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How far can we get with eco driving tech?

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ABSTRACT

Individual, car-based mobility contributes significantly to worldwide greenhouse gas emissions. Driving style accounts for up to 30% of fuel consumption and manufacturers have implemented technologies such as energy-efficient “eco” driving modes to reduce emissions. Here we report evidence from a field experiment with battery-electric vehicles. Two behavioral interventions, changing the mode’s default to on and informing drivers about the frequency of other people’s usage of the mode, i.e. providing a descriptive social norm, successfully increased eco mode usage. However, the cars’ acceleration and energy consumption remained unaffected due to a behavioral rebound, and were instead predicted by a situational factor, trip distance. While behavioral interventions proved effective, the results suggest that technological interventions aiming to reduce the environmental impacts might focus more strongly on alterations of situational rather than dispositional factors of people or cars.

Individual car-based mobility accounts for 12% of total EU carbon dioxide emissions (Cabuzel, 2019; IPCC, 2014). To meet global emission goals (Paris Agreement, 2015), a host of efficiency measures targeting individual mobility have been implemented around the globe. Among those are the introduction of manufacturer-side limits to carbon emissions of their fleets (European Parliament & Council, 2019) and subsidies for electric mobility (IEA, 2019). Yet, despite reductions in official fleet emissions and the number of electric vehicles on the rise, exceeding 7 million globally in 2019 (IEA, 2020), net emissions continue to climb (Peters et al., 2020).

Influencing driving behavior offers another lever to reduce emissions. Research suggests that an acceleration-prone driving style including high speeds uses up to 30% more energy as compared to a steady driving style at lower speeds (Alessandrini, Orecchini, Ortenzi, & Villatico Campbell, 2009; Bingham, Walsh, & Carroll, 2012; Knowles, Scott, & Baglee, 2012). Yet, while interventions that target drivers, such as “eco driving” reminders and trainings, prove effective initially, effects tend to be transient (af Wåhlberg, 2007; Beusen et al., 2009; Lauper, Moser, Fischer, Matthies, & Kaufmann-Hayoz, 2015; Rolim, Baptista, Duarte, & Farias, 2014). It thus seems tempting to use technologies that influence driving style more directly by changing car parameters. In line with this idea, car manufacturers have integrated optional settings in most cars that affect parameters relevant to energy consumption. Typically, these settings reduce the power delivered at a certain inclination of the accelerator or cap maximal speed. Hinting to their goal, the settings are labeled “eco”, “green”, “efficient” or similar.

The physical assumptions motivating such eco-modes are indisputable. Inertia and air-friction will always increase consumption with higher acceleration and higher speeds. The behavioral assumptions for those parameter changes, however, are questionable. Changing car parameters, just as training drivers, will only be effective to the degree that car or driver are the main cause for the driving style. While explaining driving style with dispositional attributes of the driver or stable specifics of the car is intuitively appealing (Jones & Harris, 1967), situational causes should not be neglected.

For example, drivers report feeling pressure to assimilate to the drivers around them (Fleiter, Lennon, & Watson, 2010; Lauper et al., 2015; Leandro, 2012), which is supported by driving data (Connolly & Åberg, 1993; Haglund & Åberg, 2000). Driving style is influenced by the physical setup of the road situation, with higher road grade leading to higher acceleration and more energy consumption (Costagliola, Costabile, & Prati, 2018), while type of land use near the road, access from other roads, and narrower lane widths have been shown to lower speeds and acceleration (Godley, Triggs, & Fildes, 2004; Yagar & Van Aerde, 1983). For battery-electric vehicles, the length of a planned trip is another situational influence on driving style that has been reported to

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lead to a change in driving style for longer journeys (Neaimeh, Hill, Hübner, & Blythe, 2013; Neumann, Franke, Cocron, Bühler, & Krems, 2015). Because of these situational causes, eco-modes' potential to change driving style in real life situations might be limited.

To clarify the potential impact of the eco mode technology, we investigated whether its activation would affect the driving style and the consequent energy consumption under real driving conditions. To allow for a causal interpretation, we aimed to experimentally manipulate the eco mode's activation. We did so employing prominent behavioral interventions (Tannenbaum, Fox, & Rogers, 2017).

