distraction and workload could not be assessed.

Though distraction in the vehicle has been investigated by a variety of researchers (e.g. [18, 29, 34, 62]), research specifically looking at distraction by eco-feedback is less abundant. Wada *et al.* [72] offer a description of one such investigation, however the distractive qualities of the eco-tool assessed were only investigated through post-task questionnaires offering subjective workload ratings, not direct measures of distraction. To find such a measure we can look to a study by Birrell and Young [10]. In this research a device that provided information regarding both safety (e.g. lane departure, headway maintenance) and economy (acceleration and deceleration) was assessed not only in terms of the tool's efficacy in encouraging safe, economic driving (in which it succeeded), but in terms of distraction using both post-task questionnaires and a concurrent peripheral detection task. Interestingly, of the two interfaces investigated, one saw participants perform better on the detection task and received more favourable subjective ratings, however neither were deemed to be distractive [10].

5. THE ROLE OF ERGONOMICS

As we have seen from the preceding discussions, the careful design of technology and feedback, specifically in-vehicle HMI, offers a promising avenue for the reduction of transport's destructive effect on the world we inhabit. Furthermore, it is encouraging to note that this can be achieved without necessarily impacting negatively on usability and safety. That is not to say the challenge has yet been met; researchers in the field would do well to focus their efforts in order to achieve the greatest beneficial impact on the issue of sustainability in transport. This is especially important now considering the introduction, and increasing uptake of low-carbon vehicles (e.g. hybrid and electric vehicles), and the new challenges, and indeed opportunities, they represent.

As such, the current authors have identified four primary areas where the application of Ergonomics to the design of the in-vehicle environment may be most beneficial; the necessity to overcome the significant and oft-cited issue of range anxiety (e.g. [13]); the need to support the development of accurate mental-models of the novel, often poorly understood technology; the issue of rising in-car complexity, and the effect this will have on workload, distraction, and the resulting safety implications; and the opportunity to take advantage of this novelty in fostering the development of new, economical, yet safe driving habits. While these four concerns have been stated separately it should be noted that they are inter-related, in that any single design intervention strategy will need to be considered in terms of its impact on all four issues. It is for this reason that the current authors introduce and argue for the continued and increased application of Ecological Interface Design (EID; [12, 70]) to the driving domain. EID is an approach to interface design that considers the system in its entirety, taking into account the inter-relatedness of system components and functions. It will be argued that interfaces developed with this technique can offer unique benefits over more traditional vehicle interface designs.

5.1 Ecological Interface Design

Ecological Interface Design (herein referred to as EID) is based on the tenets of Cognitive Work Analysis (CWA), an analysis technique primarily offered as a formative methodology, describing how a system could perform given the constraints of the domain and the functional links between low-level system components and high-level system functions and purposes (e.g.

[69]). EID is essentially about representing the environmental constraints (graphically or otherwise) of the domain such that direct perception is possible, thus removing the requirement for indirect mental representations of external reality. Creating and maintaining an indirect representation of the world is problematic in that not only does it require more cognitive resources to construct (particularly significant considering the safety-critical, cognitively demanding nature of the driving task), but also is more susceptible to inaccuracies [94], with such inaccuracies leading to an incomplete and incorrect understanding of the system or environment in question. In the following discussion some of the potential benefits of EID (as related to in-vehicle interface design) are offered; this is intended as suggestive and exploratory, bringing attention to areas where potentially interesting research may be applied, rather than an exhaustive list of concrete possibilities for interface design. For a thorough description of the EID method itself the reader is referred to [70].

5.2 Reducing range anxiety

Range anxiety, a widely recognisable phrase that often appears in the popular media, is arguably the most influential barrier to the more wide scale uptake of electric vehicles (e.g. [58]). It has, however, been shown to decrease with experience in an electric car (e.g. [21, 25]). Furthermore, Franke *et al.* [25] argued that it may be possible to help drivers overcome range anxiety with information and interface design. Despite finding sub-optimal range utilisation in their field-study of electric vehicle drivers they put forward the argument that increasing the *actual* range of an electric vehicle may be less important than merely providing the driver with reliable, accurate information about the usable range of the vehicle. Importantly, it is about reducing the *perceived* barriers associated with range anxiety. This is one area where EID could have a beneficial impact; it is partly in a driver's (mis)understanding of the system in its entirety (including the vehicle, the driver, and the environment in which they find themselves) that range anxiety finds its basis. This is intimately linked with how a system is represented, and the resulting mental models developed and maintained by the user. Such an investigation of the effect of interface design on range anxiety is currently lacking from the extant literature.

