OBDEnergy

Making Metrics Meaningful in Eco-driving Feedback

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Abstract. This paper describes an eco-driving feedback system, OBDEnergy. Twenty-six drivers described their understanding of environmental impacts of driving before and after using OBDEnergy. Before OBDEnergy, participants discussed impacts in abstract, global terms (pollution, global warming). After OBDEnergy, participants appealed to concrete reference points (gallons of gas, trees required) with calculations and comparisons. We conclude that user-centered eco-driving feedback can contribute to pro-environmental behavior via increased awareness of the concrete environmental impacts of driving.

Keywords: eco-driving · feedback · integrated technology · carbon emissions

1 Introduction

Fuel economy estimates posted on every car sold in the US state the caveat, “Actual results will vary for many reasons, including driving conditions, and how you drive and maintain your vehicle.” Eco-driving is strategically taking advantage of this variability through driving and maintenance practices (e.g., by minimizing braking and hard accelerations, ensuring proper tire inflation, and avoiding traffic). Estimates of fuel economy improvements and concomitant carbon emission reductions resulting from eco-driving range from 5% to 20% [1].

1.1 Eco-driving Feedback: The Technology

In-vehicle feedback displays are becoming more prevalent and increasing in variety (Fig. 1), especially in hybrid, plug-in, and electric vehicles; gas vehicles typically have at most a numeric indicator for real-time and average fuel economy (Fig. 2). Eco-driving feedback systems are also available after-market via devices and web or mobile applications. A search in iOS and Android app stores revealed more than 40 eco-driving apps (at least 24 originating outside the US).

Fig. 1. Lincoln MKZ (Hybrid)

Fig. 2. Mazda CX-5 (ICEV)

Fig. 3. Drivee

Fig. 4. CaroO Pro

Some apps integrate with a device that plugs into a vehicle's OBD (OnBoard Diagnostic) port, usually located underneath the steering wheel and standard for all cars after 1996. Use of OBD improves accuracy by collecting data directly from the engine (e.g., fuel level, Mass Air Flow), whereas app-only feedback is limited to factors external to the engine (e.g., GPS, speed, acceleration) and user input. Examples of app-only feedback systems include Geco and Drivee (Fig. 3). Systems with OBD include Metromile, Torque, Dash, and CaroO Pro (Fig. 4).

1.2 Eco-driving Feedback: The Psychology

Research suggests eco-driving feedback results in average fuel and emissions savings of 5%, ranging from 0% to 18% [3]. Some of this variation is undoubtedly due to variation in the feedback itself in terms of information provided and design, which have implications for its effectiveness in shaping and motivating behavior.

Schwartz's Norm Activation Model (NAM) [4] contends pro-environmental behavior is supported by awareness of the consequences (AC) of one's behavior, perhaps especially concrete consequences: "A person who becomes aware intensely and in detail of how his potential actions may affect others is likely to experience activation of moral norms" (p. 357). Raising awareness of concrete consequences via eco-driving feedback may involve quantification of environmental impacts. In scientific and popular climate change discourse, kilograms (kg) of CO2 is commonly used to convey environmental impact (Fig. 2). Eleven of the 40+ eco-driving apps we found report carbon emissions, typically in kilograms. Whether such a specific, quantified consequence is meaningful may depend on how familiar or tangible the metric is; for example, icons of clouds or power plants are sometimes paired with quantifications of carbon (Fig. 2). In perhaps yet another sense, concrete consequences might be personal or emotionally evocative; e.g., nature imagery (e.g., Fig. 1) is often used in eco-driving feedback.

Relational Frame Theory (RFT) [2] is a behavior analytic theory of language and cognition applicable to this predicament of fostering awareness of concrete consequences. This theory focuses on the phenomenon of framing events relationally, which means responding to (thinking about or speaking about) some event in terms of another event (a relational frame). Relational frames of coordination are based on identity or similarity (e.g., fuel combusted equates to carbon emitted). Comparative relational frames involve comparing one event to another in terms of a specific dimension (e.g., one gallon of gas weighs less than the carbon emissions from its combustion). Temporal relations are a special case of comparative frames whereby someone understands an event in terms of its relationship to time.

