International Journal of Industrial Ergonomics 64 (2018) 134–142

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

Eco-driving for the first time: The implications of advanced assisting technologies in supporting pro-environmental changes

Daniele Ruscio [a, c, *], Giandomenico Caruso [a], Lorenzo Mussone [b], Monica Bordegoni [a]

[a] Department of Mechanical Engineering, Politecnico di Milano, Milan, Italy
[b] Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Milan, Italy
[c] Psychology Department, Università Cattolica del Sacro Cuore, Milan, Italy

A R T I C L E I N F O

Article history:
Received 20 February 2017
Received in revised form
31 October 2017
Accepted 16 January 2018

Keywords:
Assistance technologies
CO2 emissions
Pro-environmental behavior
Human-machine interaction
Acceptance
Workload

A B S T R A C T

Eco-driving assistance devices are being introduced to reduce CO_2 emissions, but the overall changes in the user behavior have not been sufficiently explored. While in-vehicle driver advanced systems are designed to support a single driving task (e.g. reducing emissions), they also imply the adoption of a different driving behavior and different driving attitudes in order to be efficient. Adopting for the first time a new driving style could affect driver's acceptance and undermine new technologies' efficacy. Purpose of the present research is to measure and evaluate the user's responses to first-time use of eco-driving assisting technology. Driver's performances in a virtual simulator were compared between experimental and a control group. The actual driving parameters and CO_2 emissions were recorded and compared to the optimal eco-driving style calculated by CarMaker software. The cognitive costs of the new driving style were measured by changes in the modulation of autonomic nervous system and NASA-TLX workload scale. Acceptance of the assisted driving style and general eco-friendly attitudes were analyzed by self-reported measures. Results show that being exposed for the first time to eco-driving technology produces a reduction of cumulate fuel consumption only due to speed reduction, and not to changes in the driving style parameters, as recommended by the assisting software. Overall CO_2 emissions of eco-driving group were not different from the control group. Rather, the first time use of the eco-driving assistance increases perceived fatigue and the physiological cardiac autonomic balance related to increased workload over time. These difficulties show that eco-driving style cannot be simply adopted by following the assistance device indications. It seems rather a process, which requires specific support during in the first driving-interaction with eco-driving technology. The design of assistance device that aims to change the driving style, could benefit from the measurement of the user's workload to avoid primacy effect that potentially undermine technology efficacy in supporting user-sustainable behaviors.

1. Introduction

Fuel consumption and CO_2 emissions are relevant topics in environmental research and mobility policies (Hunecke et al., 2010). Eco-driving style is commonly estimated to induce a reduction of fuel consumption between 10 and 30% (Sivak and Schoettle, 2012). To support the driver in learning and maintaining eco-driving style, eco-driving assistance systems (EDAS/EDSS) are being introduced in new vehicles, to provide support-intervention and feedbacks (Hof et al., 2014).

The effectiveness of built-in or nomadic eco-driving devices are based on the assumption that the introduction of assisting technology will promote change in the driving style of the driver: smooth accelerations, steady speed, early gear change, efficient deceleration, and moderate brake behaviors. The implicit consideration is that the driver will be willing to follow the sufficiently good feedbacks (e.g. that will not distract nor affect drivers too much) of the device, in a proper way. However, the effective introduction of new assisting systems implies that the driver not only changes his driving style, but also accepts the new driving style and perceive the costs of the transition inferior to the perceived benefits (Af Wåhlberg, 2006). Since the driver needs to

* Corresponding author. via La Masa, 1, Dipartimento di Meccanica - Politecnico di Milano, Italy.
E-mail address: daniele.ruscio@unicatt.it (D. Ruscio).

https://doi.org/10.1016/j.ergon.2018.01.009
0169-8141/

accommodate or change an already existing consolidated driving automation, the new eco-driving solutions should also consider the effects on the user of the modification of the driving style.

1.1. Considering the effects of introducing advanced assisting devices

The impact of introducing new device has been extensively studied in terms of effectiveness in reducing overall emission (Barkenbus, 2010), as well as for the effect on driver's dual-task workload (Kircher et al., 2014), safety (Young et al., 2011) and acceptability (Vlassenroot et al., 2010).

The way drivers actually adapt to the first use of eco-driving devices and the related effects on workload and acceptance, are currently not certain. The question may be relevant especially considering that advanced driver assisting systems are rarely tried by drivers before use (Biassoni et al., 2016) and the potential side effects of assisting technologies are not always considered in the design manufacturing process (McLoone et al., 2010). Several research works have shown that inadequate design and user experience, could affect user's satisfaction (Gaspar et al., 2014), perceived value of technology (Boztepe, 2007) and impact on risk management processes (Hood and Jones, 2003). In addition, the first impressions of the usability of a new device (Saade and Otrakji, 2007) can be crucial to determine the willingness to buy the device (Park and Han, 2013) and the intention to use again the device in the future (Steg et al., 2016). If eco-driving assisting technologies can already provide good feedbacks for the driver, the question why correct eco-driving style is yet not easily being adopted by drivers on a wider scale and with long-term effects (Wåhlberg, 2007; Whitmarsh and O'Neill, 2010) remains still open (Rakotonirainy et al., 2011), especially if considering that pro-environmental attitudes are increasing among the population (Ohtomo and Hirose, 2007). These open questions are suggesting that adopting an eco-driving style may be a complex process that involves several cognitive processes, which are maybe worth being better investigated in order to avoid the development of “not completely compelling” devices (Ahlstrom and Kircher, 2017).