5.3 Supporting mental model development

The suggestion that range anxiety may be associated with *perceived* barriers [25] implies that the barriers may not necessarily be present in the physical world, but are based in people's beliefs, right or wrong, about electric cars and the range people are likely to require. The question of how to design to overcome barriers then becomes a question of how to support an accurate mental model of the system [27]. When a user does not have an accurate or sufficiently detailed understanding of a system (i.e., they lack an accurate mental model) he or she is more likely to display undesirable behaviours. Thus the sub-optimal range utilisation found by Franke *et al.* [25] could be explained in terms of their incomplete or incorrect mental models of the system.

As aforementioned, it is the aim of EID to represent the system to the user in such a way that supports the development of an accurate understanding of the system through aiming to directly represent environmental constraints and system boundaries; it is about supporting accurate mental models. This concept is particularly important in an environment that is becoming increasingly augmented with automated systems, such as the private road vehicle (e.g. adaptive cruise control, park assist, lane departure warnings). The user should be aware of the functioning

of the automation to avoid confusion and enhance trust, both of which, if not properly designed for, could induce distraction and increase, rather than decrease, workload.

5.4 Minimising workload and distraction

Even though many in-vehicle automations are aimed at reducing the workload of the driver, the presence of such systems does not necessarily equate to a reduction in task demands. If the way in which a system functions is not wholly apparent (e.g. the feedback or interface is not designed successfully) mode error can result; this is where the user does not understand in which mode the automation is functioning, or how or why the automation is functioning in the way it is [44]. Such confusion can undermine the intended benefits of the system. Research from Seppelt and Lee highlights this issue [63]; they found that making the functioning of Adaptive Cruise Control (ACC) apparent to the driver, using an EID based approach, supported safer driving behaviours both when the ACC was activated and when driving manually. The authors therefore argued that providing drivers with information regarding the state of the automation (an important tenet of EID) was more useful than simply providing collision-warning alerts. Mendoza *et al.* [55] offered similar arguments following their investigation of EID guided Advanced Driver Assistant System design. It was found that the presentation of information not immediately relevant to the task at hand provided a significant source of distraction; that EID can specify what an interface has to display in given situation or for a given function [43] means the display of irrelevant information can be avoided. This effect is further highlighted by work by Birrell and Young, described above [10] (see also [76]). The more successful of the two interfaces investigated was designed using EID. Other examples of successful use of EID can be found in Jenkins *et al.*'s lateral collision warning research, where an EID-based interface compared favourably with a traditional display [38], and in Lee *et al.*'s investigation of lane departure warning systems. This research found that EID-inspired displays performed at least as well, if not better than traditional displays, particularly in situations where the participants could only view the scenario for a short time period [42]. The ability of an interface to be understood quickly is an important feature if it is to avoid being distractive.

5.5 Dealing with complexity and novelty

The aforementioned studies point to the possible benefits of designing in-vehicle systems with EID. There still remains the challenge of bringing together the various safety and economy systems discussed thus far. Moreover, new in-vehicle information systems will need to cope with the added novelty and layers of complexity associated with low carbon vehicles. Though Young, Birrell and colleagues have begun to use EID to address the issue of combining safety systems with those encouraging economical driving [10, 11, 76], these studies do not address the unique challenges brought by hybrid and electric vehicles.

It is not only in the novelty of electric and hybrid vehicles or in the added complexity of the various engine modes in which a parallel hybrid vehicle may operate (e.g. battery only, engine only, engine and battery together) or in the difficulty with which a regenerative braking feedback tool can be incorporated into any future vehicle interface that the challenges lie. Products that people perceive to be 'eco-friendly' can incur excessive use; the 'rebound effect' describes how a product is used more often if a user thinks each use is less environmentally damaging [7]. The extra usage (of the vehicle) incurred negates any improvements in the energy savings made through the design of the product. This is

particularly important for electric cars, as just because tailpipe emissions are zero doesn't mean the energy is clean and abundant. Is it possible, therefore, to develop an interface that discourages this kind of behaviour?

Tackling the HMI challenges posed by the wide scale uptake of electric and hybrid vehicles, in both safety, economic and enjoyment terms, will require careful consideration, however it is important not to lose sight of the opportunities provided by such a technological advancement. As has been described, there is a large potential for environmental benefit arising from encouraging behavioural change through design. This may be particularly true for private road vehicles, not only because they themselves incur such high energy costs, but through the ability to take advantage of the novelty of low-carbon vehicle technology.

