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How I reduce fuel consumption: An experimental study on mental models of eco-driving

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ABSTRACT

Eco-driving has the potential to reduce fuel consumption and therefore emissions considerably. Previous research suggests that drivers have a certain level of eco-driving knowledge and skills, which they refrain from practising in their everyday lives. At the same time misconceptions and ambiguous messages from eco-driving support systems can confuse and demotivate. This research aimed to identify the mental models of eco-driving that regular drivers have. A driving simulator experiment with a varied road layout comprising urban and motorway sections was designed. The study used simple driving task instructions to investigate changes in the participants' behaviour and thoughts in three conditions. Sixteen drivers were asked to 'Drive normally', 'Drive safely' or 'Drive fuel-efficiently'. Behavioural measures, think aloud protocols and interviews were compared and analysed. The emphasis of this study was on eco-driving relevant indicators such as accelerating, braking, coasting and car-following. The results show that the participants do have mental models of eco-driving, which they did not use in the Baseline drive, when they were instructed to 'Drive normally'. Misconceptions about speed and travel time provide the potential for more effective communication with the driver about the momentary efficient speed as well as resulting time losses and fuel savings. In addition, in-vehicle guidance can increase driving safety compared to practicing eco-driving without them.

1. Introduction

1.1. Background

In 2012 road transport accounted for 19% of the total carbon dioxide emissions in the EU (European Environment Agency, 2014). Eco-driving can facilitate a decrease in fuel consumption and therefore carbon dioxide emissions of conventional internal combustion engines by 5–10% (Barkenbus, 2010). Eco-driving is a set of behaviours that drivers can practise to save fuel and reduce emissions (Mensing et al., 2014). Hof et al. (2012) summarised a number of effective practises. In their wider scope, they include regular vehicle maintenance, tyre pressure checks and an optimal route choice. When the vehicle and route are given, eco-driving is about maintaining a constant speed, avoiding unnecessary braking and accelerating where possible by anticipating traffic situations, using higher gears and optimal acceleration.

In order to achieve a considerable reduction in emissions, the behaviour of a large proportion of drivers needs to be changed. These large-scale behavioural changes cannot be achieved by educational material alone (Delicado, 2012; Martin et al.,

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2012). In addition, recent research suggests that monetary savings may not be a sufficient motivator for people to take on the effort of practising a new driving style (Stillwater and Kurani, 2013; Tulusan et al., 2012). A study by Harvey et al. (2013) conducted with focus groups and questionnaires, revealed that the perceived costs of eco-driving can outweigh the comparably small monetary benefits. One of these perceived costs is the potential for increased travel time.

Despite these educational and motivational hindrances, behavioural change can be attained by in-vehicle technology providing continuous real-time feedback on parameters such as pedal pressure, gear or miles per gallon (e.g. Kim and Kim, 2012; Nouvelière et al., 2012; van der Voort et al., 2001). A growing body of research focusses on the psychological processes behind eco-driving to further improve the human–machine interaction (Stillwater and Kurani, 2013). Because there is a need to shed light on drivers' understanding of eco-driving and to identify their information requirements, mental model research is the chosen approach in this study.

1.2. Mental models

Mental models are defined as representations of reality stored in people's minds (Johnson-Laird, 1988). As they are retrieved and brought into use, these schemas or scripts guide perceptions and actions (Schank and Abelson, 1977). Mental models are organised on different levels of cognitive control and therefore include strategic and easily accessible knowledge, goal-oriented subroutines (rules) and highly automated action sequences referred to as skills (Anderson, 1982; Rasmussen, 1983). Researchers (e.g. Morgan et al., 2002; Vogt and Schaefer, 2012) have explored and measured mental models in order to assess people's knowledge about risks. Moreover, studying mental models is useful for exploring cognitive processes that people are unable to access with introspection (Rasmussen, 1983).

Mental models have been researched using questioning techniques and interviews (e.g. Bellet et al., 2007; Morgan et al., 2002), but also by observing behaviour in experiments (e.g. Goodrich and Boer, 2003; Henning et al., 2008). Adding think aloud protocols to an experiment allows the capture of momentary thoughts whilst actions are carried out. For these protocols the participants are instructed to speak out loud whatever is going through their minds. They are neither asked to explain nor focus on anything (Ericsson and Simon, 1980; van Someren et al., 1994).

1.3. Eco-driving support systems

Numerous studies have evidenced that in-vehicle eco-driving support systems (EDSS) can be effective in reducing fuel consumption. A proven strategy is the correction and maturation of the drivers' mental models. For example, Nozaki et al. (2012) found that EDSS that communicate with the driver instead of manipulating the vehicle encourage the driver to participate, expend more effort and ultimately improve their skills. Adapting to the driver's eco-driving proficiency (Wada et al., 2011) or making it obvious where the driver is standing in relation to their goal (Stillwater and Kurani, 2013) can further improve fuel savings, acceptance of the technology and interest in eco-driving.

Still, EDSS have their limitations. In most studies considerable fuel savings are achieved, whilst it remains unclear which behavioural changes are due to the system's communication and which are due to the driver's eco-driving proficiency triggered by the system or experimental situation (Birrell et al., 2014; Tarkiainen et al., 2014). A control condition in which participants are asked to eco-drive without any feedback has been effective in accounting for these unwanted effects (van der Voort et al., 2001). Furthermore, it is not always clear to drivers which actions are most effective in improving their eco-driving scores (Man et al., 2010). For example, a miles per gallon measure alone can be misleading, because it does not take kinetic energy into account and therefore encourages suboptimal acceleration and deceleration (Stillwater, 2011).

1.4. The current study

In this research eco-driving mental models were investigated in a driving simulator experiment supplemented with think-aloud protocols and open interviews. This research aimed to identify the mental models regular drivers have of eco-driving by measuring changes in their behaviour and thoughts after being asked to drive in an eco-friendly manner. The measures were contrasted to their usual (Baseline) driving, but also safe driving behaviour. The Safe condition was added to enable distinguishing eco-driving mental models from driving with special instructions and therefore possibly increased attentional resources. Specifically, longitudinal driving behaviour was examined. It includes accelerating, car-following, cruising (free flow driving) as well as decelerating using braking and coasting. Coasting was described by Beusen et al. (2009) as smooth deceleration by releasing the accelerator pedal whilst not pressing the brake pedal.

2. Methodology

2.1. Design

A two-way (4 × 2) mixed design was employed, with Instruction as a within-subjects factor with 4 levels. Each level corresponded to an experimental drive with different instructions ('Baseline 1', 'Safe', 'Eco', and 'Baseline 2'), Table 1. The Baseline conditions were always conducted as the first and the last drive of the experiment. For these drives the participants were

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