An important property of every relational frame is *transformation of stimulus functions*, which refers to a change in the functions of a stimulus as a result of its relation to another stimulus; e.g., given a frame of coordination between kilograms of carbon and trees required to offset emissions, if trees required evokes an emotional response and motivates conservation, kilograms of carbon will have a similar effect. Eco-driving feedback systems are operating with assumptions that align with RFT and NAM. They attempt to change how drivers understand (i.e., respond to) abstract environmental impacts by framing them in relation to concrete concepts, such as money, time, or trees.

1.3 Present Research

We present a behavioral study of the effectiveness of an integrated mobile app and OBD eco-driving feedback system called OBDEnergy in promoting awareness of concrete environmental consequences of personal vehicle travel. The system's user interface (UI) juxtaposes abstract and concrete metrics for trip-level and historical data. Based on RFT and NAM, we hypothesized that users' awareness of consequences would become more concrete. OBDEnergy does not directly prompt specific behavior through real-time feedback, but to the degree that it enhances awareness of consequences we anticipated some effect on behavior and intentions in accordance with NAM.

2 Method

2.1 OBDEnergy

An Android application was programmed to communicate with vehicle engines via a Bluetooth-enabled OBD-II plug-in device. The engine is queried constantly throughout a drive for Fuel Level and Mass Air Flow. At the end of a drive, a formula for each parameter is used to calculate gallons of gasoline used for that drive and the two numbers are cross-checked. Gallons of gas used is multiplied by the EPA's constant (8.9 kg CO_2) to estimate kilograms of carbon emissions.

The UI has three screens. A 'Drive' screen is hands-off to prevent driver distraction; this screen simply has prompts to activate the system. Pressing 'START' activates data collection and the button changes to 'STOP'. Pressing 'STOP' at the end of a drive activates the 'Metrics' screen (Fig. 5), which presents metrics with corresponding icons. The third screen, 'Graphs' (Fig. 6 & 7), presents metrics accumulated over time. Clouds accumulated much faster than trees since it requires only 0.026 trees to offset 1 kg of carbon; therefore we visualized trees in terms of accumulations of 10 leaves for greater sensitivity. 'Graphs' can be viewed anytime and is the most interactive screen.

Fig. 5. Metrics screen

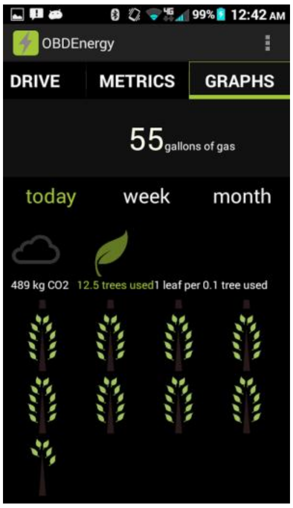

Fig. 6. Trees in 'Graphs'

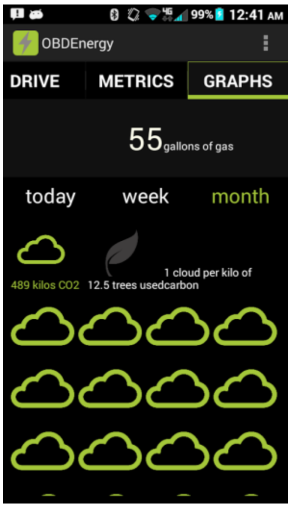

Fig. 7. CO_2 in 'Graphs'

2.2 Study Design, Participants, and Recruitment

In a within-subjects, pre-posttest, quasi-experimental design, 26 University of California, Davis, students (23), staff (2), and faculty (1) were recruited via department listservs and exposed to the same feedback. They completed a survey before and after using OBDEnergy for at least one month (*M* = 36 days, min. = 28, max. = 42). Participants were male (15) and female (11), ranging from 19 to 47 years old (*M* = 25.87 years, *SD* = 7.21 years). They were required to have a valid driver license, Android phone, and personal vehicle—1997 or newer, and to confirm driving at least 20 times per month on average. Participants received a $30 gift card.

