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Eco-Driving with Electric Cars: Effect of Continuous and On-Demand feedback on Driving Behavior and Safety

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ABSTRACT

Analysis of driver behavior has been the purpose of many studies for several years. A new aspect is the introduction of electric vehicles on the car market and the fact drivers are more concerned with their consumptions in EV (Electric Vehicle) due to the lack of the appropriate infrastructures. However, only a few studies focusing on ecological behavior and consumption have been carried out.
The primary goal of the present study was to assess empirically the impact of feedback on EV driving behavior involving autonomy management performance. We hypothesized that we could help the driver to manage his autonomy more efficiently if we'd give him feedback on his driving behavior and battery consumption. Our second hypothesis is that participants would allocate more attention on feedback information when they reach a critical battery autonomy situation, so the subjects had to drive a course with 100% and 15% autonomy left.
Preliminary results indicate better driver performances and enhanced safety with econometer gauge feedback, probably due to the increased driver control and better applied driver attention.

Keywords: Electric Vehicle, Human-Machine Interface, Range Anxiety

INTRODUCTION

More and more companies are concerned with eco-driving, in order to reduce fuel consumption and CO2 emissions (Anable & al, 2007), and reduce accidents risks. The interest in this field of driving studies and analyses of driving behavior is also linked to the expansion of driving assistance systems in modern vehicles. In the meantime, improvement in digital and immersive technologies has enabled more precise experimental study conditions for behavior analysis with the help of simulation technology for well controlled immersive driving situations.

In the frame of EV research field, the energy issue comes a different way due to the lack of charging infrastructures. People are more concerned with their consumptions. They fear that a vehicle has insufficient range to reach its destination and would thus strand the vehicle's occupants. This phenomenon is called “Range Anxiety” (Eberle & al, 2010; Backstrom & al, 2009; Schott & al, 2009; Rahim & al, 2010).

Graham-Rowe & al. (2011) suggest that the EV possibilities are in contradiction with drivers’ expectations about their cars specified by Mann and Abraham (2006) like the need for autonomy, the positive experience produced by the feeling of being independent, comfort, physical effort to make a course, etc. Yet Graham-Rowe & al. (2011) and Wellings & al. (2011) also indicate that the anxiety is reduced when the driver is accustomed to EV. Those results are coherent with Taylor (2009) which shows that anxiety decreases after a few weeks of EV usage.

Several studies suggest that the autonomy available in the majority of EV actually matches the average daily courses majority of drivers do with traditional ICE (Internal Combustion Engine) cars (less than 50km per day), nevertheless it does not satisfy autonomy drivers are asking for (Sonnenschien, 2010). Thus, Sonnenschein (2010) confirms that the “Range Anxiety” problem is not only autonomy but how the driver deals with autonomy and the anxiety that results in it.

The primary goal of the present study was to assess empirically the impact of feedback on EV driving behavior involving autonomy management performance. Two specific interactive guidance systems based on ecologic and safety criteria were developed at this occasion.

We hypothesized that we could help the driver to manage his autonomy more efficiently if we’d give him feedback on his driving behavior and battery consumption.

This feedback display consisted in a guidance system integrated in a motion based driving simulator (Kemeny 2003) that give to the driver information about his consumption depending on his driving behavior. Participants were randomly assigned to four different groups depending on the conditions. The first group participants were only told to drive normally. The second group had a continuous feedback display that gave them real-time information about their consumption in the form of a classical econometer gauge. But this type of feedback, despite of his wide spread democratization, may add cognitive load during driving task since it’s providing permanent information. So with the third group, we built a new type of feedback that provides more control to the driver. This asynchronous econometer gauge appeared only when the drivers wanted by pushing on a button placed on the steering wheel and gave the driver his average consumption behavior. In the last group, participant had the two types of feedback available on their dashboard.

Our second hypothesis is that participants would allocate more attention on feedback information when they reach a critical battery autonomy situation, so the subjects had to drive a course with 100% and 15% autonomy left.

Another objective of this experiment is to enable driver to improve their eco-performance, in the respect of environmental and safety rules, with a string practical experience, in order to reinforce position and utility of driving simulation in practical learning

ECO-DRIVING SIMULATION

Driving simulators are mainly used for driving learning, experimental research on human behavior, and automotive engineering (Parodi-Keravec & al 2011; Azzi & al 2001; Kemeny, 2003). With evolutions and improvements of simulation techniques, as well as the increasing popularity, simulators have gradually become testing tools that could be provided turnkey. These more accessible solutions enabled to focus on contents (teaching, scripting, realism, interactivity). Fidelity of simulation provided by these tools is useful for application such as eco-driving learning. This experimental study required specific content in order to enable validation of simulator as a pertinent learning tool for eco-driving. New interactive guidance techniques based on ecologic and safety criteria were set up.

