Goal Setting, Framing, and Anchoring Responses to Ecodriving Feedback

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ABSTRACT

Ecodriving, defined here as the adoption of energy efficient driving styles and practices (primarily moderating acceleration, top speed, increased coasting, and improved maintenance practices), has long been recognized as a potential source of reductions in transportation energy use. Estimates of energy savings attributed to ecodriving range widely, from less than 5% to as high as 20% depending on the driving and experimental context. To explore the effects on ecodriving of interaction between drivers and in-vehicle energy feedback, a customized, interactive energy feedback interface was deployed in a field test with real-world drivers. This paper presents the results of interviews with 46 Plug-in Hybrid Electric Vehicle (PHEV) drivers who were given the ecodriving feedback interface for a multi-week trial including an interface off (baseline) and on (treatment) condition. This paper relies specifically on self-reports of driver motivations and behaviors to better understand what types of information motivated new ecodriving behavior; a future paper will investigate quantitative fuel consumption effects. Driver interviews at the conclusion of the study revealed that the introduction of feedback led three fourths of drivers to change driving styles to maximize on-road efficiency, at least in the short term. In addition, this study finds that the context of the feedback information, provided by a built-in goal or other contextualizing information such as a comparison value, is important for both comprehension and motivation. Personalization of the information allowed different drivers to access pertinent information, increasing the motivational value of the information. Instantaneous performance feedback such as real-time energy economy or power is used primarily for experimentation and learning of new ecodriving behaviors, whereas average performance feedback is used primarily for goal-setting and goal achievement. In addition, the direct comparison of personalized driver goals and average performance created a game-like experience that encouraged high achievement. Finally, the driver interviews revealed that feedback frames driving as a time to act in an efficient manner.

Keywords

1.1 INTRODUCTION
Ecodriving is defined here as the adoption of driving styles that reduce energy consumption. In the broadest sense, ecodriving could be interpreted as any vehicle related behaviors that save energy, including not only driving behavior per se, but maintenance behaviors, trip-chaining, mode shifting, vehicle purchase choice. However, in the short term, and for the purposes of this study, the primary behaviors of interest are those displayed on-road, such as moderating acceleration, top speed, and increased coasting since the energy impact of those behaviors are most directly reflected with in-vehicle energy feedback. Ecodriving has long been recognized as a potential source of reductions in transportation energy use, although estimates of the energy savings range widely from less than 5% to as high as 20% depending on the driving and experimental context, some of which provide only training, and others of which examine only in-vehicle feedback (Barkenbus, 2010; Greene, 1986). One experiment found that in the short term, individuals who were simply asked to drive more carefully increased their fuel economy by 10% (Greene, 1986).

Although many studies have empirically tested in-vehicle fuel economy feedback, fewer have advanced a theoretical basis to explain the effects of feedback, e.g., the psychological processes of drivers who use such devices. Behavioral theory as well as recent research into energy saving behaviors indicate that behaviors such as ecodriving are more likely to be adopted by drivers under a certain set of psychological conditions that include the alignment of attitudes, perceived social norms, and perceived behavioral control, with appropriate driver goals (Ajzen, 1980; Perugini & Conner, 2000; Stillwater & Kurani, 2011). The qualitative interview-based analysis presented here is meant to help elucidate the role of these conditions in supporting or mitigating the effectiveness of in-vehicle feedback in leading to behavior changes, as well as how to design feedback to support ecodriving.

This paper examines the results of interviews with 46 subjects who each used an experimental vehicle in place of their own household vehicle for one month, with the feedback device activated for the final two weeks. The experimental interface was designed to test the effect of various behavior-change relevant displays on ecodriving habits of the drivers using the results of a study on driver responses to the 2008 Toyota Prius interface as a guide (Stillwater & Kurani, 2011).The results are interpreted based on emergent themes from interviews with the drivers. Those themes are compared to predictions from the Theory of Planned Behavior (TPB) (Ajzen, 1980) and the Extended Model of Goal Directed Behavior (EMGDB) (Perugini & Conner, 2000). The TPB's main contribution is to incorporate social norms and perceived behavioral control (perception of one's own ability to effect change) into the same framework as attitudes and valuations on intentions to perform behaviors of interest. The EMGDB re-orients the TPB framework to focus on achievement of behavioral goals (e.g., getting 50mpg for a certain trip or tank of gas), rather than intentions to perform specific actions (e.g., moderating one's acceleration).

1.2 Previous Driver Feedback Studies
Of several studies testing driver feedback for fuel economy (Ando, Nishihori, & Ochi, 2010; Boriboonsomsin, Vu, & Barth, 2010; Greene, 1986; Larsson & Ericsson, 2009; Lee, Lee, & Lim, 2010; Satou, Shitamatsu, Sugimoto, & Kamata, 2010; Syed & Filev, 2008; Wahlberg, 2007; van der Voort, 2001), the large majority were based on feedback that consisted of a real-time numeric or graphical display of mile-per-gallon (MPG) fuel economy. However, none of these studies investigated the psychological effects of feedback, i.e., why drivers changed their

behavior in response to the feedback. One previous qualitative study of the fuel economy feedback in the 2008 model year Toyota Prius found that driver responses supported hypotheses generated from the TPB and EMGDB, indicating that better alignment between the feedback design and implementation and those theories could result in more effective feedback (Stillwater & Kurani, 2011). The results of that study indicated that an in-vehicle interface could be more effective if it targeted the hypothesized behavioral factors – a conclusion and general methodology that led directly to the design of the interface presented here.

2.1 DESCRIPTION OF THE EXPERIMENT

A driver feedback experiment was conducted in California's Yolo, Solano, and Sacramento Counties from September 2009 to September 2010 with 24 households and 46 individual drivers. The experiment was conducted as a part of the UC Davis Plug-in Hybrid Electric Vehicle (PHEV) Demonstration in which households drove a PHEV for a month in place of one of their own vehicles (Kurani et al., 2010). Households for the feedback experiment were selected from the pool of respondents for the PHEV demonstration. The respondents included a demographically wide range of individuals, from middle to high income, young to retirement-age adults, and single occupant to multi-member households.

The PHEVs used in the experiment were model-year 2008 Toyota Priuses modified to operate as plug-in hybrids. The conversions used the standard Prius drivetrain, so the electric driving potential was limited in the same way as a standard Prius. In general this meant that the vehicle would operate on electricity-only under light to moderate accelerations and under 35 mph. At higher power demand or speeds, as well as after the conversion-battery is depleted, the vehicle would blend energy from its gasoline and electric energy sources.