2.3 Procedure

The lead researcher installed an OBD-II plugin in each participant's vehicle, emailed them a link to download the app to their phone, tested the system to ensure valid data communication between the engine, OBD, and app, and oriented participants to the app. Both pre-test and post-test surveys were paper-based and administered in an office building at the University of California, Davis. The pre-test survey consisted of seven open-ended questions, one closed-ended question, and prompts for demographic information; it took approximately 10 minutes to complete. The post-test survey consisted of 12 open-ended questions, one closed-ended question, and included items regarding system usability; it took approximately 20 minutes to complete.

Awareness of concrete consequences was gauged by asking participants to describe the environmental impact of one gallon of gas (priming a relational frame between a tangible, familiar metric and a more abstract concept). Similarly, we queried participants about their understanding of carbon emissions and their personal energy footprint. The post-test survey included one item about behavior change, inquiring how, if at all, OBDEnergy affected participants' behavior.

3 Results

We organize our analysis around four lines of questioning. Three relate to awareness of consequences and relational framing, in general and specific terms (carbon emissions broadly versus kilograms of carbon and one gallon of gas), and impersonal and personal terms (impact of gas and carbon versus personal footprint). A fourth line of inquiry concerns self-reported behavior change. Responses to these sets of questions were coded separately according to emergent themes. Each response could yield multiple codes; all participants answered all questions.

3.1 Impact of One Gallon of Gas

Before and after using OBDEnergy, participants were prompted to consider the environmental impact of one gallon of gas. In the pre-test survey, 17 of the 26 participants indicated that they did not know and did not venture a guess. Four participants cited general impacts, including mention of smog, pollution, or global warming (e.g., *I imagine the carbon entering the atmosphere adds to the global warming problem*). Two made a vague normative observation about emission being "bad" (e.g., *I just know that carbon emissions are bad*). Even participants who seemed well-versed in the climate change discourse were unable to specify a concrete impact in relation to this familiar metric:

> *I do realize that it's more polluting than simply releasing the CO2 into the atmosphere (…) there is a huge amount of energy that goes into getting the gas out of the earth, processing, packing, and transporting it to the gas station. And then of course there's all the energy and materials required to build each gas station… So the impact depends on where one draws the life cycle*

> *parameters, but I really have no idea what impact one gallon of gas used by my car has on the atmosphere.*

Five participants implied that they should know or want to know (*I would like to see just how much an impact just one gallon has*); two of these were inferred by the fact that they qualified their "no" with "honestly", but others were more explicit (*Sadly, I do not know*; *I unfortunately do not - I routinely dismiss it as negligible*). One participant was able to quantify a specific impact of one gallon of gas in a relational frame of coordination, although it was not an environmental impact: *1 gal is about a 1 way trip to work*. In sum, the pre-test survey revealed that none of the participants could provide a specific impact of one gallon of gas on the environment.

In the post-test survey, participants described environmental impact in relation to metrics provided in the feedback. Four participants described the impact in terms of the trees (e.g., *Needs ~1/4 of a tree to offset its carbon emission; I know we don't have nearly enough trees!*). Two referenced weight of carbon emissions—neither explicitly in kilograms, however, and both rather tentatively (*I'm pretty sure that one gallon of gas releases more weight than the actual gallon of gasoline; For every gallon of gas my car used it generated close to 20 lbs of CO2?*). Six expressed surprise that the impact was greater than anticipated (e.g., *It is quite a large impact!*). In contrast to the pre-test survey, there was no mention in the post-test surveys of general impacts concerning pollution and global warming.

Just eight participants still reported very little understanding of the impact of a gallon of gas at the end of the study (e.g., *I have a vague idea after looking at the app*). Of these, four had technical difficulties that prevented them from viewing retrospective feedback and two reported minimal app use (e.g., *I don't think I drove enough to really understand the impact of a single gallon of gas*). Some affirmative responses were too vague to interpret (e.g., *Now I do, I had almost no idea of the impact before!*). One response very clearly affirms our hypothesis regarding increased awareness of consequences: *This app just made me more aware of what I'm releasing into the environment.*

3.2 Carbon Emissions

Participants were asked about their understanding of carbon emissions, the metric of kilograms of carbon, and the environmental impact of carbon emissions. Again, we looked for differences in awareness of specific consequences and relational frames before and after using the app. In the pre-survey, most participants (19) described general impacts (e.g., *I know carbon emissions play a role in global warming*), frequently using the terms *global warming* (6), *greenhouse gas* (5), *ozone* (6), and *climate* (6). Other responses were vague (e.g., *It adds up*) or offered a general normative statement (e.g., *Carbon emissions are bad. Beyond that I have very little understanding*).