The CARDS simulator is a driving simulator developed by the Technical Center for Simulation team at RENAULT. The simulator is composed of a cabin including an adjustable seat, a steering wheel, gas and brake pedals. The simulator had been physically modified to fit like an EV, the clutch and gearstick had been dismounted for the experiment. The participant was immersed in the simulated environment by means of three screens, audio speakers located in front and behind the seat, and vibrators embedded in the seat. While driving, the scenarios are projected on the screens in front of the cabin, and in the wing mirrors and in the rear-view mirror (which is projected on the screen).
This dynamic simulator is built on 6 hydraulic cylinders, and reproduces the acceleration sensations, the swaying motion, switchback motion, and pitching motion. A microphone and 4 cameras are available in the cabin. The driver is in permanent audio and visual contact with the supervision room.
The simulator is used for the development, the tune-up of the systems of interface man-machine, adaptive cruise control or characterization of driver's behavior in accident situations. For further studies on driver behavior, the simulator is an ideal tool to create reproducible and safe experiments.

Figure 1: CARDS prototype at RENAULT

- **Software architecture**

Simulation was based on SCANeR™ Studio v1.2, developed by Renault and Oktal and SCANeR™. Software evolutions were made so that utilization of SCANeR™ tool could remain generic. Yet, some developments had been set up concerning the integration of new simulator cockpit specific acquisition module to Studio v1.2 and integration of new information from cockpit commands, and the set-up of the VEN interface (Virtual Extended Network), enabling communication and data exchange between distinct soft environments (vehicle data, driver evaluation variables, etc…).

Figure 2: CARDS virtual cockpit

- **Eye-tracking material**

The eye-tracking is a faceLAB apparatus and the eye-tracking data and the driving performance data are recorded at a frequency of 60 Hz.

- **Scenarios and event design**

The scenarios were developed in order to put the driver in various situations, including urban and rural context of traffic. The rural phase had the driver to drive fast and put the driver in situations where he was able to anticipate some expected events (e.g. a "stop" signal) or unexpected events (e.g. a road work zone). The urban

phase had the driver to face low speed driving. Some of the events were announced by a road sign (e.g. modification of the speed limit), but some other hazardous events could not be anticipated (e.g. pedestrians). Drivers were guided through the scenarios by arrows seated on the floor.
In order to prevent from bias induced by difference in courses, or even habituation, a counterbalance system was used for initial and final courses between two half of subjects group. Courses were also equivalent in terms of curves, straight lines, specific events, etc.
Driving scenarios were designed, in order to evaluate different guidance techniques proposed. Each scenario lasted about 10 minutes of driving time.

- **Eco-driving analysis**

A driving style measurement and analysis method was implemented and improved in order to adapt former measurement system and to validate this tool for simulated and real driving. A technical demonstrator was built in order to test interactions between SCANeR™ and the feedback display tool.

This tool analyses driving style with data based on driver actions on vehicle. These data acquisition system is implemented via a CAN bus interface and takes into account all vehicle and engine data (pedals position, acceleration, speed, distance, etc…). While comparing several identical driving courses data it enables to determine global driving behavior (cumulated braking time, accelerations duration) and autonomy consumption.

- **Interactive guidance technique**

Innovative interactive guidance techniques for eco-driving on EV were built and implemented. A preliminary study was carried out, focusing on the guidance tools optimization, and the courses the subjects would have to drive on. We also wanted to be sure that the guidance tools did not disturb the driving behavior and activity.
These guidance metaphors was connected to vehicle data and acquisition module, they had to be interactive, easy understandable and not too heavy in terms of cognitive load. It consisted in visual information released on the dashboard screen, relative to driver's consumption and battery state of charge situation.
For all the courses, dashboard provided speedometer and gearbox indicator information.