In first instance, we used the tendency of individuals to stay with the default, the option that is effective when no active choice is made (Thaler & Sunstein, 2009). This tendency has been demonstrated for a variety of behaviors, from mundane decisions about research participation (Paunov, Wänke, & Vogel, 2019) or computer configurations (Brown & Krishna, 2004) to medical decisions like the type of end-of-life care (Halpern et al., 2013) or the registration as an organ donor (Johnson, 2003). For example, countries with a donation opt-in such as Germany indicate much lower donor registration numbers than countries that by default require an opt-out such as Austria (Johnson, 2003; McKenzie, Liersch, & Finkelstein, 2006). Setting the default to more sustainable choices, for example to more expensive 'green' energy tariffs (with active opt-out) has also been shown to be effective (Ebeling & Lotz, 2015; Pichert & Katsikopoulos, 2008; Vetter & Kutzner, 2016). Such findings have prompted EU legislators to establish a framework for eco design (European Parliament, 2018), including, since 2010, mandates for default energy efficiency settings in, among others, dishwashers, washing machines and refrigerators. The effectiveness of default interventions has also been shown to vary depending on, for example, the domain (more effective in consumer as compared to environmental domain) (Jachimowicz, Duncan, Weber, & Johnson, 2019), and the intentionality of the behavior (more effective with intentional behaviors) (Dinner, Johnson, Goldstein, & Liu, 2011; Jachimowicz et al., 2019).

Many processes to contribute to defaults' effectiveness, such as decision inertia (Levav, Heitmann, Herrmann, & Iyengar, 2010). Yet, most of these processes to contain a social aspect (Van Der Linden, 2018). Defaults seem to act as messages to imply "typical" choices or even a recommendation (Davidai, Gilovich, & Ross, 2012; McKenzie et al., 2006) and they trigger conversation-like responses changing the meaning of the default options (Dinner et al., 2011).

In the second instance, we relied on an overtly social appeal, the tendency of individuals to adapt their behavior to the behavior of others (Bergquist, Nilsson, & Schultz, 2019; Cialdini, Reno, & Kallgren, 1990; Goldstein, Cialdini, & Griskevicius, 2008), to manipulate the activation of the eco mode. For example, regarding waste disposal habits of one's neighborhood increased the amount of material recycled (Cialdini et al., 1990; Schultz, 1999) and feedback about neighbors' electricity consumption led to an assimilation of consumption (Alcott, 2009; Schultz, Nolan, Cialdini, Goldstein, & Griskevicius, 2007).

We hypothesized that an increased proportion of a drive would be spent with the eco mode activated when, by default, the eco mode had been activated ("ON") versus deactivated ("OFF") at the start of the drive; and when the driver had been informed about the number of times the eco mode had been previously activated by other drivers ("social norm"), versus only provided with information about the purpose of the eco mode ("control"). Further, we analyzed whether the default and social norm interventions would influence driving style as measured in average car acceleration and energy consumption. Finally, we analyzed whether a directly measurable situational factor, trip length, would predict driving style and energy consumption as suggested by previous research.

Based on medium-to-large estimated effect sizes ($d = .6$) in meta analyses conducted on default effects (Jachimowicz et al., 2019) and social norm effects (Poškus, 2016), we conducted a power analysis for four groups and an average of four participations per driver; to achieve a power of 0.95, this would require 176 data points; while the final number of drives was out of our control due to the nature of the trial, we attempted to achieve double this number.

1. Methodology

We conducted a field experiment, carried out in accordance with German ethics requirements of the DGPS. We employed the fleet of a car-sharing operator that operates in an area of 7000 km^2 in rural and semi-rural districts in the south of Germany, consisting of, at the time, 200 battery electric vehicles (EVs) of various makes. Their most frequently booked model was a compact car that also accounted for 10% of global annual EV sales as of January 2018 (Nissan Global, 2018).