Each vehicle was outfitted with a custom feedback device measuring 7 in. by 5 in. mounted directly over the standard center console screen. The original Prius energy display was covered by the custom device for the duration of the experiment, i.e., during both the baseline and treatment phases. The large majority of drivers had no prior EV or PHEV experience prior to the experiment. A few drivers owned or had driven standard (hybrid) Toyota Priuses.

During the first two weeks of the vehicle placement the experimental interface showed only the PHEV battery state of charge, simulating information that a commercial PHEV would have. At the beginning of the second two-week period, the interface was modified to display a variety of energy economy, cost, and emissions information in driver-selectable panels. The subjects were given a pamphlet describing the meaning of each panel, although no ecodriving training or encouragement was given to the subjects and the term "ecodriving" was not used with the participants.

The subjects participated in semi-structured interviews in which they discussed the PHEV experience in general and the experience of using the interface in particular; interviews were conducted at the beginning, middle, and end of the experiment, although only the final interviews are used in this study, as those interviews are the only ones that occurred after the experimental interface was seen by the participants. Drivers completed a questionnaire measuring goals and attitudes at the start of the experiment, at the midpoint when the interface was activated, and again at the end. Finally, a data-logger recorded vehicle performance throughout the course of the experiment. The mixed-method experimental design made it possible to record and analyze the verbal responses of drivers to the introduction of feedback using interviews, as well as to experimentally determine both if and how hypothesized psychological factors such as perceived behavioral control and goal setting influence driver

behavior and energy outcomes. A preliminary quantitative analysis of energy outcomes and survey responses is presented in (Stillwater, 2011). The survey responses and driving data will be incorporated into a future paper estimating the importance of these factors in the effectiveness of the feedback, but neither is reported here.

2.2 INTERFACE THEORY AND DESIGN

The interface shown in Figure 2 was designed to test feedback designs and metrics suggested by the conceptual framework of the TPB and the EMGDB, as shown in Figure 1. The interface design, energy economy metric, and design of the individual display panels are described below.
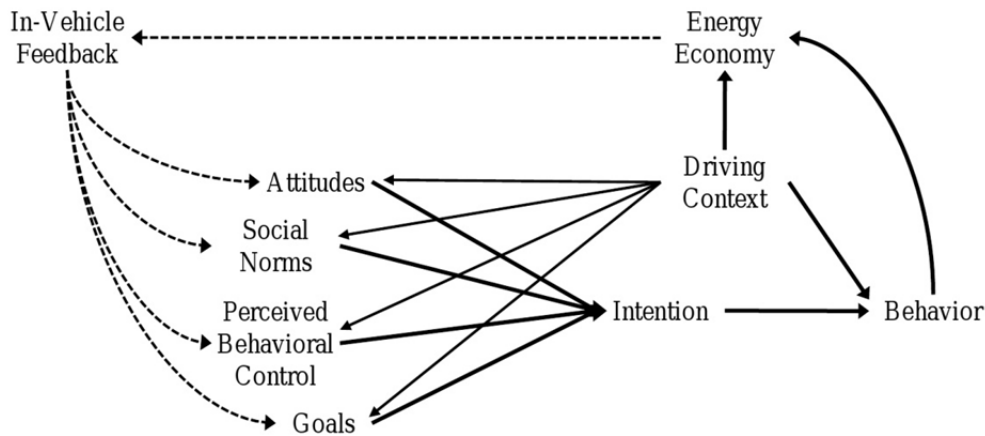

FIGURE 1 The Theoretical Framework Used to Design the Interface, based on the TPB and EMGDB (shown using solid lines) adapted to the driver behavior context for this study. The closed-loop feedback system created by the introduction of in-vehicle feedback is shown using dotted lines.

2.2.1 Use of the Energy Economy Measure MPG+

Based on the results of a separate analysis (Stillwater, 2011), drivers were shown "energy economy" rather than fuel economy. Because the vehicles were PHEVs, energy economy incorporates electricity and gasoline, as well as kinetic and potential energy to more accurately depict the vehicle's energy use and efficiency in real-time operation. Because the vehicles are hybrids, kinetic and potential energy can be partly recaptured; because they are plug-in hybrids, we must account for energy stored in the conversion battery from the electrical grid. This energy economy measure was converted into units of gallons of gasoline equivalent (one gallon of gasoline is equivalent to approximately 33kwh), making this measure similar to a real-time equivalent of the new MPGe measure used by the Environmental Protection Agency (EPA) in fuel economy labels for multi-fuel and electric vehicles ("New Fuel Economy and Environment Labels for a New Generation of Vehicles," 2011). Energy economy was displayed as "MPG+" (pronounced MPG plus) to aid in driver comprehension and comparison to standard fuel economy.

2.2.2 Information Layout, Personalization, and Driver Interaction

To aid drivers in observing changes in energy economyand achieving any goals they may have set (as well as to make detailed data analysis possible), the interface was personalized for each driver. At the start of a trip, the driver was prompted to sign in by selecting her name on the touch-screen interface. The interface then displayed a layout, personal MPG+ goal (shown visually as a goal-line on the MPG+ panels), and driving history based on saved driver data.

Each interface also recorded fuel cost and electricity cost on a dollar-per-gallon and cent-per-kWh basis, and this data was shared among all users of the same vehicle and was used in calculations of driving cost. Driver's specified their electricity and gasoline prices for these calculations.
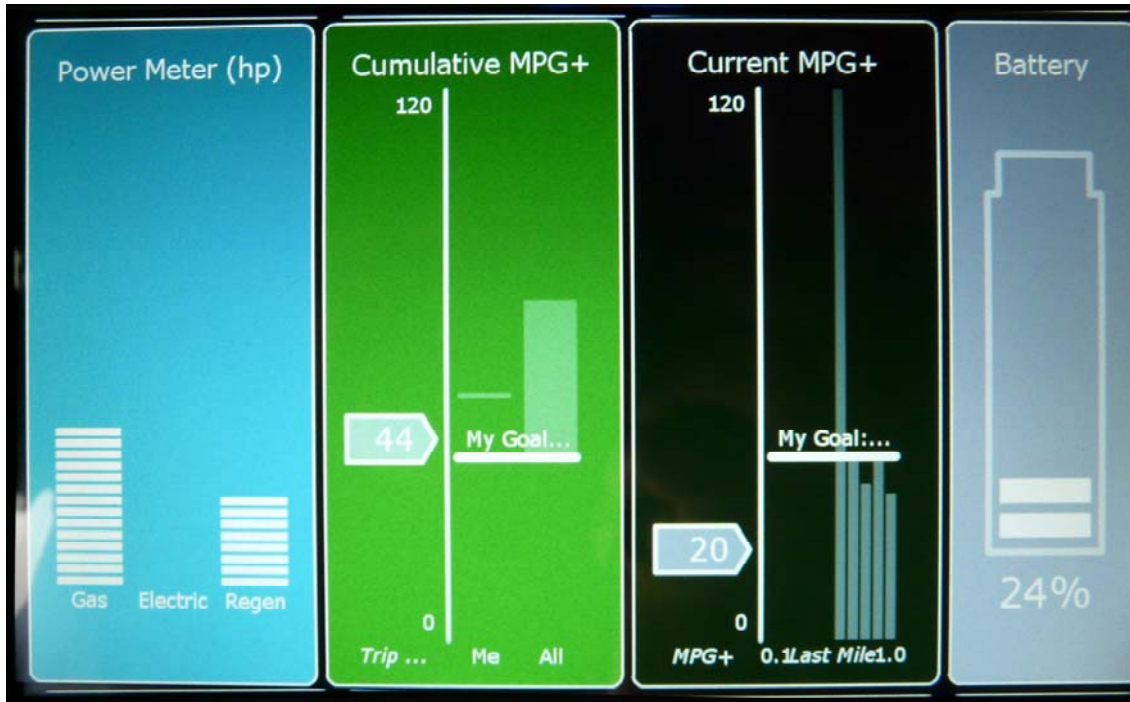

