**“ecoDriver” HMI feedback solutions**

Antonella Toffetti¹, Alessandro Iviglia², Claudio Arduino¹, & Mirella Soldati¹

¹Centro Ricerche Fiat (CRF)
Orbassano (Torino), Italy

²Fiat Group Automobiles
Torino, Italy

Abstract

The European Project ecoDriver - Supporting the driver in conserving energy and reducing emissions, was aimed at identifying an appropriate HMI to be given to the driver to suggest him/her how maintaining an eco-drive style. Two different testing activities involving forty users were held. The first activity, conducted in the CRF Usability Laboratory and involving twenty users aimed to evaluate adequacy and comprehensibility of different types of visual feedback, graphic layouts, kind of personalisation and rewarding solutions to be used in an eco-driving system. The first phase results were used to identify visual stimuli for the second part of the activity, conducted in the CRF Virtual Reality Driving Simulator. Twenty users were asked to drive for about an hour, using an eco-drive system which gave, when appropriate, visual advices and feedback or visual stimuli plus a haptic feedback on the gas pedal. Performance data regarding driving behaviour and fuel consumption were recorded during the driving sessions. Moreover, subjective evaluations were collected using several questionnaires, to identify the best feedback solutions in terms of usability, acceptability and perceived mental effort. Collected data (objective and subjective) allowed to identify HMI solutions that can lead to important contributions to the fulfilment of an eco-drive style and to a real benefit in reducing consumption, without making drive too annoying or unsafe.

Introduction

The ecoDriver project (http://www.ecodriver-project.eu) targets a 20% reduction of CO2 emissions and fuel consumption in road transport by encouraging the adoption of green driving behaviour, through delivering those most appropriate eco-driving advice or feedback for any given situation. ecoDriver aims to deliver drivers the most effective feedback on green driving, optimizing the driver-powertrain-environment feedback loop. Drivers will receive eco-driving recommendations and feedback adapted to them and to their vehicle characteristics.

It is an important project that addresses the need to consider the human element when encouraging “green” driving.
Several HMIs, developed by different partners in ecoDriver, following common defined guidelines, are tested in 2014 in long term naturalistic or controlled studies, following FESTA methodology (FESTA Handbook, 2011) regarding Field Operational Tests, to understand aspects like perceived mental effort, usability and acceptability vs. on-field consumption. The CRF HMIs were defined following the User-Centred Design approach (ISO 9241-210:2010) through different phases of qualitative analysis to highlight users’ eco-driving mental model, collection of creative ideas on innovative eco-HMI, parallel visual icons design, to arrive to the evaluation phases described in this paper.

**Usability laboratory HMI evaluation**

This laboratory study was aimed at identifying the types of visual interfaces that could guarantee most adequate solutions for displaying eco-driving information to the driver. A parallel design of several kinds of icons, representative of different events during the drive, visual advice and feedback on fulfilment of eco-drive behaviour, graphical layout, personalisation and rewarding options concerning an eco-drive system were developed (Jenness, Singer, Walrath and Lubar, 2009). Designed solutions were tested with users in the CRF Usability Laboratory.

**Method**

**Participants**

Twenty CRF employees (6 women, 14 men), not belonging to technical departments, took part in the experiment with ages between 29 and 60 years. The majority of the group (70%) had a university degree, 20% had a high school certificate and 10% a post-graduate degree. On average, they had their driving licence for 19.75 years, with an annual mileage of 17050 km/year. Participants drove almost every day in an urban context, less often on suburban road, highways, and country-side or mountain roads.

All participants were frequent users of mobile phones and personal computers while other devices (i.e. smartphones, MP3 players, portable or on-board navigators) were less used. The percentage of users that had rarely used an integrated navigation system (70%) were particularly high, lower were those of participants that rarely (25%) or never (50%) used a portable navigation system. The majority of participants (65%) never experienced driving with an eco-system and moreover, most of the users that had previous experience with eco-systems used them everyday (43%).

**Stimuli**

Several visual stimuli (Figure 1) representing information gdisplayed by an eco-driving system were shown to participants (Manser, Rakauskas, Graving, and Jenness, 2010). In particular:

- Fifteen visual stimuli on events during the drive (e.g. road signs), advice and feedback on eco-driving behaviour, given in different way (e.g. static icons, continuous bars...);
Four types of feedback solutions to notice the driver about the compliance or not with an eco-driving behaviour;

Three levels of an eco-system layout complexity with increasing number of information;

Three solutions of display personalisation with different kinds and style of eco-information displayed on it

Moreover, a list of rewarding solution highlighted from previous studies was proposed.