Using this popular model, we recorded car information via on-board diagnostics (OBD module) attached to the CAN bus of the car and transmitted via telecoms networks. This information included distances covered, the speed of the car, the position of the accelerator pedal and the state of charge of the battery in KWh as well as eco mode activation status. In this car model, the eco mode is activated by pressing a button labeled "eco" next to the gear shift (c.f. Fig. 1A). The eco mode reduces the sensitivity of the accelerator pedal and limits the maximal speed to 90 km/h. It also changes the color of the display from purple to blue.[1]

On a weekly basis, cars[2] were randomly allocated to one of four conditions, following a 2 (default: eco mode ON vs. OFF) x 2 (social information vs. control)[3] experimental design. The social information condition was presented on a sticker prominently placed next to the steering wheel (c.f. Fig. 1B). The German text on the stickers translates as "Eco-mode. Greener. Further. Activated 5971 times at E-Wald in 2016", in the social norm condition and "Eco mode. Greener. Further." in the control condition (c.f. Fig. 1C). Frequencies reported on the stickers were true, based on logged eco mode activations.

We were able to record driving data for 431 drives between June and December 2017. We excluded 92 drives in which driving data was lost for more than 10% of the driving distance due to missing network coverage. Exclusion was tested with a Pearson's Chi-squared test, and was found to be unsystematic with regard to the allocation to the default ($\chi^2(1) = 0.56$, $p = 0.45$) and the social norm ($\chi^2(1) = 0.00$, $p = 1$) conditions. The median distance covered during the remaining 339 drives was 7.00 km (mean = 23.67 km). The distribution to the conditions was 87 with eco mode ON and with sticker, 44 with eco mode ON and without sticker, 123 with eco mode OFF and with sticker and 85 with eco mode OFF and without sticker. The drives were completed by 121 different drivers with a median number of participations in the trial of 2 (mean = 2.79). Following our hypotheses, three main dependent variables were analyzed: (1) the proportion of time spent driving with the eco mode activated (0–1.0), (2) the average acceleration of the car ($|m/s^2|$), and (3) the average electricity consumption (kWh).

To check whether we successfully manipulated the activation of the eco mode with our interventions, we predicted the proportion of drive

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[1] The mode also affects other parameters relevant for energy consumption, such as the power delivered to the air conditioning system.

[2] Cars, and not participants, were randomized to conditions for practical purposes. Since we relied on volunteers to change the default and stickers, doing so per participant would have been an impossible logistical effort, also because users are able to book cars at a minute's notice, and cars are available for booking back-to-back with minimal downtime.

[3] Following previous research (Goldstein et al., 2008) we implemented two different versions of the social information condition, a specific one referring to the number of times the eco mode had been activated in the given car, and a less specific version referring to the whole fleet (i.e. 5971, c.f. Fig. 1B). We also implemented two different versions of the control condition, one containing information about the eco mode (c.f. Fig. 1C) and one only containing a smiley without reference to the existence of the mode. Since no differences emerged between the two social norm conditions and between the two control conditions, the respective conditions were collapsed.

Fig. 1. Illustration of the location of the eco mode button (A), the social norm information about the frequency of activation of the eco mode in the fleet (B) and the information about the eco mode in the control condition (C).

time with eco mode activated from the default (ON vs. OFF) at the start of the drive, from the social information being present or not, and the interaction between these two manipulations. We included the distance of the trip and its interaction with the other factors.

We used the R-package lme4 with z-standardized variables and estimated random intercepts and slopes for individuals to account for random and multiple allocation of participants to the treated cars (Longford, 2011). With z-standardized variables, regression coefficients can be interpreted as partial correlation coefficients (Snijders & Bosker, 2012) to gauge effect sizes (Cohen, 1992). Cell sizes were as follows: 44 drives in eco mode off/social norm absent, 87 in eco mode off/social norm present, 85 in eco mode on/social norm absent and 123 in eco mode on/social norm present.

2. Results

We found that the default manipulation influenced the proportion of drive time with eco mode activated, $\beta = 0.61$, $t = 11.47$, $p < .001$, 95% CI [0.50, 0.71]. When the eco mode was the default, i.e. ON at the start, it was activated in roughly 70% of the drive time. When it was not the default, it was only activated in about 10% of the drive time. The eco proportion was also affected by the social norms, $\beta = 0.08$, $t = 2.38$, $p = .019$, 95% CI [0.01, 0.15]. When social information was present the eco mode was activated in a larger proportion of the drive time (c.f. Fig. 2A). The interaction was not significant, $\beta = 0.04$, $t = 1.15$, $p = .257$, 95% CI [-0.03, 0.12].