FIGURE 2 Example Interface Layout during "Interface On" Period. From left: The Power Meter shows real-time gasoline, electric motor, and regenerative braking in HP; The Cumulative MPG panel shows round-trip MPG+ (the left arrow) in relation to the driver's MPG+ history and peer history of MPG+ at the current distance (ranges on the right of the panel), and the driver's personal MPG+ goal-line; The Current MPG+ panel shows the real-time MPG+ of the vehicle in the left arrow, and the average MPG+ of the previous 10 consecutive 1/10th mile periods on the right of the panel. The personal MPG+ goal is also shown; The battery state-of-charge is on the right. The driver goal is a MPG+ value that defaults to 40MPG+, but can be changed to any number by the driver at the start of a trip, and is preserved between trips. The "My Goal" line is then raised or lowered to match the selected value. The MPG+ panels change color based on the relationship of the current vehicle value (on the left arrow of each panel) and the goal line. Surpassing the goal-line leads to brighter, greener coloring of the panel.

Using the touch-screen display, drivers were also able to input information such as their MPG+ goal and fuel prices, and modify the layout of the information on the screen. Users were instructed on how to manipulate the panels and options, and drivers were asked to input data or modify the display only while the vehicle was stopped to avoid on-road distraction.

2.2.3 Panel Descriptions
The interface design included a variety of metrics inspired by the TPB and EMGDB as well as prior research (Stillwater, 2011; Stillwater & Kurani, 2011). To focus specifically on quantitative feedback, motivational feedback such as statements of achievement like "good job", and emotive information (such as smiley faces or other imagery) were both avoided. Driver education or training materials were excluded from the study as well. The selected feedback metrics, all

presented to drivers numerically or in bar-chart format, and corresponding theoretical factors are described in Table 1.

TABLE 1 Descriptions of the Experimental Interface Information Panels.

Panel	Description and Connection to behavior theories
Power Meter (Shown in Figure 2)	The power meter provides the driver with information about vehicle operations, building perceived behavioral control. The meter shows (from left) power from gasoline, electricity, and regenerative braking, all scaled to kilowatts (kW). The scale extends from zero to 20kw. This upper power limit corresponds to the limit of the 2008 Prius electric drive power. Thus, it indicates the potential for all electric driving, although whether or not the vehicle actually maintained all electric drive was a function of the control system and battery state of charge, in addition to driver behavior. The power screen can be used to help achieve goals about maintaining the vehicle in all electric operation.
Cumulative MPG+ (Shown in Figure 2)	Trip average MPG+ provides users with trip-level outcomes and compares the trip average directly to the personalized driver MPG+ goal. The MPG+ goal had a default value of 40MPG+, which was the average energy economy of a previous group of drivers not included in the feedback experiment. The driver could modify the personal goal could be modified at any time and each driver's goal was displayed for them. Personal historical ("Me" in Figure 2) and Peer ("All" in Figure 2) MPG+ ranges were shown to encourage comparisons to similar previous trips (where trips are grouped by pre-set distance categories). These may enhance drivers' perceived behavioral control and provide a social comparison to encourage goal setting and achievement.
Current MPG+ (Shown in Figure 2)	Display of the current MPG+ enables drivers to modify their behavior and see instant results, thereby increasing perceptions of behavioral control, and helping them achieve MPG+ goals. 1/10th mile average MPG+ bars help display contextual information about the previous mile of driving that may encourage goal achievement or a better understanding of the relationship between the driving context, behavior, and outcome energy economy.
Cost per 100 miles (Available to a subset of Drivers)	This panel is an instantaneous measure of cost that could motivate more financially economical driving behavior. The cost information is hypothesized to influence the behavior of drivers who reported strong attitudes or goals related to cost.
Total cost (Available to a subset of Drivers)	This panel estimates total trip cost based on driver-defined gas and electricity prices. The panel makes the cost of each trip explicit, potentially motivating more economical driving habits related to a driver goal of saving money.
Lb. CO_2 per mile (Available to a subset of Drivers)	This panel provides direct CO_2 feedback based on current driving conditions and actions for those interested in reducing environmental impacts. The emissions information is hypothesized to influence the behavior of drivers who reported strong attitudes or goals related to the environment.
Total CO_2 (Available to a subset of Drivers)	This panel provides a cumulative CO_2 measure for the trip, showing the total (CO_2) environmental impact.

2.2.4 Panel Sub-groups

To explore the effect of variations in the design of the interface including the addition of more information on the screen as well as cost and emissions information, four sub-groups received distinct designs based on the set of available panels shown in Table 1. The panel sub-groups 1 through 4 in Table 2 vary by complexity (either three or four simultaneous information panels), available information (groups 3 and 4, termed the "comprehensive information set," include four optional Cost and CO2 panels), and color display style (groups 3 and 4 used continuous color gradients rather than discrete color shifts). The decision to change the way the colors were

presented was based on user feedback that discrete color changes looked like flashes and were distracting.

TABLE 2 Descriptions of the Experimental Interface Information Panels.