![Figure 1. Examples of visual stimuli.](image)

*Bar developed by TNO who gave kind permission to ecoDriver partners to test it.

**Experimental design**

A within-subjects design was conducted. The different stimuli belonging to the same class (e.g. single visual stimuli, types of feedback, personalisation solutions…) were randomized in order to avoid learning and sequence effects.

**Procedure and questionnaires**

First participants were welcomed by the experimenter and briefed about the test they were invited to participate and then required to fill in a short socio-demographic questionnaire. After that the different stimuli were shown and participants were requested to evaluate those, using ad hoc developed questionnaires.

As a first step, participants were shown all the single images (15) with no explanations about their meaning and they were asked to explain their meanings to verify whether icons were self-explanatory or not. After this, all icons were explained and then participants evaluated their comprehensibility and the adequacy to represent the message (Campbell et al., 2004).

Three different types of eco-driving information layout with increasing level of complexity were shown to participants, who were requested to explain the meaning of the icons present in the different visualisation solutions. Then, each layout
solution was explained and participants evaluated some of their characteristics (e.g. comprehensibility, adequacy, utility, etc.).

Four feedback solutions (correct or wrong fulfillment of the action suggested by the interface for driving in an eco-mode) were shown and explained to participants, who had to indicate their preferred solution.

Immediately after that, participants evaluated different types of hypothetical “reward”, given eventually after the correct eco-driving behaviour. Participants had to choose three preferred rewards and answered questions about possibility of rewarding to enhance the use of an eco-system, to distract the driver if presented on the display and about willingness to have a reward.

Following that, participants were asked to evaluate the possibility to “customize the graphics” showing eco-information on the display. Three hypotheses were shown in which the customization was on number, type and style of eco-driving information. Participants judged different aspects such as the possibility to choose by themselves among the three different cluster configurations, the possible distraction induced, the adequacy and utility of the different displayed information. After the trial the experimenter thanked and said goodbye to participants.

Results
Participants considered most of the different types of visual icons presented as comprehensible and adequate. Only graphics which displayed a time related concept received negative judgements. Feedback by icons was preferred if displayed with other visual signs (e.g. labels, bars, time). The TNO bar was the preferred one among the tested bars types, because it displayed both current and average trip eco-scores.

The complete interface that showed eco-driving detailed information received the most positive votes, but from participants comments emerged that they would prefer to have a medium level of eco-information complexity, when the vehicle is in motion, to reduce distraction.

According to participants’ votes a reward can contribute to enhance the eco-driving behaviour \([t=3.1, p<.05]\). Anyway they had a neutral position on the possibility to have rewarding directly displayed on the on-board instrumentation.

In general, participants evaluated positively the possibility to have personalization features in their vehicles \([t=2.7, p<.05]\). They did not think eco-system would be distracting (this value is significantly different from the neutral point (3)) and they did not want to have a system in which visualization automatically changes while driving \([t=2.1, p<.05]\) (Figure 2).
From users’ comments emerged that the personalization is appreciated if the selectable visual solution, shown when driving, is not too crowded.

HMI solutions highlighted as the best ones in the Usability Laboratory study were used to define the visual HMI adopted in the second study, in the CRF Virtual Reality Driving Simulator.

**Virtual Reality Driving Simulator User Testing**

The aims of the study were to identify the feedback modalities (Visual or Visual & Haptic) that guarantee an effective eco-drive performance, to identify and compare the consumption with eco-drive system off vs. eco-drive system on and to identify the eco-drive interface solutions that better guarantee an adequate compromise among consumption, perceived mental effort, usability and acceptability (Fricke & Schießl, 2011).

The experiment consisted of three driving simulator sessions, during which each participant drove in two different scenarios with and without the eco-drive system which gave, according to the experimental condition, visual feedforwards and Visual or Visual&Haptic (a counterforce on the gas pedal) feedback (ISO/TR 16352:2005) to the driver in relation to his/her driving behaviour.

**Method**

**Participants**

Twenty people were recruited for the experiment (mean age = 37 years), of which 75% was male and 5% female. Participants were recruited from CRF employees who had non-technical professions. Only participants with a low score on the motion sickness questionnaire were invited for the test in the Virtual Reality Simulator.

The large majority of the sample had a university degree (85%); 10% had a high school degree and 5% a post-graduate degree.
On the average, the participants held a valid driving licence for 18 years and reported they had driven more than 16,000 km per year. Participants drove almost every day in an urban context, less often on suburban roads, highways, and countryside or mountain roads (in decreasing frequency order).