The distance of the trip also predicted the eco proportion, $\beta = 0.17$, t

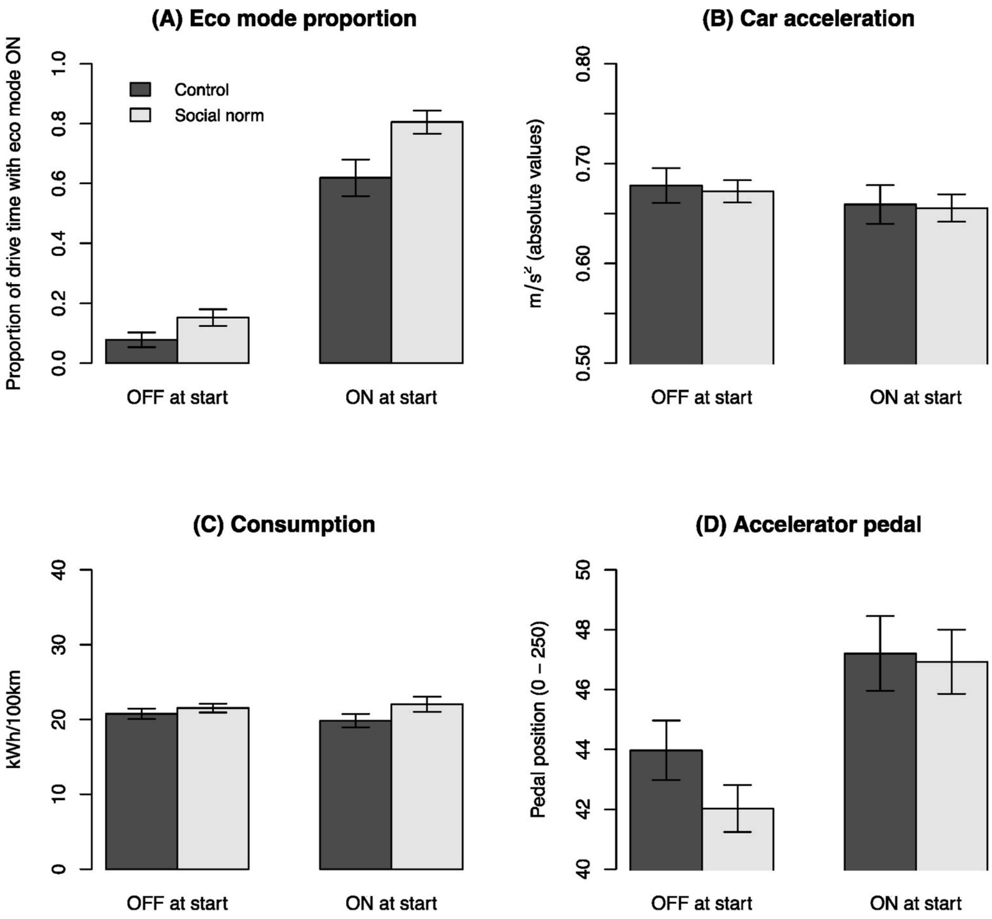

Fig. 2. Illustration of results. (A) Proportion of drive time with eco mode activated; (B) average car acceleration; (C) average consumption in kWh/100 km; (D) average position of the accelerator pedal.

$= 3.31$, $p < .01$, 95% CI [0.07, 0.27], with longer trips associated with larger eco proportions. Finally, the default manipulation and the distance of the trip interacted, $\beta = -0.21$, $t = -4.08$, $p < .001$ 95% CI [-0.31, −0.11], indicating that the influence of the default was smaller for longer trips.