Despite the prevalence of climate change language to describe general consequences of carbon emissions (19 participants), 6 of those participants qualified their response to indicate uncertainty or a limited understanding (e.g., E*missions contribute to global warming and thinning of the atmosphere? Is that even right[?] I just know that they are bad and we are always trying to reduce our carbon footprint*). Seven participants related carbon to fossil fuels (e.g., *My understanding is that carbon emissions come from fuel and energy usage?; Carbon as a fuel source isn't infinite; burning fossil fuels…*). Three participants referenced trees but not in terms of negative environmental impact of carbon emissions (*Trees take in CO2 and output O2 during photosynthesis; forest loss; cutting down our environment*). None quantified the impact of carbon emissions or mentioned a specific carbon metric (e.g., kilograms or pounds).

The post-test survey item asked participants directly about any change in their understanding of kilograms of carbon compared to the beginning of the study. Nine participants related kilograms of carbon to metrics in the feedback in frames of coordination or comparison (trees, gallons of gas, trip distance) and/or time (trip comparison or accumulation across trips). There were six relations to time or distance (e.g., *It doesn't take a lot of driving to rack up a lot of kg of carbon; I got a much better understanding of how the ways I drive changes the emissions of my car on a drive-by-drive basis*). There were two relations to trees (*I had no clue of how much is 1 kg. but over time I started comparing "trees required"; It is like using up a lot of trees! It showed me how much carbon I use when I drive compared to using trees*). There were three relations to gas (e.g., *I have more of an idea of how gas used compares to CO2 emitted*).

Two participants quantified relations between carbon and other metrics or time (*I had generated over 400lbs of CO2 over the month study period; I was driving under 9 kilograms of carbon per day*). Five participants expressed surprise at the amount of kilograms of carbon their vehicle emitted (e.g., *I realized I use more kilograms of carbon than I would think; … at times it felt like I was killing off a whole forest!*). Two participants implied that social comparisons in the feedback would increase their understanding of kilograms of carbon (e.g., *It would be more helpful if I could compare my results with other users or avg American driving similar cars*). Six participants had technical difficulties and/or low driving frequency so their responses were not applicable and five others reported no change in awareness of kilograms of carbon or their answer revealed misunderstanding (e.g., *Trees required to make the gas?*).

3.3 Energy Footprint

We asked participants to discuss their understanding of their personal energy footprint before and after using the app. All but two participants listed or implied some of their energy-related behaviors, often focusing on energy-responsible behaviors (e.g., *I use energy efficient bulbs, try to turn off lights, have solar on my roof*). Sixteen of these participants mentioned personal transportation behaviors (e.g., *I am conservative with gas too, won't take a long route or drive wastefully all over town; I probably destroy the environment with my driving habits. Deep footprint!*).

Many participants ranked themselves in relation to others (e.g., *Maybe slightly less than average*), perceived norms (e.g., *Probably quite a bit since I commute a lot*), or even other time periods (*… more than I would have if I'd been born 100 years ago!*). A few participants also used self-comparison, considering their footprint in terms of different energy-use domains (e.g., *I don't try to save gasoline so much but I am very conservative with energy in the home*). Only one participant provided a quantitative assessment: *I recall taking an online carbon footprint/test and the results stated if everyone lived as I did we would need about two earth's worth of resources.* A few participants explicitly noted their inability to quantify their footprint (e.g., *I couldn't really give an accurate description of my energy usage/carbon footprint, because there's nothing that measures how much I use),* and one participant remarked: *I* *would love to be even better and hopefully this app will know* [my footprint] *better.*

In the post-test survey, twelve participants explicitly reported or clearly implied an increased quantitative understanding of the energy footprint associated with their personal vehicle travel (e.g., *I can quantify it now. I'm still not sure of the impact*; *I gained a better idea of what my energy consumption is*). Some responses were too vague to ascertain any change as a result of the app (e.g., *I could do better*). Five participants reported no understanding or a vague understanding of the concept after using the app; of these, three reported technical problems.

