Assessing the Effect of a Power-Flow Gauge on Driving Behaviors Affecting Energy Consumption

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Abstract. The objective of this study was to investigate the effects of a power-flow gauge for indicating current level of "economic" driving for a simulated electric vehicle based on drivers' acceleration and braking pedal pressing behaviors. Sixteen participants were asked to drive a driving simulator with/without integrating the power-flow gauge interface for city and highway. The mean and kurtosis (stability) of acceleration and brake pedal press positions were recorded. Results showed stable (non-aggressive) acceleration behaviors when drivers used the interface. This indicates that the presence of a power-flow gauge encouraged the drivers to maintain a relatively steady acceleration pedal position as well as how the changes in driving behavior may affect energy consumptions in forms of economic driving.

Keywords: Power-flow gauge interface, Driving behaviors, Economic-driving.

1 Introduction

With awareness rising about depleting fossil fuels, concentration on alternative energy sources for vehicles is at an all time high. Hybrid vehicles are still of some interest, but the main focus now is on electric vehicles. Due to a lack of sufficient charging stations around the world and a quickly rechargeable battery, drivers are experiencing extreme amounts of anxiety with regards to reaching their destination. As a result, it is important that drivers utilize any means of conserving energy.

For conventional internal combustion powered (gasoline engine) vehicles, historical studies have demonstrated that the modification of driving behaviors can help reduce levels of fuel consumption and emissions. This behavior is referred to as "eco-driving," a non-aggressive and smooth driving behavior. Eco-driving is thought to improve fuel economy because drivers observe the speed limit and avoid rapid acceleration [1]. Evans demonstrated that a driver could reduce fuel consumption by as much as 14% without increasing trip time by reducing acceleration levels and generally driving more 'gentle' combined with a skillful avoidance of stops [2]. Waters and Laker also found fuel savings of approximately 15% when drivers were asked to drive economically [3]. In order to provide drivers with an external guide to prevent

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non-economic driving behaviors, Larsson and Ericsson suggested an acceleration advisory tool to present advice to drivers through resistance in the accelerator pedal when they try to accelerate rapidly [4]. The empirical results demonstrated the presence of the advisory tool significantly reduced strong acceleration behaviors and affected emissions.

There have been other approaches to affect driving behaviors leading to fuel consumption; one example is the addition of a driving interface that would give feedback regarding driving behaviors. Voort et al. demonstrated a prototype of a fuel-efficiency support tool including a human-machine interface [5]. The results of their experiment showed drivers were able to reduce overall fuel consumption by 16% compared with 'normal driving' while the same drivers were only able to achieve a reduction of 9% when asked to drive fuel efficiently without the support. A recent study conducted by the National Highway Traffic Safety Administration confirmed that the addition of an interface reduced fuel consumption in gas vehicles [6] [7]. They developed several interface prototypes (FEDI: fuel economy driver interface) to provide instantaneous feedback for drivers to be aware of if their driving behaviors are energy efficient or not. Through usability testing using static conceptual prototypes, they evaluated and investigated user interpretation of several combinations of interface features (e.g., bar, symbols, and/or text) being used today [6]. Based on the findings, horizontal bars and figure representations were most usable and text increased comprehension. They then conducted an experiment using working prototypes integrated with a driving simulator [7]. The results showed that once drivers become familiar with how the FEDI works, they would be able to adjust their driving behaviors in a manner that reduces energy consumption. In addition to this study, an automotive manufacturer recently announced that an interface using a metaphor of a glass of water indicating aggressive driving behaviors is expected to decrease fuel consumption [8].