Zachrisson and Boks [45] argued that a product's ability to break old habits is related to the novelty of the interaction with that product, with more innovation or novelty having a stronger ability to break previous habits. This may be because prior schemata (organised knowledge structures, based upon past experiences, that interact with information in the external environment to guide behaviour in a given situation [6, 60, 67]) are evoked to a far lesser extent when interacting with a novel product than when interacting with a more familiar product. These schemata affect the way we perceive the world, influence the decisions we make, and direct our actions [56]. If the situation or environment is one of novelty then it is unlikely that a fully developed schema will exist to guide behaviour. To put this in a driving context, the more familiar the human-vehicle interaction or interface design, the more similar to prior driving habits the observable behaviour will be, including any previously learned habits. A novel interaction will more readily support the modification (or Accommodation in Piaget's terminology; [59]) of previously held schemata. Hence it is argued that interface design in electric and hybrid cars, aided by the novelty of the technology and its ability to encourage schema adaption and development, can be used to foster new economical driving styles, replacing fuel-intensive habits.

6. CONCLUSIONS

Given the underlying current of the over-consumption of resources and excessive production of waste with which our environment cannot sustainably cope, and considering the relatively recent introduction and uptake of new, low-carbon vehicle technologies, the potentially challenging, yet promising opportunities in vehicle HMI design offer a positive outlook for the future of private road transport. Bearing in mind the added complexity and novelty that come with low-carbon vehicles, workload and distraction must be carefully considered when designing in-vehicle feedback tools, however the prospects for encouraging behaviour-change through design are clearly promising. It is in the current authors' judgement that with an appropriate approach to design, for example EID, it will be possible to design in-vehicle information environments that not only minimise workload and distraction (hence maximise safety), but also help individuals reduce their energy consumption and alleviate their feelings of range anxiety.

While this paper provides some example areas in which the application of EID may have positive impacts, both on safety and on fuel consumption, it is important to reiterate that this is not intended to be an exhaustive list of the potential benefits of the design methodology, nor is it an empirical justification for EID. Rather this paper suggests some research areas and topics that EID appears well suited to address and, in the current authors' judgement, merit further exploration. The current authors' on-

going research efforts will aim to address some of the points raised in this article, with empirical investigations of EID-based interfaces forming a necessary part of these research efforts.

Finally, it is in these authors' opinion that electrically powered vehicles currently present the most promising avenue for the mitigation of climate change through the reduction of transport-related CO₂ emissions; as such, the application of Ergonomics now is likely to have significant, positive and lasting impacts in the transport domain.

7. ACKNOWLEDGMENTS

This research was joint-funded by the UK's Engineering and Physical Sciences Research Council (EPSRC) through the Transport and Environment programme, and Jaguar Land Rover PLC.

8. REFERENCES

- [1] Abrahamse, W., Steg, L., Vlek, C. and Rothengatter, T. 2005. A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology*. 25, 3 (Sep. 2005), 273–291.
- [2] Ajzen, I. 1991. The Theory of Planned Behavior. *Organizational Behavior and Human Decision Processes*. 50, (1991), 179–211.
- [3] Ammons, R.B. 1956. Effects of knowledge of performance: A survey and tentative theoretical formulation. *Journal of General Psychology*. 50, (1956), 279–299.
- [4] Arroyo, E., Sullivan, C. and Selker, T. 2006. CarCoach: A polite and effective driving coach. *Proceedings of the CHI: Conference on Human Factors in Computing Systems* (2006), 357–362.
- [5] Barkenbus, J.N. 2010. Eco-driving: An overlooked climate change initiative. *Energy Policy*. 38, 2 (Feb. 2010), 762–769.
- [6] Bartlett, F.C. 1932. *Remembering: A Study of Experimental and Social Psychology*. Cambridge University Press.
- [7] Berkhout, P.H.G., Muskens, J.C. and Velthuisen, J.W. 2000. Defining the rebound effect. *Energy Policy*. 28, (2000), 425–432.
- [8] Bilodeau, E.A. and Bilodeau, I.M. 1961. Motor-skills learning. *Annual Review of Psychology*. 12, (1961), 243–280.
- [9] Bingham, C., Walsh, C. and Carroll, S. 2012. Impact of driving characteristics on electric vehicle energy consumption and range. *IET Intelligent Transport Systems*. 6, 1 (2012), 29–35.
- [10] Birrell, S.A. and Young, M.S. 2011. The impact of smart driving aids on driving performance and driver distraction. *Transportation Research Part F: Traffic Psychology and Behaviour*. 14, 6 (Nov. 2011), 484–493.
- [11] Birrell, S.A., Young, M.S., Jenkins, D.P. and Stanton, N.A. 2012. Cognitive Work Analysis for safe and efficient driving. *Theoretical Issues in Ergonomics Science*. 13, (2012), 430–449.
- [12] Burns, C. and Hajdukiewicz, J. 2004. *Ecological Interface Design*. CRC Press.
- [13] Cocron, P., Bühler, F., Neumann, I., Franke, T., Krems, J.F., Schwalm, M. and Keinath, A. 2011. Methods of evaluating electric vehicles from a user's perspective – the MINI E