Group	Complexity (# panels)	Feedback Options						Screen Colors
1	3	Battery	Cumulative MPG+	Current MPG+	-	-	-	Discrete
2	4	Battery	Cumulative MPG+	Current MPG+	Power	-	-	Discrete
3	4	Battery	Cumulative MPG+	Current MPG+	Power	Cost (all)	CO_2 (all)	Continuous
4	3	Battery	Cumulative MPG+	Current MPG+	Power	Cost (all)	CO_2 (all)	Continuous

Battery, Cumulative and Current MPG+ panels were available to all groups. In the latter two of these panels, participants were free to set their MPG+ goal. If they did not set a goal, the goal would default to 40MPG+, which was the average MPG+ of a prior set of drivers not included in this experiment. Groups 1 and 2 had a pre-set arrangement of the panels, although participants could turn off individual panels (leaving a blank area). Groups 3 and 4 had a wider range of available panels (eight in all including the battery state-of-charge), and were able to choose which panels to display. User preferences such as the MPG+ goal, fuel cost, panel selection, as well as a driving history (which was displayed as a part of the cumulative MPG+ panel as shown in Figure 2) were retained for each participant and automatically reloaded at the start of each trip after a driver selected her name from the entry screen.

2.3 Interface Technology
Tablet computers running Adobe Flash in Windows XP were used for the interface, providing a programming platform with a flexible graphical interface. The tablets were further modified to enable them to switch on automatically each time the vehicle was started, and were powered through the vehicle 12v system using a custom electrical harness. To conserve the 12v battery, the units entered a hibernation mode when the vehicle was turned off. A separate data-logger unit interpreted the raw vehicle data red from the OBDII port and relayed it to the tablet using a wireless router. Cables were concealed within the vehicle upholstery and dashboard so that the overall appearance was much like the OEM console display.

2.4 ANALYTICAL METHODOLOGY
The analysis is based on the participant interviews after two weeks of exposure to the interface. Interviews were semi-structured and broadly addressed the use, charging, and experience of driving a PHEV, with special emphasis on the interface. Quantitative measures of changes in driving behavior are presented elsewhere (Stillwater, 2011). Overall, 46 individuals were interviewed; 44 reported driving the vehicle during both phases of the interface experiment.

The semi-structured interviews allowed participants to generally lead the discussion into areas of interest to them. However, if a participant did not mention her response to the interface, the interviewer prompted her to remember the introduction of the interface and describe if she looked at it or altered her behavior in any way due to it. At the completion of the study the interview transcripts were processed using the Keyword In Context (KWIC) methodology, in

which relevant sections of the transcripts are identified using broad keyword searches, and then individually coded for themes (Stillwater & Kurani, 2011; Weber, 1984). Four hundred statements about the interface were identified using KWIC and read in order to identify themes related to the behavioral hypotheses. The statements were first grouped by theme, for instance, "goals," and then sub-themes within each were identified. Finally, the statements were re-read to ensure the clarity and consistency of the themes and sub-themes.

   To avoid double-counting similar statements from the same individual, repeated statements by one individual about behavior change due to a particular aspect of the interface were removed such that a list of unique participant-theme pairs was generated. These lists were then tallied and are shown in Figure 3 for an overall view of how many drivers reported ecodriving due to particular aspects of the feedback. Separate tallies of any behavior change and reported distraction are also included.

   In addition, a discussion of each theme is presented along with representative statements from the participants, identified by an interview code and gender. In some cases the statements are edited slightly for readability, but the words are the participants not the researchers. Excerpted text is shown using an ellipsis; brackets surround text added by the authors for clarity.

3.1 RESULTS

The behavioral theories TPB and EMGDB posit that setting goals, increasing perceived behavioral control, information relevant to attitudes about driving, and the presentation of such information in social contexts will facilitate increases in MPG+. The feedback design presented in this study tested the ability of driving data to facilitate behavior change through direct feedback to the driver within this theoretical framework. The hypothesized relationships described in Table 1 are explored in the analysis of the interview transcripts, both through a tally of how many drivers used each information type to attempt to drive more efficiently (Figure 3) and through direct interpretation of the driver statements themselves.

   The interview results generally support that goal setting was important for drivers to relate to the feedback in situations that lent themselves to goal-setting, such as average MPG+ over time and periods of all-electric driving. In addition, drivers were not restricted to goals introduced by the researchers, but set performance goals based on all-electric driving when power feedback was introduced that made periods of all-electric driving clear. Although translations of energy economy feedback information into cost and CO_2 were important to behavior change when drivers were given the additional feedback options, these types of information did not lend themselves to goal-setting due to the lack of clear points at which performance could be deemed successful, e.g., lower cost and CO_2 are always preferred, but these values can never reach zero.

   It is clear from the tallies of user reports of behavior change that the interface creates a strong framing effect (Kahneman, 2011), i.e., individuals presented with specific information tend to focus their thoughts and behavior on it. The high proportion of participants who accepted the default driver goal, and yet responded strongly to it also suggests an anchoring effect, i.e., wherein arbitrary values placed in relation to information of interest influence user's understanding of what values may be considered high or low, was important to the driver experience of the feedback.