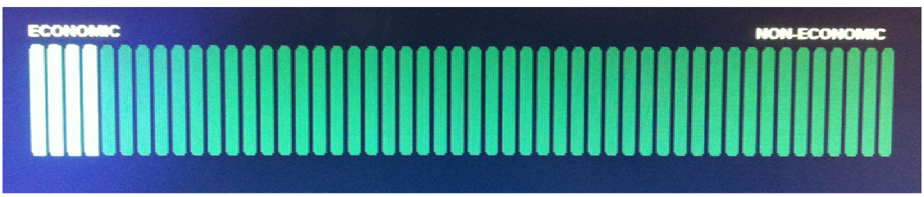
However, even though the previous studies showed effects of the interface on fuel consumption, it has been focused on conventional gas vehicles. Since not only acceleration may affect energy consumptions in electric vehicles, but braking does also (i.e., regenerative braking allows the battery to recover charge). Braking behaviors must also be examined when using such an interface. In addition, it also is necessary to investigate how the interface affects driving behaviors, such as acceleration and brake pedal pressing, which may affects energy consumption.

This study was to investigate the effect of a power-flow gauge interface on driving behaviors including acceleration and braking (potentially reducing energy consumption), in terms of human-machine interface (HMI). An experiment was conducted using a driving simulator integrated with a prototype interface. Unlike previous studies, which have focused primarily on gas vehicles, this study simulated the usage of the interface in a battery electric vehicle (BEV).

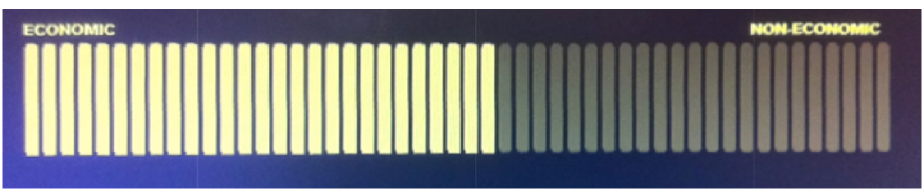
2 Methods

2.1 Prototype Interface

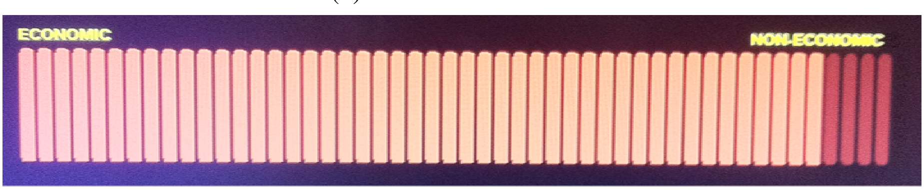
A Java-based prototype interface for displaying the power-flow gauge was developed and integrated with a driving simulator. The prototype application was designed to display the current status of economic driving to the user. The design incorporated changes of acceleration and brake pedal levels (accelerations and decelerations) and current driving speed. Aggressive and abrupt pedal presses increased the non-economic driving level and it was displayed in the interface in real-time. The graphical feature of the interface was a horizontal bar indicating the driving behavior of the driver, which was shown by Jeness et al. to be more effective [6]. A longer bar represented more non-economic driving. Along with the changes in length of the bar, the color of the indicator also gradually changed from green to red as the driver drove in a non-economic fashion (see Fig. 1 (a) through (c)). Since the interface was developed for electric vehicles, the gauge was designed to change its color to green and to show a blinking text of "Charging" when the brake pedal was pressed for stopping or slowing down the simulation vehicle (see Fig.1 (d)). In addition to this, the Java application was designed to record the values of gas and brake pedal positions as a text file. The pedal values ranged from 0 to 10000 and were recorded on every 100 msec (10 Hz).



