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The impact of numerical vs. symbolic eco-driving feedback on fuel consumption – A randomized control field trial

Andre Dahlinger[a,*], Verena Tiefenbeck[b], Benjamin Ryder[b], Bernhard Gahr[a], Elgar Fleisch[a,b], Felix Wortmann[a]

[a] ITEM-HSG, University of St. Gallen, Dufourstrasse 40a, 9000 St. Gallen, Switzerland
[b] Information Management, ETH Zurich, Weinbergstrasse 58, 8092 Zurich, Switzerland

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ABSTRACT

Despite the fact that more and more car dashboards are being equipped with powerful, high-resolution displays, allowing for radically new ways to design driving feedback, the question of what impact different design types and features have on real-world eco-driving remains largely unclear. To address this research gap, we conducted a randomized control field trial in Switzerland with 62 road assistance drivers over a period of 10 weeks, covering over 245,000 km. We evaluate the effect of eco-driving feedback on fuel consumption for two types of feedback: numerical feedback (which uses numbers and gauges to present numerical values) and symbolic feedback (which translates numerical values into symbolic representations). Both, numeric and symbolic eco-driving feedback were tested against a control group. Data analyses are performed on the level of 265,939 dynamic road segments with constant road characteristics to account for the significant effect of road attributes on fuel consumption. Results of a fixed-effects regression models reveal that only the symbolic feedback design led to significant reductions of 2–3% in fuel consumption. The effect is robust across different model specifications that control for the influence of road attributes and other covariates. We conclude that the design of eco-driving feedback can have a significant impact on its effectiveness for promoting a less fuel-consuming driving style. We conjecture that there is a large untapped potential for manufacturers to use modern digitalized dashboards that can improve the impact of driver feedback systems.

1. Introduction

Mobility is crucial to our modern society yet relies almost entirely on fossil fuels. Road transportation alone accounts for 18% of the worldwide CO_2 emissions (IEA, 2017). Despite decades of efficiency improvements in technology and infrastructure, carbon emissions from road transport are expected to increase, not only in absolute numbers but also relative to other energy-intensive sectors (ITF, 2010; Sims et al., 2014). Fuel consumption depends heavily on driving style, in particular one should try to avoid heavy accelerations, heavy braking, driving with high revolutions per minute, idling and unsteady speeds (Ericsson, 2001; Gonder et al., 2012). Due to its potential, there have been various major attempts to promote eco-driving, i.e., a less fuel-consuming driving style. For instance, the comprehensive EU research project “ecoDriver”, which investigated the “human element when encouraging ‘eco-driving’” (Carsten et al., 2016, p. 1), was funded with €14.5 million over a period of 4.5 years. The consortium focused on eco-driving

* Corresponding author.
E-mail addresses: andre.dahlinger@unisg.ch (A. Dahlinger), vtiefenbeck@ethz.ch (V. Tiefenbeck), bryder@ethz.ch (B. Ryder), bernhard.gahr@unisg.ch (B. Gahr), elgar.fleisch@unisg.ch (E. Fleisch), felix.wortmann@unisg.ch (F. Wortmann).

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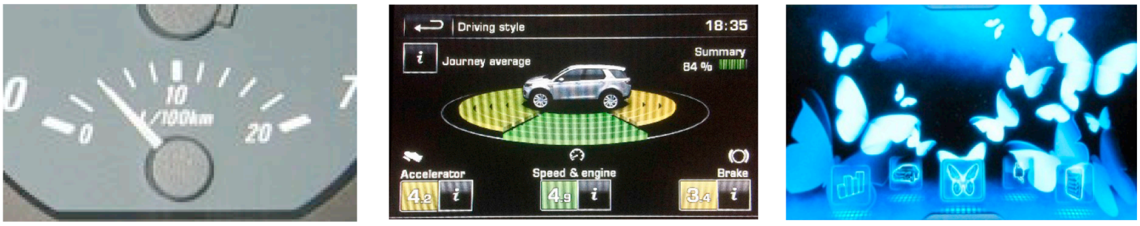

(a) fuel consumption gauge **(b) modern numerical EDFIS** **(c) modern symbolic EDFIS**

Fig. 1. Different EDFIS: (a) a classic fuel consumption display in the BMW 7 from 1982; (b) an example of a numerical EDFIS (in Jaguar/Land Rover cars); (c) an example of a symbolic EDFIS (from Ford's SmartGauge).

feedback information systems (EDFIS) as they seem to be a promising way to reduce fuel consumption significantly in a cost- and time-efficient way. Providing individuals with real-time feedback on the environmental impact of a specific activity has been shown to induce considerable behaviour change and large energy savings in other domains, such as residential energy consumption (Karlin et al., 2015; Tiefenbeck et al., 2018). However, in the mobility context, rigorous field studies specifically designed to examine the effect of EDFIS are scarce and reported results have been mixed (Dahlinger and Wortmann, 2016a). Some studies that were conducted under very controlled conditions find reductions in fuel consumption of up to 32% (Barić et al., 2013). The majority of studies that were conducted under more realistic conditions – albeit with still small samples and over short periods of time – report fuel savings between 4 and 10% (Barkenbus, 2010; Caulfield et al., 2014; Dahlinger and Wortmann, 2016a).