Basic Energy Information Set

■ 3 panel ■ 4 panel

Comprehensive Information Set
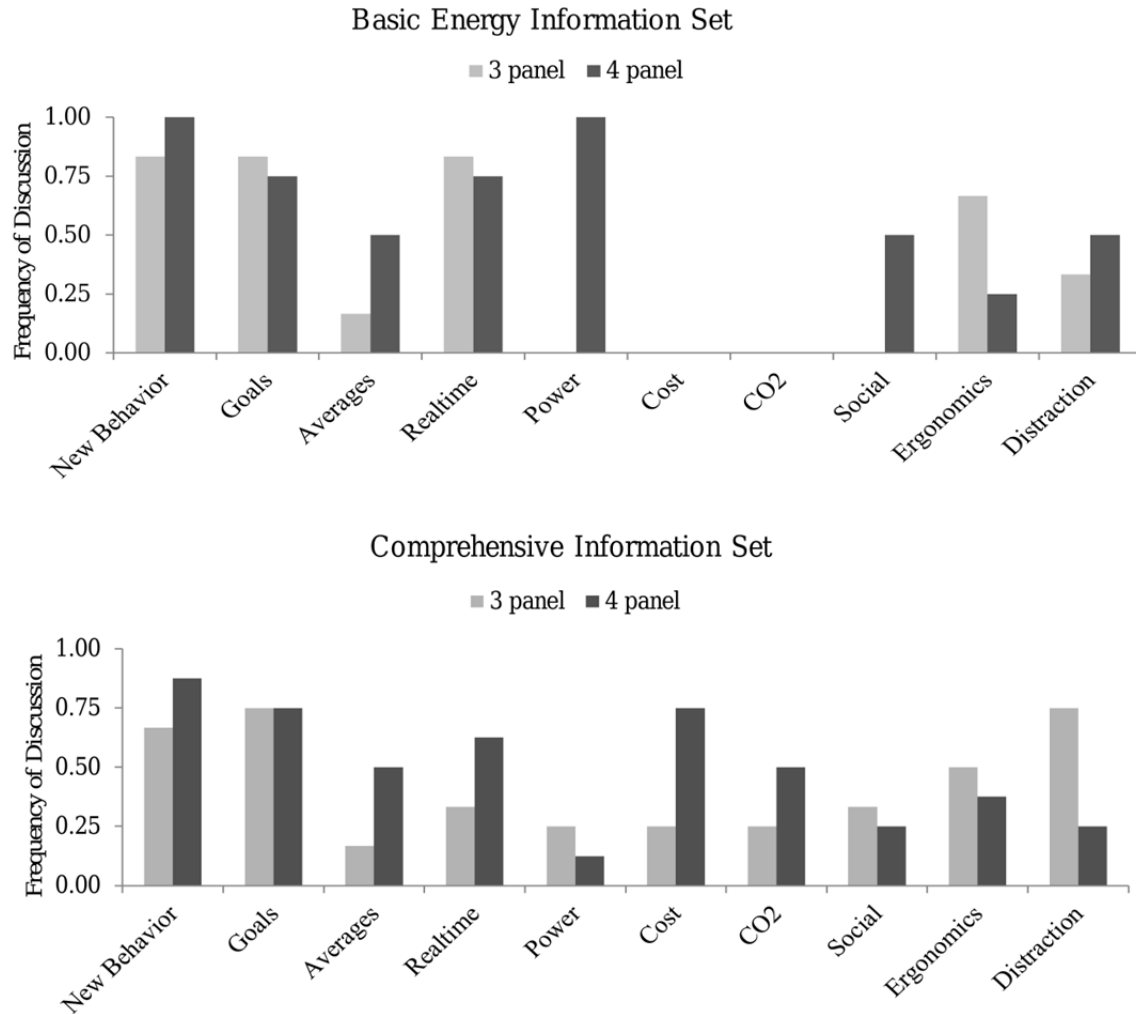
■ 3 panel ■ 4 panel

FIGURE 3 Proportion of Driver Responses Indicating Use of the Interface for New Ecodriving Behaviors by Information Type and Overall. Responses are shown individually for each display sub-group. Proportions are based on the number of respondents for each display sub-group. For the information types (real-time, average, and goal information) only responses that indicated that they were used to support or motivate ecodriving behaviors were included in the tally.

3.1.1 Real-Time MPG+

Overall, the real-time feedback showing current MPG+ and 1/10th mile averages was the most talked about information and resulted in the strongest positive statements of curiosity, excitement, and use. The responses indicate that the use of real-time feedback has three main positive effects: experimentation with new behaviors, motivation for short periods of high achievement, and fine control over the vehicle using the feedback as a guide. The use of the real-time feedback for experimentation was important for drivers to develop accurate perceived behavioral control that could later be used to sustain high levels of performance. The real-time MPG+ information therefore directly supports the TPB construct of perceived behavioral control. Driver observations of high MPG+ were also exciting and motivating, an outcome that indicates the importance of instant feedback, even if momentarily high MPG+ values are not sustainable over time, i.e., drivers could often reach greater than 100MPG+ for a few minutes, but whole

rarely could reach above 50MPG+ for whole trips. For some drivers, however, the rapidly fluctuating real-time values created confusion and resulted in disengagement. It seems likely that these individuals did not have enough basic knowledge of vehicle operations to make sense of the numbers.

3.1.1.1 Experimentation and Learning

176208 Male: [the interface] tells me a lot here about what acceleration does in terms of mileage. I mean, I knew that intellectually, but, again, to have that visual feedback it was really quite striking. It was powerful for me.

176204 Female: Well when I was out on the road, you know, if I varied my speed at all it would cause [the Real-time MPG+] to drop.

175309 Male: I caught myself paying a lot more attention to it to see what happened when I would start up a grade and when I would go downhill. I mean, you take your foot off the gas, when you start braking, right up to the top. You know, you get on a long downhill and, man, it'd show you like you're getting like a 180 miles per gallon. It was kind of fun.

3.1.1.2 Motivation

176206 Male: … Real time feedback on what you're doing and it's like the machines at the gym, you know. When you're on there you can see your heart rate and … your calories that you're burning. I mean, it's a great incentive.

175308 Male: I preferred the [Real-time MPG+] because it was constant and it was right now. It gave me current information... it was like, okay, you know, you're down here possibly below 40 what are the conditions and how can you change ... to get that higher?

3.1.1.3 Using Feedback to Control MPG+

175107 Male: … I like it because I could adjust my pressure on the pedal, and you could see the gas mileage go up and you could ... maybe just decrease -- let's say you're doing 67 [mph]on the freeway, 68 and get back down to 65 or just below that you could see a dramatic change.

175308 Female: Yeah, because it told you what you were doing right then so you could actually do something about it. I drive in traffic a lot though, so for me my patterns were interrupted by people cutting in, and slowing down, and stopping.

176206 Male #2: And even when I went up a small hill I would decelerate more, because normally, I mean, if I'm driving any other vehicle I'll usually keep it so that my speed is the same, and I'll obviously make the car work harder, whereas when I saw exactly what my numbers were on the Prius I would decelerate when going up even minor hills just to keep my efficiency up, regardless of my speed.

3.1.1.4 Extension to Other Vehicles

175314 Male: It did cause me to move my indicator on the mode on the Sequoia [one of the household's own vehicles] from just telling me the temperature outside and what direction I'm driving, to what is my instant gas mileage.

176208 Female: I thought it would be cool to have that in every car so you could kind of watch in the moment.

3.1.1.5 Confusion

175314 Female: I could never know what speed was [optimal], You know what I mean? So, it wasn't like I could correlate [his] driving with that. It was just you could see on the freeway versus on the street and that's it.

176204 Female: ...what did I just do that made it go to 170... miles per gallon? What did I just do that made it drop to 20? But I wasn't able to find the pattern I found it a little frustrating. But that's me.

3.1.2 Trip Average MPG+, Goals, and Game Playing

The goal-line display was a common way for drivers to find meaning in the fuel-economy numbers. The goal provided a standard against which the instantaneous or trip average could be compared, showing a close relationship between the goal and the feedback time period. Numerous drivers customized the goal to be increasingly ambitious or simply to reflect a better sense of their control over energy economy. Even drivers that simply accepted the default goal value (no explanation of the origin of the default value was given to participants) responded to it as if it had personal meaning, suggesting that even goals originating from outside the individual can be motivating.