1.2. Modelling the adoption of eco-driving behaviors

In a recent research Ahlstrom and Kircher (2017) reported that the visual behavior of ten drivers that interacted with eco-driving assisting device produced high amount of glances toward the system, looking for feedback on the driving style. At the same time, a considerable amount of relevant assisting feedback pop-ups (form 20%–40%) were actually ignored by the drivers during the assisted driving. The researchers conclude that improvements to the already designed system should be made in order to avoid the disregard of important EDAS feedbacks. However, the research did not investigate the reasons behind this significant disregard of the assisting device feedbacks, nor the subjective feelings related the willingness to use the ecoDrive system, nor the actual changes in the drivers' behavior during the interaction. To better understand the nature of the interaction with assisted driving, a model of the user behavior can be proposed (Fig. 1) to combine the Theory of Planned Behavior for advanced driver assistance systems (Biassoni et al., 2016) and a cognitive taxonomy to explain the change (Bloom et al., 1956) to the eco-driving. According to the Theory of Reasoned Action (Fishbein and Ajzen, 1975) and the Theory of Planned Behavior (Ajzen, 1991), the best predictor of a person's behavior is the users' intention to use a technological device, which is based on two main features: 1) perceived usefulness of the device (defined as the extent to which a person believes that using the system will enhance his/her performance) and; 2) perceived ease of use (defined as the extent to which a person believes that using the system will be free of effort). In Fig. 1, the *INPUT* of the process are the driving parameters required to be modified when EDAS feedback promote the adoption of an eco-driving style (e.g. adaptation of cruise speed and gears change frequency).

The *OUTPUT* of the transition represents the result of the modification of the driving style, in terms of application of the knowledge learned in the virtual training (Parmar et al., 2016), which, in this case, can be measured as CO_2 emissions while following the assisting device. The initial *BENEFITS/COSTS ANALYSIS* associated to the use of the device is crucial to determine the user's acceptance and is dependent on the direct/indirect workload effects activated in this process (Backs et al., 2005). User's initial *acceptance* can be measured as a judgment based on attitudes and behavioral experiences toward a system, which emerged after the actual use of the device (Beggiato and Krems, 2013). According to Malleable attentional resources theory (Young et al., 2011), workload can accommodate according to the performance demand (Gaspar et al., 2014) and this accommodation can be measured elaborating the autonomic nervous system modulations (Hoover et al., 2012).

To achieve a global comprehension of the assisted modification

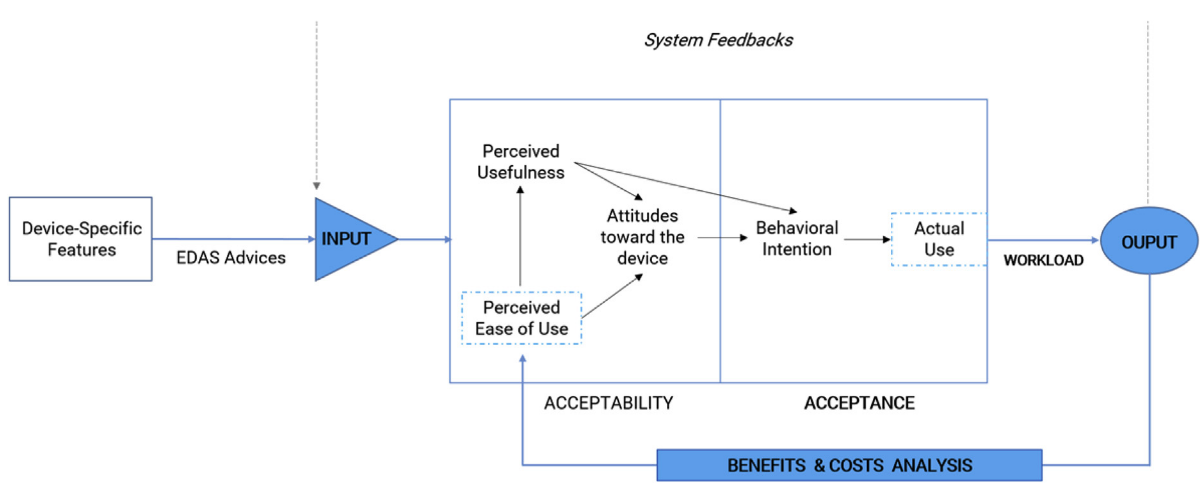

Fig. 1. The model of user-behavior interaction with assisting technology, derived from the Technology Acceptance Model (Davis et al., 1989), used to explain the impact of using eco-driving assistance systems.