While most of the research on the impact of eco-driving feedback has been conducted within the last 10 years, systems that encourage environmentally friendly driving styles have been embedded in car dashboards for decades. The BWM 7, built 1982, was one of the first vehicles to provide an eco-feedback gauge that displayed the fuel consumption in real-time (Fig. 1a). Until recently, the limited capabilities of analogue displays meant that the visualization of driving-related information was essentially restricted to numbers and gauges, as often used for the mileage display or the speedometer. The increasing digitalization of car dashboards has created more possibilities and room for designer creativity. An almost infinite range of colours and animation features facilitate the delivery of information that is potentially easier for drivers to perceive, process, and to act upon (Carsten et al., 2016; Gilman et al., 2018).

As car manufacturers have started to take advantage of these possibilities, more and more car models provide different types of eco-feedback. One key characteristic in the design is the level of symbolic visualization of information. While some eco-driving feedback systems provide detailed numbers on eco-driving parameters, such as braking and acceleration (Fig. 1b), other systems convert these numbers into symbolic representations. One example is Ford Focus' EDFIS, which features a varying number of butterflies depending on how eco-friendly the car is being driven (Fig. 1c). Electric vehicles seem to be more likely to exhibit a larger number of eco-driving feedback elements and a wider range in their design. This may be due to the fact that today's battery-powered electric cars still have a more limited driving range than cars with internal combustion engines. As a result, less energy-consuming driving styles can contribute to mitigating this problem and the associated "range anxiety" experienced by drivers of electric vehicles (Franke et al., 2012). Against the background of different EDFIS design options, the question remains to what extent EDFIS actually affects driver behaviour and, in particular, what impact different design types and features have on eco-driving and fuel consumption.

While there is extensive research on the general effect of EDFIS on fuel consumption, the majority of these studies suffer from small sample sizes, short observation periods and research designs that do not allow for strong causal inference (for a literature review, see Dahlinger and Wortmann, 2016a). Furthermore, we could not find any study that investigates the effect of design elements of visual eco-driving feedback on eco-driving and fuel consumption in the field. Yet, the design of eco-driving feedback is a relevant issue in the transportation research community, as indicated by several studies that either investigate the topic in a different research setting or measure other dependent variables than fuel consumption. Jamson et al. (2015), for example, compared several designs of eco-feedback that aimed at improving the driver's use of the accelerator pedal in a laboratory setting. Their study, however, did not focus purely on visual feedback, but also included the impact of auditory and haptic feedback. The comparison of visual feedback types did not reveal significant effects overall but found effects for certain types of feedback in different driving scenarios; the study did not provide further information to explain these differences. In another simulator study, Kircher et al. (2014) compared an intermittent and a steady visual eco-feedback design, but only with respect to their impacts on driver distraction. While the number of studies assessing the impact of eco-driving feedback designs on metrics of driving performance is still scarce, several researchers have investigated drivers' preferences regarding different types of design. Using an online survey, Meschtscherjakov et al. (2009) found that user acceptance is highest for an "EcoSpeedometer", similar to the BMW 7 fuel gauge (Fig. 1a), but with additional colour-coded indicators for whether the driving is eco-friendly or not. By contrast, the "EcoDisplay", resembling Ford's SmartGauge (similar to Fig. 1c), received lower user acceptance ratings. Similar results about subjective EDFIS design evaluations were found in other surveys (Loumidi et al., 2011; Tulusan, 2013) and in focus group studies (Jenness et al., 2009; Vaezipour et al., 2017). Beyond the transportation research community, scholars from other disciplines, such as environmental psychology or human computer interaction (HCI), have studied the design of similar feedback systems, (Froehlich et al., 2012, 2010; Lockton et al., 2017). In line with feedback intervention theory (Kluger and DeNisi, 1996), HCI research distinguishes between "low-level feedback", which provides detailed information on behavioural outcomes, and "high-level feedback", which aims to strengthen goal-directed