A number of drivers referred to their experience driving with energy feedback as "playing a game," a statement that may simply indicate they enjoy the experience, or may suggest a true similarity between games and energy feedback. Many games share TPB and EMGDB concepts such as multiple levels of performance summaries (in game points, level summaries, and end-of game summaries), goal achievement (high scores and competition), and personalization (personal scores and lists of named high scores).

3.1.2.1 Goal Achievement Using the Average Panel

175308 Male: I would only look at it towards the end of my trip, saying, okay, this is what it was for my trip. It wasn't as needed, not necessarily needed but you just didn't look at it as much because it was what it was. And so you really didn't change how you were driving versus when you were looking at the [Real-time MPG+]...

176204 Female: I'm not going to ... reach that goal so maybe I should get it down here [reduce my personal goal] so I'm in the green [achieving the goal and causing the screen to turn green]. No, that's cheating. So I just left it there [at 40MPG+].

3.1.2.2 Playing Games with the Average

175308 Male: Yeah. Like a little game in a sense. You say, okay, how can I drive to get it up to 70 miles per gallon or whatever.

176206 Male #2: It was a game for me. I started seeing it … then I had your cumulative MPG+ and I just tried to get that as high as I could.

3.1.3 Social Comparisons

The distance-based peer energy economy range showed the range of MPG+ from the 5th to the 95th percentiles of previous drivers at similar trip distances (Figure 2, panel 2 from left). It received little attention from drivers, possibly because of the oversimplified labeling system. Some drivers specifically referred to the social information as not being useful, indicating this

presentation of a peer comparison is not a clear motivating factor. One problem with the social comparison could be that the range (5th -95th percentiles) of previous MPG+ scores at the distance of the current trip was so broad that it may have been too difficult for drivers to find a reasonable reference point for a goal. A narrower range of prior peer outcomes, presentation as quantiles, or a simple ranking system might be more motivating to more drivers.

3.1.3.1 Using Personal and Peer Distance-Based Comparisons
176207 Male: I did like the fact that you had combined our scores against all the other users of the other cars that you have going. That I thought was interesting just comparing different driving styles.
176205 Male 1: At the beginning I just drove it kind of normally until later on I guess I got interested to find out if I could like meet my goal and kind of be the one to use the least amount of gas or something like that. So I started to … drive in a way to save the most amount of gas, but … it wasn't really efficient. So I pretty much resumed back to my normal driving habit.

3.1.3.2 Not Interested in Personal and Peer Distance-Based Comparisons
175308 Male: That really wasn't as useful because for me it was just saying, okay, there's the range but you don't know what they were getting. And you really can't do anything about it so it was just like you can only worry about yourself...
175107 Female: …as far as the other screen … everybody else and then me, … that doesn't make any difference. I don't know why that even was there.

3.1.4 Power Information
Unlike the energy economy panels, the power panel showed the magnitudes of the current energy use of the gas engine, electric motor, and regenerative braking scaled to horsepower. When the vehicle used less than 10kw of total power, the screen would be bright blue, and it would decrease in brightness as more power was used.

Power information motivated ecodriving experimentation in all the drivers who saw only the core energy and power panels (group 2), but was not nearly as influential when drivers had a choice over which panels to view (groups 3 and 4). One reason the power information was so influential for those that saw it is that it had a direct connection to behavior (easing back on the pedal leads to less power and therefore a higher proportion of electricity), whereas the other panels have a more complex, and occasionally inscrutable, relationship to drivers' behaviors.

The power panel had a mixed influence on drivers depending on their area of focus. One beneficial effect of the power information was that it helped some drivers understand basic vehicle operations, e.g., the PHEV electric drive was limited to 10kw, and allow them to make sense of an otherwise hidden internal hybrid control system. For other drivers the panel was used as a predefined all-electric driving goal, although the limited number of situations in which all-electric driving was possible was a source of frustration. For others, the regenerative braking was understood to be a positive result, causing confusion about what driving style would result in the lowest energy use, e.g., is it better to coast to a stop and not generate electricity, or slow down abruptly and generate more electricity?

3.1.4.1 Learning About Vehicle Operations
174507 Male 2:   ...it really helped when we had the second phase where you were showing us, you know, what was going on. And so it was kind of interesting, sometimes when I thought it was just running on battery it was running on gas. But I like to get it so that the thing would, you know, come up to the stop, and then I'll just kind of shut down and then take off real slow, see if I could hold that battery, run it the whole way.

3.1.4.2 Frustration with the Implied Goal of All Electric Driving
175310 Female: Okay. So if it was a longer stretch and not start/stop/start, which I have a lot of start/stop from here to work, if it was a longer stretch, like, if I hit all the lights right going down Walnut, I stay in the black [high power] until I get to that first, probably, light which is a couple blocks [to a left turn], and then I can keep it in the bright blue [low power] for a long time if I don't have to stop. And then I get irritated when I have to stop, I'm like "God bless America, now I'm going to be in the black."

3.1.5 CO$_2$ Information

The most common theme from statements about the CO$_2$ information is that drivers were surprised by the large amount of CO$_2$ that the test vehicle was emitting. However, none of the drivers interviewed had a context in which to understand the reported CO$_2$ values. This suggests that the drivers don't have enough basic knowledge to understand CO$_2$ feedback in numeric form and without a predefined anchor, such as a CO$_2$ goal.

Driver interest in CO$_2$ information seemed to be consistent across members of the same household, indicating that environmental values or at least a dialogue about them are shared among household members. This indicates that CO$_2$, if placed within a clear and meaningful context, has the potential to provide the basis for a more motivating social comparison than MPG+; in particular, peer or household emissions could provide the needed context for a CO$_2$ reduction goal.

176207 Female: It was interesting to see, okay, that's how many pounds of CO$_2$ you put out, but I have no frame of reference as to what that equates to.
176207 Male: [I] didn't have any real usage for the CO$_2$ output because I don't know comparatively what that is.
176206 Male #2: I'm really not familiar with how much CO$_2$ a regular car puts out, so I wasn't too familiar with that.
176206 Male: And it seemed high, I mean, given the -- you know, that it's a hybrid. So, that was the only thought I had and then I immediately just put it out of my mind, because I don't like to think about the poison, you know, that I add into the environment. I thought it was really high, so I wondered what it is for regular cars. I said, oh, my God.

