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Drivers' ability to learn eco-driving skills; effects on fuel efficient and safe driving behaviour

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ABSTRACT

Whilst driving is inherently a safety–critical task, awareness of fuel-efficient driving techniques has gained popularity in both the public and commercial domains. Green driving, whether motivated by financial or environmental savings, has the potential to reduce the production of greenhouse gases by a significant amount. This paper focusses on the interaction between the driver and their vehicle – what type of eco-driving information is easy to use and learn whilst not compromising safety. A simulator study evaluated both visual and haptic eco-driving feedback systems in the context of hill driving. The ability of drivers to accurately follow the advice, as well as their propensity to prioritise it over safe driving was investigated. We found that any type of eco-driving advice improved performance and whilst continuous real-time visual feedback proved to be the most effective, this modality obviously reduces attention to the forward view and increases subjective workload. On the other hand, the haptic force system had little effect on reported workload, but was less effective that the visual system. A compromise may be a hybrid system that adapts to drivers' performance on an on-going basis.

1. Introduction

Whilst the process for gaining one's driving licence varies widely worldwide, the underlying premise of both professionally run training courses and the subsequent driving test, is that of safety. Safe driving has been studied extensively and league tables are produced regularly to monitor the global impacts of road deaths. As an example, the WHO Global status report on road safety (2013) serves as a baseline for the Decade of Action for Road Safety 2011–2020, declared by the UN General Assembly. Being such a high profile concern (road accidents are one of the top ten causes of death worldwide), and with motoring consumers having access to independent assessments of the safety performance of vehicles via EuroNCAP, it is not surprising that vehicle manufacturers have focussed their research and development efforts on safety systems. These safety systems range from those that provide advice (e.g. curve speed warning) to those that intervene in safety–critical situations (e.g. emergency brake assist).

Fuel efficiency ratings are also readily available and published by vehicle manufacturers. Nearly all new car models which are type approved for sale in the European Union have to undergo standard tests to determine their fuel consumption. However, the fuel consumption figures quoted are obtained under specific test conditions, and therefore may not necessarily be achieved in 'real life' driving conditions. A range of factors may influence actual fuel consumption – for example, external

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temperature, vehicle load and use of auxiliary systems such as air conditioning. In addition, individual driving style can also play an important role in fuel efficiency.

In some countries, driving instructors are encouraged to teach eco-driving skills and some elements are evaluated in both the theory and practical driving test. This is a sensible approach given that studies have estimated that, independent of the vehicle and the technology on board, the driver can have a significant impact on fuel efficiency. van der Voort (2001), for example, cites potential fuel-savings in passenger cars in the region of 10–15%, when fuel-efficient driving styles are practised. These savings can be achieved without impacting on travel times (Barth and Boriboonsomsin, 2009; Beusen et al., 2009). For the commercial sector, savings can be even higher and thus dedicated training courses for truck drivers have been developed and evaluated. Some studies have demonstrated positive long-term effects (Symmons et al., 2008), whilst others have reported that drivers eventually return to their old driving patterns (Beusen et al., 2009).

The automotive market has responded to consumers' interest in greener driving by producing vehicles which have in-built eco-driving systems, providing advice to drivers and feedback on their fuel efficiency. In addition, stand-alone or "nomadic devices" are also available on the market, as are various smartphone applications. Examples include DriveGain (http://drivegain.com) which is an application using GPS data to monitor driver behaviour and provide advice on optimal driving and greenMeter (http://hunter.pairsite.com/greenmeter) which provides in-trip advice for eco-driving. The advantage that eco-driving systems have over the training courses described above is that they are ever-present; support is always at the driver's fingertips if they require it. These eco-driving support systems vary in many ways, including how they source their input data and how the information is relayed to the driver. This paper focusses on the latter point – how best to present eco-driving advice to the driver such that it is easy to follow and has minimal impact on other aspects of driving.

Numerous studies have reported positive effects of a range of eco-driving systems on drivers' fuel efficiency. For example, Rakausas et al. (2010) evaluated a number of visual eco-driving support displays. The displays conveyed a range of information such as average fuel efficiency and instantaneous acceleration and all were successful in reducing fuel consumption in the short term (as was simply asking the driver to drive more fuel efficiently). Instantaneous (continuous) acceleration information was found to be the most effective, although the impact of such continuous visual information on drivers' glance patterns and hence distraction was not evaluated. Whilst visual displays have their advantages (e.g. the information can be "ignored" if necessary, Mollenhauer et al., 1994), the concern that increasing amounts of visual information may compromise driver safety has led to developments in other modalities for both safety and eco-driving applications. Haptic feedback (via the accelerator or brake) for collision avoidance (Lee et al., 2007), headway (Mulder et al., 2008), speed (Adell et al., 2008), and lane departure (Deroo et al., 2012) have received attention. More recently, Birrell et al. (2013) evaluated the effects of a haptic accelerator pedal on driving performance and perceived workload and found positive changes to driver behaviour compared to a baseline condition. Subjective workload also decreased when driving with the haptic pedal leading to the conclusion that this modality was useful in this context as it does not encroach on other attentional resource pools that are used in driving (i.e. mainly visual). The study reported here extends the previous work on haptic feedback by including a direct comparison with visual feedback (as well as a baseline condition). Importantly, the efficacy of the systems is evaluated in the context of both fuel efficiency and safety.

In addition to a direct comparison between modality types, this study examines the concept of skill acquisition – do different modalities increase the pace of learning eco-driving skills? Skill acquisition, such as learning a new language, playing a musical instrument or learning to drive a car, requires the performer to move between several stages. In the first stage, coined the *cognitive stage* by Fitts and Posner (1967), users are exposed to and commit to memory the facts relevant to the skill. This declarative (knowledge) stage is then followed by the *associative stage* whereby the knowledge is transformed into a procedural form, such that the user "knows how" to perform a task. Finally, following repetitions of the task, an *autonomous stage* is reached whereby the procedure can be undertaken without conscious thought.

Experimental psychologists, as far back as the late nineteenth century (e.g. James, 1890) recognise the role played by automaticity in skilled performance and it features in theories of manual control (Shiffrin and Schneider, 1977). Automaticity allows performers to execute a task efficiently, unintentionally and unconsciously. The automatic behaviours are stimulus-driven, requiring limited or no controlled response (Trick et al., 2004). Moving from a controlled response, which requires access to declarative knowledge, to automaticity reduces effort and attentional demand (Logan, 1988). Some components of driving are a good example of this process; gear changing is considered to be an automated task (Baddeley, 2006; Michon, 1985). For a novice driver, gear changing is slower than for expert drivers (Duncan et al., 1991) and becomes automated after sufficient practice. Even after such practice, however, Shinar et al., 1998 report that there is still a cognitive cost in the process of changing gear manually. Using verbal report methodology, Renge (1980) found that novice drivers were more likely to comment on operational issues such as changing gear, steering or applying the brakes. On the other hand, experienced drivers referred to features deemed vital for safe driving, such as lead cars and pedestrians.

The rate of learning of eco-driving skills during experience with an eco-driving system is an important factor to consider when designing such a system. This will allow the delivery of information to be tailored to optimise learning, and also will allow identification of the point in time at which it is appropriate to reduce or remove the guidance to prevent the presentation of redundant in-vehicle information. A key premise behind this study is that drivers who are able to learn eco-driving skills readily do not need constant eco-driving support. In fact, if advice is provided too frequently, this may become annoying for drivers, therefore influencing overall acceptance, and ultimately engagement with the system.