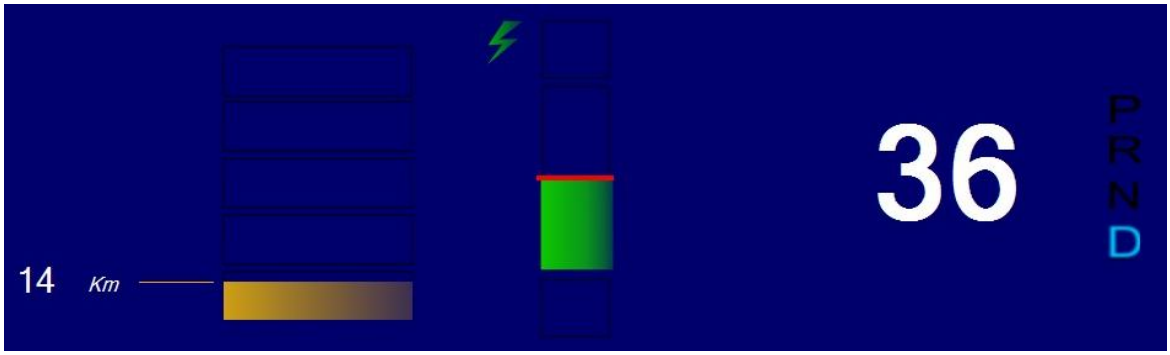

Figure 3: Feedback Display – Condition 1 (continuous feedback) – Modality 2 (15% battery left when starting)

ECO-DRIVING SIMULATOR EXPERIMENT

- **Participants**

55 participants were recruited at Technocentre Renault. All the participants who worked in a domain that could potentially be in touch with the field of EV and HMI had been excluded. Participants were specifically asked to have their driving license since at least a year and wear no glasses because of the eye-tracker material. Due to few technical problems and simulator sickness, some subjects had to stop the experiment and their record had not been used for the driving analysis. 44 participants were left for the study. The sample were composed of 29 males and 15 females, the average age was 37,4 y.o.

- **Procedure**

Subjects were randomly assigned to four different groups. All the participants started with a habituation phase while they learned about the simulator functioning and the safety instructions. The participant also had to answer a small survey about their driving experience, and knowledge about EV. Then the experiment started. The control group had to drive with no particular condition. The two following groups had a guidance system diffusing driver's consumption information. They were told that they could possibly manage their autonomy consumption with the help of the econometer gauge. They either had an econometer gauge which gave

continuous consumption's information, or they had to display this gauge by pushing a specific button on the screen whenever they wanted to. The economoter gauge were filled with green when the driver's behavior lead to low energy consumption and orange when his behavior lead to high energy consumption. A specific section of the econometer gauge was filled in blue when the driver's behavior leads to energy recovery (e.g. while braking). The last group had both continuous and on demand feedback available on the dashboard.
Medical matters wouldn't allow us to let the participants drive for hours on the simulator so we had to simulate the battery discharging performance. Each participant had to drive on 3 different battery state of charge context. First, a neutral context with no specific information about battery state of charge. They started the second course with 100% autonomy left. During the last course they had to experiment a critical situation where they started to drive with only 15% autonomy left.

RESULTS

First, it is important to point out that several indicators were analyzed to evaluate driver behavior in terms of road safety: time leaving the road, eyes position, violation of highway rules, steering wheel position, and ability to maintain the car in the middle of the lane. None of these indicators, showed a deficit in safety between the courses.

There is no significant difference in driving time to achieve courses between control group and other conditions group with different guidance systems displayed on the dashboard. Regardless of the groups the participants were in, they took approximately the same time to drive all the scenarios. There is yet a significant effect of the modality on driving time. Participants used to have longer driving time when they had 100% energy left, F (2,97)=3,397, p<.05. Conversely, when they have to start the course with only 15% energy left, their driving time match is more close to the control condition driving time. This could suggest that people are more likely to apply the econometer gauge when they feel comfortable with their energy range. This is confirmed by the fact participants tend to spend more time looking at the dashboard when they have 100% energy left.