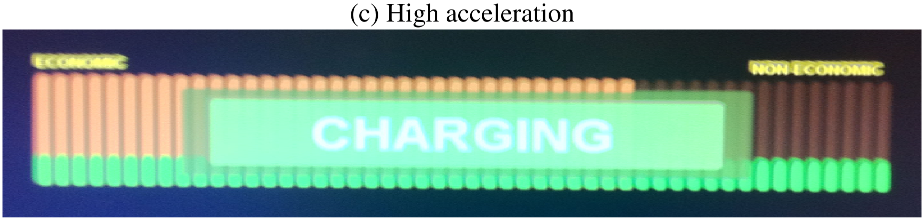
(a) Low acceleration



(b) Medium acceleration



(c) High acceleration



(d) Regenerative braking

Fig. 1. Power-Flow Gauge Conditions

Fig. 2. Driving Simulator

2.2 Experiment Setup

A driving simulator was used for the experiment, which allowed the subject to adjust the seat in two directions and the steering wheel in two directions as well. The setup included a steering wheel, a gear lever and the pedals, which are integrated with a commercial driving simulator, which simulates the driving experience. The equipment also included a projector to show driving scene and a LCD monitor to present the power-flow gauge. The Java application for the power-flow gauge was run on a PC and the gauge was displayed on the monitor in front of the driver in the place of a conventional instrument cluster. The road scene generated by the simulator software was projected on to the wall by the projector. Figure 2 shows the simulator equipment.

2.3 Participants

A total of sixteen human subjects participated in this study (mean age= 40.6 years old). Each participant was a licensed daily driver without any vision limitations or disabilities. The participants were divided into four groups according to their gender (male and female) and age (young and old). The old group represents drivers over 40 years of age and the younger drivers were from 18 to 35 years of age.

2.4 Experiment Design

As independent variables, road conditions (city roads/highway) and presence of the power-flow gauge (with/without) were manipulated in forms of a factorial design. Thus, each participant was asked to drive the simulator for four trials, consisted of two driving scenarios (road conditions) across other two conditions, the presence of the gauge. In test trials for city road driving, participants were asked to drive an urban road that required the participant to make frequent stops and turning, which were not required in the highway-driving scenario. The speed limits for city highway driving were 40km/h and 60km/h, respectively. The order of trials for participants were randomized and balanced across participants and trial conditions. Before each participant begun the test trials, practice trials were provided in order for them to be familiar with the driving simulator and tasks. During the practice trials, participants were given a demonstration of how the power-flow gauge works. They were told that their aim was to drive the vehicle normally while trying to keep the power-flow gauge bars towards the left, and green. In addition to experimental conditions, the effects of driver profiles (age and gender) were also observed.

Levels of acceleration and brake pedal pressing positions were recorded during experimental trials as response measures. Then the mean values and kurtosis of the both pedals press positions were calculated and analyzed. In particular, the kurtosis of the pedal pressings is analogous to the standard deviation of pedal position over time. This indicates that lower kurtosis represents less stable pedal pressing behaviors due to making frequent and abrupt corrections in pedal pressing.

2.5 Hypotheses

Based on this study's experimental plan and findings in previous studies, we expected the present of the power-flow gauge interface would decrease means of accelerator and brake pedals pressing positions (Hypothesis (H) 1) as well as increase of kurtosis of the pedal pressing positions (H2) due to stable driving. Along with this, the road conditions were expected to affect pedal behaviors. That is, highway driving would yield less mean (H3) and higher kurtosis (H4) for accelerator and brake pedal pressings compared to city driving.

3 Results

3.1 Effect on Acceleration Pedal Behaviors

Mean of accelerator pedal position: Analysis of Variance (ANOVA) results revealed no significant main and interaction effects of road conditions, presence of gauge, age and gender on mean value of acceleration pedal pressing positions during driving. However, an interaction effect of gender and age was marginally significant ($F(1,38)=3.69$, $p=0.0624$), indicating that the mean of acceleration pedal value for

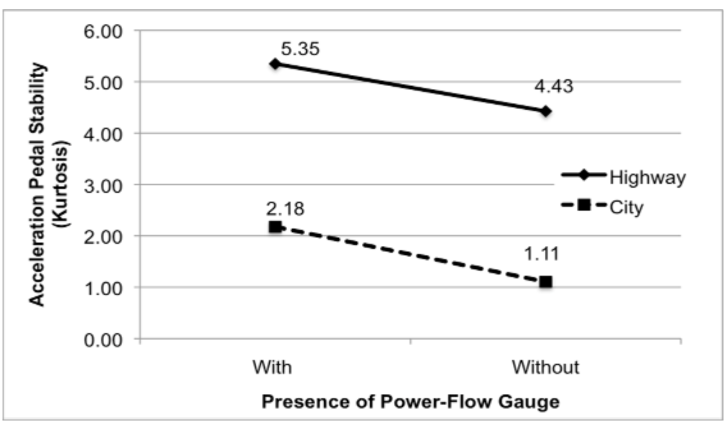


Fig. 3. Acceleration pedal stability (kurtosis) for road conditions and presence of a power-flow gauge

young males was lower than young female group while it is higher in old male than old female. Even though it was not significant, the data and trend shows that the mean acceleration pedal value is lower when driving with the gauge than without power-flow gauge for gender group, age group, and road condition.