- field trial in Berlin. *IET Intelligent Transport Systems*. 5, 2 (2011), 127–133.
- [14] Commission for Integrated Transport 2007. *Transport and Climate Change*.
- [15] Corbett, A.T. and Anderson, J.R. 2001. Locus of Feedback Control in Computer-Based Tutoring : Impact on Learning Rate , Achievement and Attitudes. *Proceedings of ACM CHI 2001 Conference on Human Factors in Computing Systems*. J. Jacko, A. Sears, M. Beaudouin-Lafon, and R. Jacob, eds. ACM Press. 245–252.
- [16] Department of Energy and Climate Change 2012. *Digest of United Kingdom Energy Statistics*. The Stationary Office.
- [17] Department of Energy and Climate Change 2012. *Statistical release: 2011 UK Greenhouse Gas Emissions, Provisional Figures and 2010 UK Greenhouse Gas Emissions, Final Figures by Fuel Type and End-User*.
- [18] Donmez, B., Boyle, L.N. and Lee, J.D. 2007. Safety implications of providing real-time feedback to distracted drivers. *Accident, Analysis and Prevention*. 39, 3 (May. 2007), 581–90.
- [19] Ericsson, E. 2001. Independent driving pattern factors and their influence on fuel-use and exhaust emission factors. *Transportation Research Part D: Transport and Environment*. 6, (2001), 325–345.
- [20] Evans, L. 1979. Driver behaviour effects on fuel consumption in urban driving. *Human Factors*. 21, (1979), 389–398.
- [21] Everett, A., Burgess, M., Harris, P.M., Mansbridge, S., Lewis, E., Walsh, C. and Carrol, S. 2011. *Initial findings from the Ultra Low Carbon Vehicle demonstrator programme: How quickly did users adapt?*
- [22] Fishbein, M. and Ajzen, I. 1975. *Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research*. Addison-Wesley.
- [23] Fogg, B.J. 1998. Persuasive computers: Perspectives and research directions. *Proceedings of the CHI98 Conference of the ACM/SIGCHI* (New York, 1998), 225–232.
- [24] Fogg, B.J. 2003. *Persuasive Technology: Using Computers to Change What We Think and Do*. ACM Press.
- [25] Franke, T., Neumann, I., Bühler, F., Cocron, P. and Krems, J.F. 2011. Experiencing Range in an Electric Vehicle: Understanding Psychological Barriers. *Applied Psychology: An International Review*. 61, 3 (Jul. 2011), 368–391.
- [26] Garnaut, R. 2011. *The Garnaut Review 2011*. Cambridge University Press.
- [27] Gentner, D. and Stevens, A.L. 1983. *Mental Models*. Houghton Mifflin.
- [28] Groeger, J.A. 2000. *Understanding Driving: Applying Cognitive Psychology to a Complex Everyday Task*. Psychology Press.
- [29] Harms, L. and Patten, C. 2003. Peripheral detection as a measure of driver distraction. A study of memory-based versus system-based navigation in a built-up area. *Transportation Research Part F: Traffic Psychology and Behaviour*. 6, 1 (Mar. 2003), 23–36.
- [30] Hawkins, T.R., Singh, B., Majeau-Bettez, G. and Strömman, A.H. 2012. Comparative Environmental Life Cycle Assessment of Conventional and Electric Vehicles. *Journal of Industrial Ecology*. (Sep. 2012).