We repeated the regression analysis for the average acceleration of the car in m/s^2, which was derived from changes in the cars' speed (c.f. Fig. 2B). Only trip distance explained the average, $\beta = -0.32$, $t = -5.09$, $p < .0001$, CI [-0.44, −0.19], with longer trips being associated with lower acceleration (all other abs(t's) < 1.58, p's > 0.115). This pattern was also evident in the energy consumption during the trip in kWh/100 km, a measure derived from changes in the battery's state of charge (c.f. Fig. 2C). Only the trip distance explained average energy consumption, $\beta = -0.25$, $t = -3.23$, $p < .01$, CI [-0.41, −0.10], with longer trips being associated with lower energy consumption (all other abs(t's) < 1.36, p's > 0.177).

As the eco-mode caps acceleration and speed, we had expected that the activation of the eco mode would be associated with lower acceleration and lower energy consumption. This was not the case and in order to explain this discrepancy between the effects on the eco mode's activation and the lack of effects on driving style and energy consumption, we conducted an additional exploratory analysis, involving the use of the accelerator pedal. To achieve equal acceleration with the eco mode activated as without it, the accelerator pedal must be pushed further. We repeated the above regression predicting the average inclination of the accelerator pedal, ranging from 0 in the resting position to 250 at the kick-down position. The analysis revealed that the average inclination was predicted by the default, $\beta = 0.21$, $t = 4.13$, $p < .001$, CI [0.11, 0.32]. When the eco mode was activated at start, the accelerator was on average pressed further (c.f. Fig. 2D). The position was also explained by the trip distance, $\beta = 0.26$, $t = 4.09$, $p < .0001$, CI [0.14, 0.39], with longer trips being associated with stronger inclinations. All other abs(t's) < 1.50, p's > 0.144.

3. Discussion

The results speak to the effectiveness of behavioral interventions. Providing social norm information and changing the default both increased the usage of an energy efficiency technology, the eco driving mode, in battery electric vehicles. Under real life driving conditions, defaults had a medium, and social norms a small effect on the proportion of drive time with the mode activated.

At the same time, the results suggest that activating the technology is not effective at reducing energy consumption. The changes in car parameters were compensated by corresponding behavioral changes. Most prominently, the decreased sensitivity of the accelerator pedal was compensated by drivers pressing the pedal further. Consequently, the intended reductions in average acceleration and average energy consumption were absent.

The data do not directly speak to the reasons for the observed driving behavior. However, results are compatible with two ideas. First, stable dispositional characteristics, such as sensation seeking or need for speedy driving, might explain a stable favored driving style, with drivers motivated to upkeep their usual speed and acceleration patterns (Jonah, 1997; Leandro, 2012; Zuckerman, 2007). To the degree that these dispositional characteristics exist, any driver- or car-focused approach targeting energy consumption is unlikely to be effective. Changing drivers' mental models about driving and targeting habits, should be further explored.

Our results are also compatible with the idea that situational causes influence the driving style. We do show some evidence supporting this hypothesis: trip length, as a situational factor, predicted energy consumption in our data, and might reflect drivers adapting their driving style to range demands as previously suggested (Neaimeh et al., 2013; Neumann et al., 2015), for example by proactively activating the eco mode, which was also predicted by trip distance. It is likely that other situational factors such as current traffic situations or road properties played a role.

More broadly, the current research highlights that usage of technologies designed to change behavior should not be confused with the behavior they try to instigate. Pre-registration technologies, such as for organ donation, can be considered another example of this confusion. While opt-out settings increase registration rates six-fold, actual donations only increase by 16% (Johnson, 2003). Similarly, promoting the use of fitness applications, for example by means of social comparisons (Edwards et al., 2016), is not necessarily related to an improvement in fitness related behaviors (Johnson et al., 2016).

For designing technological behavior change intervention, there are two implications. First, technologies should be designed to minimize behavioral rebound. Where feasible, this can be achieved by providing no opportunity to intervene once the technology is engaged, such as in the eco mode of a dishwasher or the selection of a renewable energy tariff. Second, designing behavioral interventions should start with a clear definition of the behavior to be achieved and a thorough analysis of the related situational factors and other related behaviors (e.g., Michie, van Stralen, & West, 2011). Such analysis seems especially important for more complex or "thorny" behavioral problems (Sanders, Snijders, & Hallsworth, 2018).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvp.2021.101626.

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