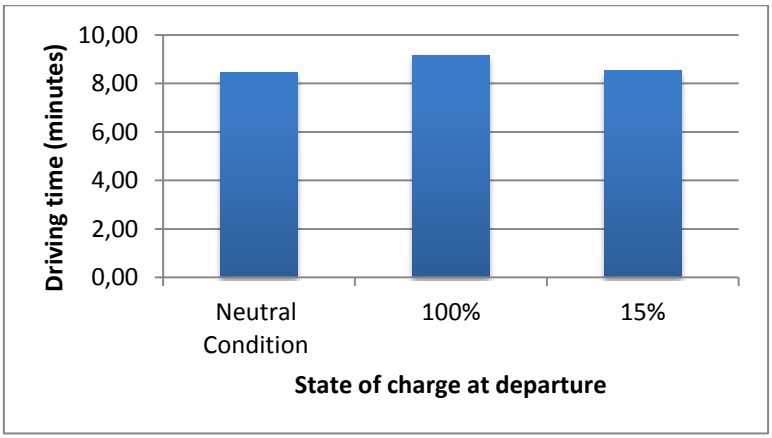

Table 1: Average driving time for each modality F (2,97)=3,397, p<.05

In the meantime, the analysis performed on the energy consumption with an ANOVA revealed a reliable decrease of energy consumption when the subjects are on the critical 15% energy left driving condition comparing to the two other starting state of charge condition, F(2,97)=6,794, p<.01. This result shows that it is possible to modify one's own driving behavior without losing any time in completing one's drive.

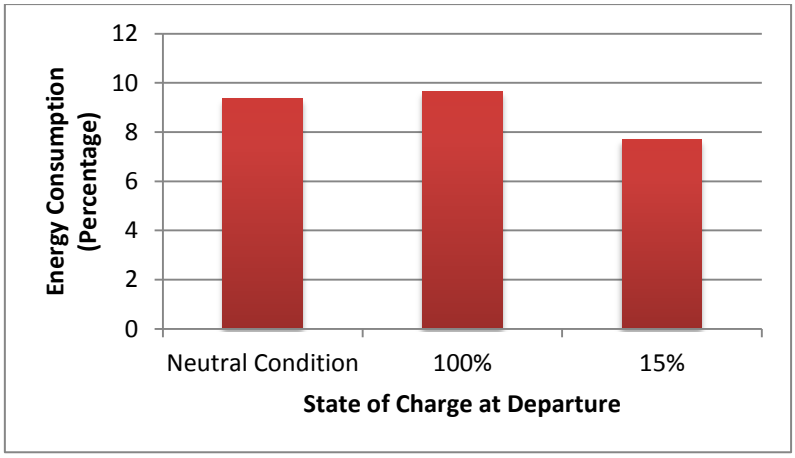

Table 2: Average energy consumption depending on the State of charge at Departure, F(2,97)=6,794, p<.01

This result could be explained by the measures on driving acceleration and braking behavior. The pressure on brake pedal, $F(2,75)=3,584$, $p<.05$, and acceleration pedal, $F(2,75)=8,076$, $p<.01$, is significantly more smooth on the critical context. The fact the subjects change their behavior toward brake pedal also enables energy recovery, which could explain the better consumption scores.

If we focus on different guidance system available for participants, we can see that drivers had a tendency to have a lower score in energy consumption with on-demand feedback display. The amount of pushing button in the conditions where it was available (condition 2, only the on-demand feedback display available, and condition 3, continuous and on-demand feedback display available) were significantly more important in the condition on-demand feedback were available alone, $F(1,33)=8,956$, $p<.01$, while the consumption were higher in the last condition with two guidance system simultaneously. Also, acceleration and braking behavior were also higher in terms of pedal pressure in this condition. Those results may suggest that people require the help of this feedback display more frequently, but the asynchronous aspect of this type of feedback makes it harder to understand and follow as an instruction, and participants in the last condition finally base their driving behavior on the continuous feedback.

CONCLUSION

Results first confirm that feedback display helps the driver to manage his autonomy and energy consumption comparing to a control condition. Participants feel more comfortable with continuous feedback when they feel like they have the time to achieve a driving course without having autonomy issues, in this situation they spend more time looking at the dashboard, their driving time increase, we can think they are more disposed to try to apply eco-driving in this context. On-demand feedback was conceived in order to enable the driver allocate more attention to the driving behavior, as a result, the asynchronous isn't helping and they couldn't change their acceleration/braking behavior on pedals pressure, and this scores are close to the control condition.

Despite the fact participants spend more time looking at the feedback display in the 100% energy left condition, they performed a better autonomy management scores when they were on the critical 15% energy left, with no significant difference noticed in safety measures, and driving time close to control condition, which is a really encouraging result for further studies.

This experiment however only considers the autonomy issue in a reaction context and we couldn't study the planification behavior associated with the range anxiety phenomenon due to the simulation context. Also, for the same reason, we couldn't really focus on the way participant change their activity linked with autonomy management in accordance with the way they develop an operating model of the way the charging decrease, because of the simulation driving time limitations.

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