- [31] Haworth, N. and Symmons, M. 2001. *The relationship between fuel economy and safety outcomes*.
- [32] Hedges, P. and Moss, D. 1996. Costing the effectiveness of training: case study 1- improving Parcelforce driver performance. *Industrial and Commercial Training*. 28, (1996), 14–18.
- [33] Hooker, J.N. 1988. Optimal driving for single-vehicle fuel economy. *Transportation Research Part A: Policy and Practice*. 22, 3 (1988), 183–201.
- [34] Horberry, T., Stevens, A., Burnett, G., Cotter, S. and Robbins, R. 2008. Assessing the visual demand from in-vehicle information systems by means of the occlusion technique : the effects of participant age. *IET Intelligent Transport Systems*. 2, (2008), 170–177.
- [35] Hypermiling: The Quest for Ultimate Fuel Economy: 2009. .
- [36] Intergovernmental Panel on Climate Change 2007. *Climate Change 2007: Synthesis Report*. Cambridge University Press.
- [37] International Energy Authority 2012. *World Energy Outlook*. OECD.
- [38] Jenkins, D., Stanton, N.A., Walker, G.H. and Young, M.S. 2007. A new approach to designing lateral collision warning systems. *International Journal of Vehicle Design*. 45 (2007), 379–396.
- [39] Kim, S., Dandekar, H., Camez, E. and Harrelson, H. 2011. Assessing the effect of a power-flow gauge on driving behaviors affecting energy consumption. *Human-Computer Interaction, Part III, HCI 2011, LNCS 6763*. J.A. Jacko, ed. Springer-Verlag. 411–417.
- [40] King, J. 2007. *The King Review of low-carbon cars. Part I: The potential for CO2 reduction*.
- [41] Kluger, A.N. and DeNisi, A. 1996. The effects of feedback interventions on performance : A historical review , a meta-analysis , and a preliminary feedback intervention theory. *Psychological Bulletin*. 119, 2 (1996), 254–284.
- [42] Lee, J.D., Hoffman, J.D., Stoner, H.A., Seppelt, B.D. and Brown, M.D. 2006. Application of ecological interface design to driver support systems. *Proceedings of IEA 2006: 16th World Congress on Ergonomics*. (Maastricht, The Netherlands., 2006).
- [43] Lee, J.D., Stoner, H.A. and Marshall, D. 2004. Enhancing interaction with the driving ecology through haptic interfaces. *2004 IEEE International Conference on Systems, Man and Cybernetics (IEEE Cat. No.04CH37583)*. 1, (2004), 841–846.
- [44] Liu, Q., Itoh, H. and Yoshimura, K. 2006. On the design of in-vehicle advice system. *2006 IEEE International Conference on Systems, Man, and Cybernetics* (Taipei, Taiwan, 2006), 2511–2516.
- [45] Locke, E.A. 1967. The motivational effects of knowledge of results: Knowledge or goal setting? *Journal of Applied Psychology*. 51, (1967), 324–329.
- [46] Locke, E.A. 1968. Toward a theory of task motivation and incentives. *Organizational Behavior and Human Performance*. 3, (1968), 157–189.