3.1.6 Cost Information

Cost information was interesting to many of the drivers who saw it; for them, it was useful for motivating behavior change. However, for most drivers who saw it the trip cost information was seen as useful for budgeting but didn't motivate energy savings. Indeed, some drivers were

pleasantly surprised by how inexpensive trips were; indicating that in some situations accurate cost information may actually discourage conservation behaviors. Among those drivers who did not see cost information, the concept of ecodriving to save money did not appear to occur to them. Cost was not discussed by drivers regarding ecodriving behaviors, even when presented information on energy, but not cost, savings. Although cost feedback could be an important motivating factor to eco-drive (as evidenced by those who did see it), it must be introduced via feedback (or potentially prior education or other driver training, neither of which was studied here).

Figure 3 also showed that cost was of interest to drivers mainly when it was available in addition to more primary feedback such as Cumulative and real time MPG+, shown by the increase in interest in cost information in the four-panel rather than the three-panel group.

175312 Male: Well, it's interesting to see, like as you're driving to see what type of gas mileage you're getting and also the screen that shows you how much you've spent is also useful.

176207 Female: ... yeah, it's very expensive to sit and idle.

176207 Female: Generally I'm so busy I'm pushing to get from one appointment to the next, but, you know, it's like there was just times I left a little bit early for work and I could just kind of relax and watch those costs go down a little bit. It was fascinating to watch. I could see if you were on a real conscious level you could save money doing that.

176206 Male #2: I was like, oh, my God, look at this. Look at my inefficiency at getting from point A to point B, as far as money goes. But as far as time went, I saved time, but I definitely enjoyed seeing the hard evidence right in front of me of how I was driving and how that affected my cost.

174912 Female: I remember seeing that, so that's not a lot, and I said, wow, a whole dollar to do all this stuff. That's pretty good.

174809 Female: And you know, sometimes you don't even look at the dollar amount because you have to buy it anyway, and so, you know.

3.1.7 Distraction

Many drivers reported various levels of distraction by the interface. Much like the responses to the OEM Prius display found previously (Stillwater & Kurani, 2011), drivers reported that the interface took attention away from the road, but also that they practiced a certain amount of self-regulation by deciding not to watch the interface if it seemed too distracting.

One important difference between the interface and other sources of in-vehicle distraction is that the interface may promote safer driving habits. Drivers who paid attention to the interface and changed their behavior reported increasing following distances and driving at lower speeds, two behaviors that normally reduce the propensity to have driving accidents (Carsten, Lai, Chorlton, Carslaw, & Hess, 2008; Young, Birrell, & Stanton, 2011). Further, recent driving simulator research testing the safety of "smart driving aids" such as ecodriving or navigational feedback suggests these aids do lead to safer driving habits even when drivers report increased cognitive load or distraction from the information (Birrell & Young, 2011).

175107 Female: It was just distracting, and then it's like, what, every tenth of a mile how much I was getting and it goes up and down and up and down and it changes colors. It changes colors. I'm going, oh, look, it's black, oh, yea, you know, oh, God, I'm

doing something wrong, and it -- you know, it's just not something I felt was comfortable.

176204 Female: And you've got to scan everything when you're in traffic, especially, front and back, and so you drive, you operate your car a little bit on remote. And I have not learned, I guess, on remote I'm not as efficient as I am when I'm paying attention to that little screen. Out in the country, you're on these roads, yeah, you have to scan, you're watching for the dog or the car pulling out, but you got a little more attention span that you can give to the efficiency.

174809 Male: I would just say no, I'm not going to even look at the screen. I'm just going to drive the car.

4. CONCLUSIONS

Design of an experimental interface to provide energy feedback to drivers was grounded in the Theory of Planned Behavior (Ajzen, 1980) and the Extended Model of Goal Directed Behavior (Perugini & Conner, 2000), leading to the inclusion of personal goals and social performance in the feedback. The interface was deployed in a plug-in hybrid electric vehicle (PHEV) demonstration project. Households drove the PHEV without energy feedback for two weeks, and then drove with feedback for two weeks.

A qualitative assessment of drivers' accounts of their experience with the interface reveals that overall, the interface design was successful in displaying contextually and behaviorally relevant energy data as well as inspiring the drivers to use the interface as a tool to gain control over energy use. Response to the feedback varied across individuals, but a number of themes were repeated by many drivers in their interviews. In particular, feedback on real-time energy economy and power in the PHEV were useful to prompt and support experimentation and learning. Drivers compared trip averages with their goals to motivate behavior changes. To many drivers, trip average scores were a kind of high-score in what became competitive or game-like situations. Drivers reported learning from the real-time measures about the impact of their behavior in the moment. However, for others real-time information had an opposite effect. For this group the real-time measure merely "showed them what the car was doing," suggesting that some individuals require other sources of education or motivation before they will make use of the instantaneous information.

Having a personal goal integrated in the feedback system was especially important to the drivers' experiences. Setting an energy economy goal provided a metric by which drivers could judge the otherwise non-normative information. This may be the primary reason driver's verbal responses to the MPG+ feedback was so much more positive than the CO_2 feedback which did not afford them an opportunity to set a goal and was otherwise not anchored to an initial value. In this way, a goal and a trip average metric worked in tandem to encourage ecodriving. Many individuals customized their MPG+ goal to suit their level of effort or drive-cycle, and generally goal achievement was described by positive feelings. The personalized goal was most important for the experiences of individuals who were motivated by increasing the goal to reach higher targets.

In total, three-fourths of the participants used some sort of goal to motivate new ecodriving behaviors. Common goals invented by participants besides the MPG+ goal included in the interface were maintaining periods of all-electric driving and achieving greater distance driven using battery power. A few individuals also spoke of per-tank of gasoline or other longer term MPG+ goals that they would have liked the interface to provide.

The hypotheses that goal setting for real-time and trip-average energy feedback would motivate behavior change are generally supported by drivers' statements; quantitative measures of changes in energy are described elsewhere (Stillwater, 2011). Much less clear is whether placing feedback within social contexts might influence driver behavior. Only a small minority of drivers found the particular peer-comparisons deployed in this study useful, an indication that the information was not clearly presented, a poor metric was displayed, or that social information was simply not as critical to the driver experience as the other available information. Many drivers claimed that the high variability across drivers of MPG+ made the social feedback irrelevant for their personal situation.

The most important contribution of the theory is from the EMGDB: the inclusion of a personal goal that could be easily compared to the trip average MPG+ was an important factor in driver motivation. Goal setting reinforced driver motivation to ecodrive and allowed drivers to set more aggressive goals as they became more proficient or ambitious. Goal setting is relatively simple to implement and could be easily and widely applied to any commercial interface system.

