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# The design of an in-vehicle assistance system to support eco-driving

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ABSTRACT

This driving simulator study was the second of two studies investigating the most effective and acceptable in-vehicle system for the provision of guidance on fuel efficient accelerator usage. Three eco-driving interfaces were selected for test (a second-order display visual display with auditory alerts and two haptic accelerator pedal systems) following a pilot study of 12 different interfaces. These systems were tested in a range of eco-driving scenarios involving acceleration, deceleration and speed maintenance, and assessed through their effects on fuel economy, vehicle control, distraction, and driver subjective feedback. The results suggest that a haptic accelerator pedal system is most effective for preventing over-acceleration, whilst minimal differences were observed between systems in terms of the effect of the assistance provided to prevent under-acceleration. The visual–auditory interface lowered the time spent looking towards the road, indicating a potential negative impact on driver safety from using this modality to provide continuous green driving support. Subjective results were consistent with the objective findings, with haptic pedal systems creating lower perceived workload than a visual–auditory interface. Driver acceptability ratings suggested a slight favouring of a haptic-force system for its usefulness, whereas the more subtle haptic-stiffness system was judged more acceptable to use. These findings offer suggestions for the design of a user-friendly, eco-driving device that can help drivers improve their fuel economy, specifically through the provision of real-time guidance on the manipulation of the accelerator pedal position.



## 1. Introduction

Changes in driver behaviour have the potential to achieving fuel savings of up to 20%, with the delivery of useful and acceptable feedback on driver performance (Gonder et al., 2011). Therefore, substantial reductions of the environmental and financial costs of road transport could be attained through the development of an efficient in-vehicle eco-driving assistance system. This paper reports on a driving simulator study that investigates and compares the designs of three in-vehicle eco-driving assistance systems, which provide real-time guidance to the driver on how to alter accelerator pedal usage to improve their fuel efficiency. This work builds on a previous study which identified that both haptic accelerator pedal and multimodal visual–auditory interfaces are able to bring immediate improvements in fuel economy (see Jamson et al., in press).

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The long-term effects of eco-driving training have been shown to be relatively weak (af Wåhlberg, 2007), hence the necessity of ongoing driver support for eco-driving. Therefore, it is important to ensure that the design of an in-vehicle system for continuous, sustained use is appropriate, both in terms of its ability to achieve the improved driver performance, but also to do so without causing negative outcomes for driver safety or annoyance (Adell et al., 2008).

### 1.1. System modality

The selection of the most appropriate – most effective and least distracting – modality for the system interface is an important consideration when designing an eco-driving assistance system for prolonged use. Currently, the majority of the systems on the market rely on the provision of visual information to the driver (Graving et al., 2010). Whilst this is an effective method for the delivery of detailed feedback on eco-driving performance after a drive has been completed, it has the potential to overload the driver and distract them from the primary driving task. The negative impacts of competing visual tasks on driving performance have been consistently seen, with impairments observed in driver reaction times (Summala et al., 1998; Muhrer and Vollrath, 2011), event detection (Olsson and Burns, 2000), and lateral control (Östlund et al., 2004).

Prior work has demonstrated a reduction in the distracting impacts of a visual eco-driving interface when combined with a complementary audio signal (Jamson et al., in press). However, there is substantial evidence in the literature of detrimental effects of an auditory task on driving performance measures such as brake reaction time (Alm and Nilsson, 1995; Consiglio et al., 2003; Beede and Kass, 2006), longitudinal control (Rakauskas et al., 2004; Ranney et al., 2005), event detection (Beede and Kass, 2006), and steering performance (Reed and Green, 1999). This suggests a need to consider an alternative presentation modality, such as a haptic accelerator pedal.

Haptic accelerator pedals have been used in a number of in-vehicle applications such as forward collision warning systems (de Rosario et al., 2010) and speed management systems (Adell et al., 2008), to produce positive effects on driving performance. More recently, this technology has been applied in the provision of eco-driving support with encouraging results to suggest that these systems can help the driver maximise their fuel economy (Larsson and Ericsson, 2009; Birrell et al., 2013; Jamson et al., in press). These studies have focused on the investigation of a single haptic pedal test case or have used a simple short duration driving task to measure the effects of a number of systems on driving performance. This work seeks to extend both of these approaches through the consideration of two variants of a haptic accelerator pedal system providing continuous eco-driving guidance in a longer drive.

### 1.2. User-centred design

User-centred design refers to the need to consider the end-user during the design of any in-vehicle system or task (Sarter and Woods, 1995; Waller, 1997; Peters and Peters, 2002). This approach is particularly important in the design of a system that provides continuous support to the driver throughout the driving task. To this end, whilst investigating the impacts of three eco-driving assistance systems on driving performance, this study also considers the effects of perceived driver workload (Hart and Staveland, 1988; Hart, 2006) and acceptance of the systems (Van Der Laan et al., 1997). This multifaceted approach will facilitate the development of an in-vehicle interface that not only functions to achieve the desired improvements in fuel economy, but provides an interaction experience that the driver understands, does not find too difficult to manage in a challenging driving environment, and if possible, enjoys. The balance of these factors is crucial to the development and implementation of a successful in-vehicle system (Roetting et al., 2003; Tango and Montanari, 2006). Furthermore, the consideration of driver impressions is critical to gain an understanding of their experience of a relatively novel in-vehicle stimulus, provided in the haptic modality (Burnett and Porter, 2001; Porter et al., 2005).

### 1.3. Objectives

This study represents the second stage in the design of an in-vehicle eco-driving assistance system for the provision of real-time guidance on the fuel efficiency of accelerator pedal usage. The preliminary study of Jamson et al. (in press) has identified three such systems for further investigation, based on both objective accelerator pedal control data and subjective feedback from the driver. These systems include a haptic force feedback system, a haptic stiffness feedback system, and a visual dashboard display with complementary audio alerts. Each of these systems provides moment-by-moment guidance on the fuel efficiency of current performance and the action required to improve fuel economy where possible. The objective of this study is to provide a more extensive testing scenario for these systems, both in terms of the number and type of driving scenarios encountered and the duration of system use. Previously, drivers had interacted with these systems for 30 s in a short speed change task without the provision of speedometer information. This study addresses these limitations in a longer duration driving task, including urban and rural areas, straight and curved sections of road, and a number of different types of task involving a speed change and therefore a focussed period in which accelerator pedal guidance would be required to optimise fuel economy. The outcome of this study will be an in-depth comparison of the impact of these systems on accelerator pedal usage (indexed by the error between system-required pedal angle and driver-selected pedal angle), on vehicle control and driver safety measures, and on driver perceptions following a longer drive. The goal is to identify the eco-driving interface characteristics that are most promising for implementation in a green driving support system.

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