All participants very often used mobile phones and personal computers and not very often smartphones, MP3 players, portable or on-board navigators. The percentage of users that never used an integrated navigation system is high (60%), as well as the percentage of participants that used rarely (40%) or never (30%) a nomadic one.

Moreover the majority of participants did not have experience in driving with eco-drive systems (55%), but mostly of the users that experienced those (45%) used them daily or several times a month.

**Stimuli**

Visual stimuli were of different types:

- Eco-drive task related: gear shift indicator, feedforward advices (curve, traffic light, roundabout, pedal release...), feedback (e.g. accelerator pedal release correct or not correct), green speed advice, eco-score behaviour indicator (e.g. eco-tree).
- Primary driving task related: speedometer
- Driving (speedometer) and eco-drive system stimuli were visualized on the cluster (Figure 3), located behind the steering wheel.
- Tertiary tasks related: during both baseline and experimental driving sessions, they were randomly administered by a recorded voice during the appearance of the feedforward advices and consisted in setting the volume or reading an SMS, which were displayed on the central head unit.

![Figure 3: Information shown on the cluster.](image-url)
The haptic stimulus was given by a counterforce pedal which produced a reverse force opposite to the force the driver applied to accelerate (Birrell, Young, and Weldon, 2010). This feedback on the pedal communicated to the user it was preferable to remove the foot from the accelerator to fulfill the eco-behaviour. The pedal opposed to the driver a force between 10 and 30N.

**Experimental design**

The experimental design was a 2x2 within-subjects. The manipulated factors were eco-drive HMI (Visual and Visual&Haptic feedback) and driving scenario (Urban and Extra-urban). In order to avoid sequence and learning effects, these four driving sections were randomized and counterbalanced.

**Procedure and questionnaires**

At the very beginning, participants were received in Virtual Reality Driving Simulator by an experimenter. They were thanked for their participation and introduced about the test, the driving simulator and the eco-drive system under evaluation. After that they filled in a socio-demographic and driving behaviour questionnaire.

A training driving session without any stimuli was performed by all the participants to guarantee each user the same level of basic expertise in driving the Virtual Reality Simulator.

Then participants performed a Baseline driving session, in which they had to drive both in urban and extra-urban scenarios without any eco-drive HMIIs and at the end they filled in a questionnaire, in which, beyond evaluating their drives, the Rating Scale Mental Effort (Zijlstra, 1993) in the different encountered events (roundabout, traffic light…) was also administered.

After the Baseline, the driving test conditions with the two HMIs (Visual or Visual&Haptic feedback) started. Each participant drove again in Urban and Extra-urban tracks with fixed obstacles and difficulties. During these sessions, different visual feedforward and Visual feedback or Visual&Haptic feedback were used during pre-defined events in the scenario (curves, traffic jam, etc.).

At the end of each experimental session, participants filled in some questionnaires about their drive, their perceived mental effort (as after the Baseline) and their evaluation on different HMIs used in each session.

At the end of the driving tests, participants filled in a questionnaire to evaluate the system interfaces in detail and to indicate the preferred Visual or Visual&Haptic feedback.

**Apparatus and Driving Scenario**

The CRF simulator is based on a six degrees of freedom dynamic platform. Besides providing the classical motion-based driving simulators functionalities such as ride vibrations, chassis translation and rotation, motion cueing, it enables the visualization of the car interior, due to Virtual Reality techniques, such as the 3D
full immersive visualization with head motion tracking and visual compensation algorithms. The system includes an I-Space and a physical mock up mounted on the mobile platform. Other features of the CRF driving simulator are the highly realistic vehicle dynamic models and a flexible and configurable vehicular traffic model, making possible the generation of critical situations.

Two different driving scenarios were simulated: urban and extra-urban. Each driver drove on a simulated one-way road with two lanes. Participants were instructed to drive at 50km/h in the urban scenario and at 70km/h and 90km/h in the extra urban one and stay in the right lane as much as possible. The surrounding traffic was made up of other cars.

Figure 4. Picture of Urban (left) and Extra-urban (right) simulated scenario.

Results

Participants reacted in the correct way to the Visual & Haptic feedback more times than to the Visual one (p<.05). The 'correct' behaviour more frequently occurs with any type of feedback than in the baseline without the eco-driving system (p<.05).