- [47] Locke, E.A. and Bryan, J.F. 1968. Goal setting as a determinant of the effect of knowledge of score on performance. *American Journal of Psychology*. 81, (1968), 398–406.
- [48] Locke, E.A. and Bryan, J.F. 1969. Knowledge of score and goal level as determinants of work rate. *Journal of Applied Psychology*. 53, (1969), 59–65.
- [49] Locke, E.A. and Bryan, J.F. 1969. The directing function of goals in task performance. *Organizational Behavior and Human Performance*. 4, (1969), 35–42.
- [50] Locke, E.A. and Latham, G.P. 2002. Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American Psychologist*. 57, 9 (2002), 705–717.
- [51] Lockton, D., Harrison, D. and Stanton, N.A. 2008. Design with Intent : Persuasive technology in a wider context. *Persuasive 2008, LNCS 5033*. H. Oinas-Kukkonen, ed. Springer-Verlag. 274–278.
- [52] Lockton, D., Harrison, D. and Stanton, N.A. 2008. Making the user more efficient: Design for sustainable behaviour. *International Journal of Sustainable Engineering*. 1, 1 (2008), 3–8.
- [53] Lockton, D., Harrison, D. and Stanton, N.A. 2010. The Design with Intent Method: A design tool for influencing user behaviour. *Applied Ergonomics*. 41, 3 (May. 2010), 382–92.
- [54] McCalley, L.T. 2006. From motivation and cognition theories to everyday applications and back again: The case of product-integrated information and feedback. *Energy Policy*. 34, 2 (Jan. 2006), 129–137.
- [55] Mendoza, P., Angelelli, A. and Lindgren, A. 2011. Ecological interface design inspired human machine interface for advanced driver assistance systems. *IET Intelligent Transport Systems*. 5, 1 (2011), 53.
- [56] Neisser, U. 1976. *Cognition and Reality*. W.H.Freemant & Co.
- [57] Organisation of Economic Cooperation and Development 1993. *Cars and Climate Change*. OECD.
- [58] Pearre, N.S., Kempton, W., Guensler, R.L. and Elango, V. V. 2011. Electric vehicles: How much range is required for a day's driving? *Transportation Research Part C: Emerging Technologies*. 19, 6 (Dec. 2011), 1171–1184.
- [59] Piaget, J. 1952. *The Origins of Intelligence in Children*. International University Press.
- [60] Plant, K.L. and Stanton, N.A. 2012. The explanatory power of Schema Theory: theoretical foundations and future applications in Ergonomics. *Ergonomics*. December (Nov. 2012), 37–41.
- [61] Pradhan, A.K., Divekar, G., Masserang, K., Romoser, M., Zafian, T., Blomberg, R.D., Thomas, F.D., Reagan, I., Knodler, M., Pollatsek, A. and Fisher, D.L. 2011. The effects of focused attention training on the duration of novice drivers' glances inside the vehicle. *Ergonomics*. 54, 10 (Oct. 2011), 917–31.
- [62] Reyes, M.L. and Lee, J.D. 2008. Effects of cognitive load presence and duration on driver eye movements and event detection performance. *Transportation Research Part F: Traffic Psychology and Behaviour*. 11, 6 (Nov. 2008), 391–402.
- [63] Seppelt, B.D. and Lee, J.D. 2007. Making adaptive cruise control (ACC) limits visible. *International Journal of Human-Computer Studies*. 65, 3 (Mar. 2007), 192–205.
- [64] Stanton, N.A. and Baber, C. 1998. Designing for consumers: editorial. *Applied Ergonomics*. 29, 1 (Feb. 1998), 1–3.
- [65] Stanton, N.A., Dunoyer, A. and Leatherland, A. 2011. Detection of new in-path targets by drivers using Stop & Go Adaptive Cruise Control. *Applied ergonomics*. 42, 4 (May. 2011), 592–601.
- [66] Stanton, N.A., McIlroy, R.C., Harvey, C., Blainey, S., Hickford, A., Preston, J.M. and Ryan, B. 2012. Following the cognitive work analysis train of thought: exploring the constraints of modal shift to rail transport. *Ergonomics*. September (Aug. 2012), 37–41.
- [67] Stanton, N.A. and Stammers, R.B. 2008. Bartlett and the future of ergonomics. *Ergonomics*. 51, 1 (Jan. 2008), 1–13.
- [68] Stern, N. 2006. *Stern Review: The Economics of Climate Change. Summary of Conclusions*.
- [69] Vicente, K.J. 1999. *Cognitive Work Analysis: Towards Safe, Productive and Healthy Computer-Based Work*. Lawrence Erlbaum Associates.
- [70] Vicente, K.J. and Rasmussen, J. 1992. Ecological interface design: Theoretical foundations. *IEEE Transactions on Systems, Man, and Cybernetics*. 22, (1992), 589–600.
- [71] Van der Voort, M., Dougherty, M.S. and van Maarseveen, M. 2001. A prototype fuel-efficiency support tool. *Transportation Research Part C: Emerging Technologies*. 9, (2001), 279–296.
- [72] Wada, T., Yoshimura, K., Doi, S., Youhata, H. and Tomiyama, K. 2011. Proposal of an eco-driving assist system adaptive to driver's skill. *14th International IEEE Conference on Intelligent Transportation Systems* (Washington, DC, 2011), 1880–1885.
- [73] Walker, G.H., Stanton, N.A. and Young, M.S. 2001. Where is computing driving cars? *International Journal of Human-Computer Interaction*. 13, (2001), 203–229.
- [74] Walters, M.H.L. and Laker, I.B. 1980. *Research on fuel conservation for cars. Report No. 921*.
- [75] Wickens, C.D. and Carswell, C.M. 1997. Information processing. *Handbook of Human Factors and Ergonomics*. G. Salvendy, ed. John Wiley. 89–129.
- [76] Young, M.S. and Birrell, S.A. 2012. Ecological IVIS design: Using EID to develop a novel in-vehicle information system. *Theoretical Issues in Ergonomics Science*. 13 (2012), 225–239.
- [77] Young, M.S., Birrell, S.A. and Stanton, N.A. 2011. Safe driving in a green world: a review of driver performance benchmarks and technologies to support “smart” driving. *Applied ergonomics*. 42, 4 (May. 2011), 533–9.