Kurtosis of acceleration pedal position: ANOVA results revealed significant main effects of presence of power-flow gauge ($F(1,38)$, p=0.0329) and road conditions ($F(1,38)$=52.08, p<0.0001) on acceleration pedal behavior (see Fig. 3). Since higher kurtosis (stability in control) indicates higher stable driving, it can be inferred that the drivers were inclined towards more stable (or mild) acceleration pedal pressing when the gauge interface was presented and when they are driving on highway roads.

3.2 Effect on Brake Pedal Behaviors

Mean of brake pedal position: There were no significant main effects of road conditions and presence of the power-flow gauge on mean of brake pedal pressing. However, ANOVA revealed the effect of age ($F(1,38)$=11.86, p=0.0014) and the interaction effect of age and gender ($F(1,38)$=20.16, p<0.0001) to be significant on the mean brake value. The young participant group had a greater mean brake value than the older ones. The young males had a higher mean brake value than the older males or females. The interaction between gender and the presence of power-flow gauge was marginally significant ($F(1,38)$=3.51, p=0.0686), along with the interaction between age and the presence/absence of power-flow gauge ($F(1,38)$=3.49, p=0.0695). The males were found to have higher mean brake value with the power-flow gauge as compared to, without. The females were found to have higher mean brake values without the power-flow gauge as compared to with. Also, the young subjects were found to have a higher mean brake value than the older ones. This could be as a result of the slow reaction times of the older subjects.

Kurtosis of brake pedal position: ANOVA results did not reveal the effect of the existence of the power-flow gauge on stability with regards to brake pedal pressings. However, as expected, the braking behavior was significantly more stable (higher kurtosis) for highway driving than for city driving ($F(1,38)$=7.32, p=0.0102). This may attributable that there were fewer stop and go situations in highway driving than in city driving. In addition to this, ANOVA results revealed the effect of age on brake pedal pressing stability to be significant ($F(1,38)$=4.11, p=0.0496). The young subjects were found to have a relatively stable braking pattern as compared to the older subjects.

4 Discussion and Conclusion

In this study, the effects of a power-flow gauge interface for electric vehicles on drivers' acceleration and braking behaviors were examined by an experiment. While the mean values of accelerator and brake pedal pressings were not affected by the present of the power-flow gauge interface (not in-line with H1), the experiment results demonstrated the stability of the accelerator pedal pressing was increased when using the interface, which is in-line with H2. With a similar pattern, the results for effects of road conditions were not in-line with H3 (less means in highway driving for both pedals) but confirmed that higher stabilities for acceleration/brake pedal behaviors in highway driving (H4). Since each participant was asked to drive the simulation with specific driving speed on each driving condition, it can be inferred that the presence of power-flow gauge interface encouraged the drivers to maintain a relatively steady acceleration as well as discouraged them from being too aggressive while driving. This supports findings in previous studies that the use of the interface could affect driving behaviors. It also may indicate that the changes in driving behavior may affect energy consumptions in forms of economic driving, not limited on gas vehicles.

The study has several caveats, including limited driving performance measures due to the use of a relatively low-fidelity simulator. In addition, the exact electric consumption during driving was not measured in the experiment since the formula for calculating power consumption may be affected many factors such as motor/vehicle dynamics, which are varied for different vehicles and driving contexts.

In regard to future research, it would be interesting to investigate an optimal feature of power-flow interfaces with various manipulations of interface features (e.g., shapes and locations) as well as measurements of driving performance (e.g., speed, lane keeping, detailed dynamic energy consumption, and driver distraction using an eye tracking system).

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