Again, participants described environmental impact in terms of metrics provided in the feedback (trees, gallons of gas, trip distance) and/or time (trip comparison or accumulation across trips) to explain their carbon footprint (e.g., *This app made me realize that all those short distances add up; I was able to visually see my carbon footprint and that my footprint does add up over time.* One participant offered a quantified relational frame: *Every 50-60 gallons or so I would need an entire tree to offset my carbon usage.* Another recurring theme was that of surprise (e.g., *My CO2 contributions to the environment are much higher than I thought*), though this time one participant was surprised by using less than she imagined. Two participants made inferences to the population at large based on their feedback (e.g., *There couldn't possibly be enough trees to get rid of all that was created from my driving plus the rest of the population*).

3.4 Behavior and Intentions

In response to the post-test survey item inquiring after behavior change, as well as in responses to other items, participants did reveal some interesting insights about how the app affected their behavior or intentions. Three themes emerged in the data related to behavior and intentions, though none was present in more than three responses. One reported behavior change was to drive less (i.e., *I have already taken steps to drive less*; *It definitely has taught me to only drive when super necessary*; *Because of this, I have tried and found a carpool system to reduce my carbon*). Another indicated influence over participants' next vehicle purchase (e.g., *Although it didn't change my driving habits, it did change my considerations on my next vehicle purchase*). Finally, one participant reflected on goal-setting in relation to the carbon metric in the feedback:

[regarding kilograms of carbon:] *it's now the unit I try to keep down because it's what I am putting into the world*.

4 Discussion

Several common themes emerged from the pre-test survey data related to a lack of awareness of concrete consequences. Before using OBDEnergy, participants were unanimously unaware of any concrete environmental impact of one gallon of gas, a highly familiar metric. Instead, their explanations circled abstract (general, global) impacts (climate change, Ozone degradation, and pollution) and norms ("bad"). Regarding their personal carbon footprint, participants cited travel mode choices, frequency of driving, and driving style; they qualitatively assessed the impact of their behavior (e.g., as minimal, average, or significant), comparing it to some standard.

The post-test survey data revealed an increase in awareness of concrete consequences after using OBDEnergy. Instead of echoes of scientific explanations and climate change discourse about abstract phenomena, participants' explanations of environmental impact involved relational frames of coordination and comparison across metrics (carbon, trees, gallons of gas, trip distance) and temporal relations (trip comparison or accumulation across trips). Another pervasive theme related to increased awareness is participants' surprise upon learning about concrete impacts of their personal vehicle travel. Finally, participants reported changes or intentions toward more conservative driving styles, travel mode choices, and even next vehicle purchase decisions, supporting the contention of NAM [4] that awareness of consequences contributes to pro-environmental behavior.

Trees and gallons of gas featured heavily in post-test survey relational frames; that is, participants referenced them in their explanations of the environmental impacts. Temporal relations were also apparent as participants calculated and compared metrics across time, often based on the historical comparisons available in the app. The kilograms of carbon metric, however, did not seem to become concrete for users in the sense of adopting it into relational frames of environmental impact. For example, of the three instances where a specific carbon measurement was provided, two translated kilograms into (or misinterpreted them as) pounds. Pounds likely would have been more successful since it is more familiar among our population. One participant translated gallons of gas into money in a relational frame of coordination.

Six users reported either infrequent app use or technical problems. Frequency of use was not controlled and varied among participants. Future research should include frequency of use as a moderating variable. Future research with eco-driving apps and OBDs should also take care to ensure uninterrupted and accurate technical performance through rigorous initial setup and pre-testing with each participant as well as regular communication with participants.

We have just scratched the surface of the opportunity to apply RFT and the concept of awareness of concrete consequences to the field of eco-driving feedback. Further conceptual work is needed to disentangle the multiple meanings of *concrete* (specific, local, tangible, familiar, quantifiable, emotional) in this context. Further research should systematically investigate the relative effectiveness of different metrics and iconography as measured by relational responding in users reported understanding of environmental impacts.

5 References

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