Finally, it is clear from driver interviews and the resulting tally of themes (Figure 3), that the information content of the interface plays a critical role in both framing and anchoring drivers' personal interest in, and motivation to, ecodrive. The content of the interface plays a direct role in framing which outcome is important to drivers, e.g., maximizing MPG or savings, or minimizing CO_2. The design of the interface and inclusion of goals then anchor the drivers' interpretation of their own driving performance. In this case, the explicit setting of a personal MPG+ goal was seen as the most crucial motivating factor. Still, the goal of all-electric driving was even more motivating for drivers who were presented with the PHEV power mix—gasoline, electricity, and regenerative braking.

5. Recommendations for Energy Feedback Design

The results suggest the importance not only of energy, cost, and emissions feedback and personal goals in motivating drivers to ecodrive, but also that interface design is intimately linked to drivers' propensity to form and act on reasonable goals. This study only tested a few types of feedback information and design on drivers' self-reports of engagement in new ecodriving behaviors. Feedback designs were simple graphical and numerical displays presenting quantitative information. The use of different color and color gradients would have allowed drivers to simplify their interpretations even further. No educational, training, or coaching materials were tested.

However, interviews with drivers yield these insights into the motivational and informational power of certain types of feedback.

- A primary effect of the feedback is to frame the driving experience as an exercise in efficiency, cost, or emissions savings. This is particularly clear from the results shown in Figure 3, where only drivers that saw power, cost, or CO_2 feedback described finding those factors as important for their motivation to ecodrive.
- Building goal setting into the feedback provides two benefits: 1) Goals allow drivers to personalize the feedback for their own level of performance and ambition; and 2) Goals also anchor the feedback to give drivers a sense of what level of performance is reasonable. The difference in driver responses to real-time MPG+ and real-time CO_2 feedback show that without such anchors, the CO_2 feedback was confusing to most drivers -- even those who had environmental goals. In addition, goals do not need to be distinct features of the interface

(such as the goal-line tested here) to be effective. The goal to drive using only electricity was adopted by drivers when the feedback design made all-electric driving obvious.

- Upon being provided energy feedback, three-fourths of drivers reported changing their driving behavior to use less energy, though interest varied.
- Many of the drivers wanted more clarifying information about the vehicle operation and methods to reduce their fuel use such as could be provided through educational or training materials or feedback. Adding such components to what was included in the study may increase the positive effects of the feedback and reduce confusion.

GLOSSARY
Ecodriving: efficient on-road driving style
EPA: Environmental Protection Agency
MPG: Miles Per Gallon
MPGe: EPA-designated MPG equivalency used for electric or alternative fuel vehicles
MPG+: The real-time energy-economy measure used for feedback in this study
PHEV: Plug-in Hybrid Electric Vehicle

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REFERENCES

Ajzen, I. (1980). Understanding Attitudes and Predicting Social Behavior. Prentice Hall, Englewood Cliffs, NJ.

Ando, R., Nishihori, Y., & Ochi, D. (2010). Development of a System to Promote Eco-Driving and Safe-Driving. *Smart Spaces and Next Generation Wired/Wireless Networking* (Vol. 6294, pp. 207-218). Springer Berlin / Heidelberg.

Barkenbus, J. N. (2010). Eco-driving: An overlooked climate change initiative. *Energy Policy*, *38*(2), 762-769. Elsevier.

Birrell, S. a., & Young, M. S. (2011). The impact of smart driving aids on driving performance and driver distraction. *Transportation Research Part F: Traffic Psychology and Behaviour*, *14*(6), 484-493. Elsevier Ltd.

Boriboonsomsin, K., Vu, A., & Barth, M. (2010). *Eco-Driving: Pilot Evaluation of Driving Behavior Changes Among US Drivers*. University of California, Riverside.

Carsten, O., Lai, F., Chorlton, K., Carslaw, D., & Hess, S. (2008). *Speed Limit Adherence and its Effect on Road Safety and Climate Change*. University of Leeds.

Greene, D. L. (1986). *Driver Energy Conservation Awareness Training: Review and Recommendations for a National Program*. Oak Ridge National Laboratory.

Kahneman, D. (2011). *Thinking Fast and Slow*. New York, New York, USA: Farrar, Straus, and Giroux.

Kurani, K. S., Axsen, J., Caperello, N., Davies-Shawhyde, J., Dempster, P., Kempster, M., Nesbitt, K. A., et al. (2010). *Plug-in Hybrid Electric Vehicle (PHEV) Demonstration and Consumer Education, Outreach, and Market Research Program: Volumes I and II*.

Larsson, H., & Ericsson, E. (2009). The effects of an acceleration advisory tool in vehicles for reduced fuel consumption and emissions. *Transportation Research Part D: Transport and Environment*, *14*(2), 141-146. Elsevier Ltd.

Lee, H., Lee, W., & Lim, Y.-K. (2010). The effect of eco-driving system towards sustainable driving behavior. *Proceedings of the 28th of the international conference on Human factors in computing systems* (pp. 4255-4260). New York, NY, USA: ACM.

New Fuel Economy and Environment Labels for a New Generation of Vehicles. (2011). US EPA Office of Transportation and Air Quality.

Perugini, M., & Conner, M. (2000). Predicting and understanding behavioral volitions: the interplay between goals and behaviors. *European Journal of Social Psychology*, *30*(5), 705-731.

Satou, K., Shitamatsu, R., Sugimoto, M., & Kamata, E. (2010). Development of the on-board eco-driving support system. *International Scientific Journal for Alternative Energy and Ecology*, *9*(852), 35-40.

Stillwater, T. (2011). *Comprehending Consumption: The Behavioral Basis and Implementation of Driver Feedback for Reducing Vehicle Energy Use*. University of California, Davis.

Stillwater, T., & Kurani, K. (2011). Field Test of Energy Information Feedback. *Transportation Research Record: Journal of the Transportation Research Board*, *2252*(-1), 7-15.

Syed, F. U., & Filev, D. (2008). Real time Advisory System for Fuel Economy Improvement in a Hybrid Electric Vehicle. *Annual Meeting of the North American Fuzzy Information Processing Society* (pp. 1-6). IEEE.

Wahlberg, A. E. af. (2007). Long-term effects of training in economical driving: Fuel consumption, accidents, driver acceleration behavior and technical feedback. *International Journal of Industrial Ergonomics*, *37*(4), 333-343.

Weber, R. P. (1984). Computer-Aided Content Analysis: A Short Primer. *Qualitative Sociology*, *7*(1/2).

Young, M. S., Birrell, S. a, & Stanton, N. a. (2011). Safe driving in a green world: A review of driver performance benchmarks and technologies to support "smart" driving. *Applied ergonomics*, *42*(4), 533-9. Elsevier Ltd.

van der Voort, M. (2001). A prototype fuel-efficiency support tool. *Transportation Research Part C: Emerging Technologies*, *9*(4), 279-296.