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Impacts of delayed feedback on eco-driving behavior and resulting environmental performance changes

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ABSTRACT

Several ways have been developed and applied to improve the environmental footprint of road transportation while contributing to a better road efficiency and safety. However, independently of these measures, the individual's behavior as a commuter and/or as a driver is also a major issue that cannot be ignored. As a result, the aim of this paper was to assess the impacts of delayed feedback on driving performance considering indicators such as average speed, excess speeding, extreme braking and acceleration; fuel consumption and CO_2 emissions, among others. Data on driving behavior was collected over a period of 6 months through the use of an on-board device installed in 40 light-duty vehicles in the region of Lisbon, Portugal. Two driving monitoring periods of 3 months each were considered: without feedback (Phase 1) and with feedback (Phase 2). Additionally, the short-term (weekly and bi-weekly) impact of feedback on performance was also assessed.

The major findings indicate that both experimental and control groups increased fuel consumption and CO_2 emissions over 5%. Both male and female drivers presented increases in these indicators with female drivers presenting higher values (up to 8%, as opposed to the 4% presented by male drivers). These results are related with increases in the number of accelerations, idling and number of small trips (below 2 km) between monitoring periods. Regarding the immediate impact of feedback on driving behavior, results indicate that when receiving negative feedback (revealing a performance decline), behavior would improve the following week. The opposite was found for positive feedback, with drivers worsening performance after being informed they had improved the previous week. Such findings might give an indication that people react differently to the feedback provided, and might depreciate the information provided when negative results are reached.

1. Introduction

Over the last decades, the issue of the negative environmental impacts associated with the transportation sector has been focus of much attention. Since the early 1900s, the dependency on vehicles powered by fossil fuels has become one of the defining components of people's lives. As a consequence of official strategies and protocols such as the Europe 2020 Strategy and Kyoto Protocol (EUROSTAT, 2012) to address this issue, efforts are already being applied to minimize the impacts of the transportation sector. Among the solutions to overcome this trend, alternative vehicle technologies, innovative transport systems and Information and Communication Technologies (ICT) applied to the transportation sector are emerging. They

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may have the potential to trigger substantial changes over time in how the transportation systems operate. However, an important aspect to take into consideration for the successful widespread implementation and adoption of such solutions is how the general public will react and adapt their habits and behavior around these solutions.

In what concerns driving behavior, ICT solutions collecting driving information have recently faced a considerable market expansion, contributing to the education of the users towards a more efficient driving performance (Rolim, Baptista, Duarte, & Farias, 2014; Toledo, Shiftan, & Hakkert, 2016). These methods, associated with training and educational programs, enable drivers' acknowledgment of driving patterns and performance, providing information and motivating the driver to change (Goldenbeld, Leveit, & Heidstra, 2000). Eco-driving has emerged as a training program providing drivers with educational tools to become more environmentally friendly and, therefore, to drive more efficiently and in a safer way. It advocates the adoption of certain driving practices such as anticipation of traffic flow, the ability to shift gears up as soon as possible and to keep a steady speed, decelerate smoothly and to manage extra energy use with care (such as air conditioning), among others (E. Project, 2013).

As a result, the objective of this paper was to evaluate the impacts of delayed feedback on eco-driving performance considering several driving indicators. For this a detailed statistical analysis was performed to assess the effect of exposure to delayed feedback on driving performance. Driving behavior was monitored over a period of 6 months through an on-board device installed in 40 light-duty vehicles in the region of Lisbon, Portugal.

This paper is organized in the following sections: the state of the art focuses on presenting relevant literature on the driving behavior assessment and the role of feedback on performance; in the methodology section the experimental and data analysis procedures are described; the main findings are presented in the results section; a conclusions section focuses on presenting the main contributions of the study.

2. Impacts of feedback on driving performance

Changing behavior is not an easy task, since people usually reveal some resistance to change. Habits have an important role in one's life, since they provide order, stability and security (Goldenbeld et al., 2000). Some changes, such as adoption of recycling behaviors, are easier to introduce and accept than others (Prillwitz & Barr, 2011). However, changes in peoples' mobility patterns have been identified as less acceptable and easily rejected, even though they know that they could contribute in the mitigation of adverse climate changes or reduce local pollution. These discrepancies are due to the different roles and influences of psychological factors, such as attitudes and habits, on behavioral changes (Prillwitz & Barr, 2011).

Driving activity is composed by two variables: (i) performance (skills of the driver) and (ii) behavior (drivers driving style). The former can improve with practice and training since it is related to information processing and motor skills. The latter is linked with the choices and habits of the drivers', e.g. speeding or aggressiveness. Driving style refers to the way drivers make choices, and is shaped by drivers' characteristics. These include intrinsic factors such as gender and age (which might also have an effect on each drivers' motor skills) and extrinsic variables like social context. (Özkan, Lajunen, Chliaoutakis, Parker, & Summala, 2006). Driving behavior will echo not only the drivers psychological profile but also the context in which driving occurs, and it can adopt several characteristics including rises in alertness and aggressiveness (Murcotts Driving Excellence, 2015).

A recent research developed to evaluate the long-term impacts of an eco-driving training course using an on-board logging device revealed significant differences in driving behavior after the training period, with an average 6% decrease in fuel consumption and a 0.26% and 0.22% decrease in the percentage of time spent in heavy acceleration and deceleration, respectively (Beusen et al., 2009). However, strong variations between drivers were observed. Also, after the course some parameters continue to improve while others like, heavy accelerations and idling tend to deteriorate, indicating that some drivers apply what they learned to continue improving, others need more repetitive training (Beusen et al., 2009). Findings of another research, using an Intelligent Speed Adaptation providing recommendations to the driver, revealed improvements not only in the number of acceleration/deceleration events but also a 10–20% reduction in fuel consumption and CO_2 emission, without affecting considerably overall travel time (Barth & Boriboonsomsin, 2009). In another study, the use of a smartphone application providing eco-driving feedback on acceleration, braking, and vehicle speed revealed statistical significant improvements on drivers performance and a 3.23% decrease in fuel consumption and 618 kg of avoided CO_2 emissions (Tulusan, Steggers, Staake, & Fleisch, 2012).

Results from an on-line survey (Delhomme, Cristea, & Paran, 2012) reveal that drivers consider behaviors of traffic conditions anticipation (e.g. lightening the pressure on the acceleration pedal when approaching a stop) as less difficult to adopt than keeping a steady speed or shifting up gears and that middle-aged women and strongly environmentally oriented drivers perceive eco-driving behavior as easy to adopt.

When comparing different learning methods, a positive impact of eco-driving on driving behavior was observed independently of the type of education technique. (Pampel, Jamson, Hibberd, & Barnard, 2015). Real-time feedback can be one of the most effective feedback options nonetheless it reduces drivers' attention and increases workload (Jamson, Hibberd, & Jamson, 2015). Additionally, real-time feedback and delayed feedback have proven to present the same impact on decreasing unwanted behaviors (harsh cornering, acceleration, braking and speeding) (Dijksterhuis et al., 2015).

The type of feedback provided to drivers also impacts performance differently. Non evaluative feedback (does not explain how people can improve performance only providing final results, such as scores or grades) led to overestimations of