Participants reacted faster when prompted by the interface. Moreover, they reacted faster with the Visual & Haptic interface than to the Visual one (p<.05).

Consumption data significantly decreased (p<.05) between the different conditions.

Figure 5. Objective performance with different interfaces [ANOVA statistical differences are reported; p<.05].
From these results we can assume that Visual&Haptic interface gives the driver the chance to react more promptly and to increase fuel consumption reduction (Figure 4). The use of both feedback and in particular the Visual&Haptic one seems to improve previous driver performances both in the Urban and Extra-urban environment.

**Perceived driving performance with different interfaces**
Comparing participants’ evaluation of their driving performance in the three conditions, there is a significant improvement of driving safety and driving accuracy perception with the Visual&Haptic system in comparison with the Baseline condition \( t=-2.17; p<0.05 \) \( t=-2.22; p<0.05 \). No other differences are statistically significant between conditions. Visual&Haptic interface is also evaluated as significantly different from neutral (3) \( t=3.5; p<0.05 \) \( t=2; p<0.05 \) for both safety and accuracy dimensions.

Participants’ perception of their driving seems to increase toward a positive perception with the Visual&Haptic system, while it remains neutral with the Visual feedback, which does not differ from the Baseline condition (Figure 6).

![Figure 6. Participants’ driving performance self-evaluation.](image)

**Participants self-perception while using the system (Visual/Visual&Haptic)**
Mean levels of anxiety, annoyance and curiosity for the two different HMI configurations are very similar (Figure 7). No statistical significance has been found between the two conditions. Anyway, anxiety self-perception was statistically different from neutral point (3) for both interfaces \( t=-2.1; p<0.05 \) \( t=-2.8; p<0.05 \). Other statistically significant data are those about curiosity towards the system, in both conditions \( t=8.7; p<0.05 \) \( t=10.2; p<0.05 \) and satisfaction, with the Visual interface \( p<0.05 \). In general, participants declare a positive perception while using both systems and they were, in particular, curious about them.
Figure 7. Users self-perception while driving.

Participants perception of systems impact on driving (Visual/Visual & Haptic)

Participants give evaluation not statistically different from neutral (3) on the idea that the system could make their driving more difficult. The evaluation is the same for both interfaces. They evaluated the systems positively in terms of making them drive more carefully: the evaluations of both systems are significantly different from neutral point (3) \[t=3.45; p<.05\] \[t=3.55; p<.05\]. The most interesting result is the significant difference between participants evaluation of the system ability to make them react more promptly to emergency situations: while the evaluation of the Visual system is not different from neutral, the evaluation of the Visual&Haptic interface is significantly more positive \[t=-2.2; p<.05\]. They feel their driving is more prompt with the combined Visual&Haptic feedback (Figure 8).

Figure 8. Participants perception of systems impact on driving.

Visual information evaluation

Participants’ evaluation of the Visual interface in all conditions is positive (Figure Figure9). The main differences in evaluations are on comprehensibility of the system: there is a significant decrement in the evaluation between Visual&Haptic condition and the overall evaluation of Visual information \[t=2.6; p<.05\].
A similar result is relative to raising alertness \([t=2.04; \ p=.055]\): there is a tendency through a decrease in the evaluation between Visual\&Haptic and final evaluation of the Visual system. No other differences are significant from a statistic point of view. The evaluation of the Visual interface, in general, seems not to be influenced by the presence of the haptic feedback.

![Figure 9. Visual information evaluation in experimental conditions and at the end of the test.](image)

**Visual information and haptic information evaluation in visual & haptic condition**

During Visual\&Haptic condition, participants evaluated visual interface as more redundant than haptic one, even if the score is near neutral point (3) \([t=3.1; \ p<.05]\). They evaluated the Haptic interface as significantly more adequate to the content than the Visual one \([t=-2.4; \ p<.05]\). They also indicated that the haptic feedback is significantly more easy to distinguish than Visual one \([t=-2.7; \ p<.05]\). In general, both interfaces are positively evaluated by participants, although the haptic one was evaluated more positively (Figure10).

![Figure 10. Visual and haptic information evaluation in Visual\&Haptic condition.](image)
Mental effort
Taking into account all different driving situations (curve, hills, etc.) participants, using the RSME scale, evaluated their mental effort significantly lower when they drove using the Visual&Haptic interface, than without the system (Baseline) \( t=2.6; p<.05 \) (Figure 11). No differences in the evaluation have been found between the Baseline and driving with the Visual interface, nor between the Visual interface and the Visual&Haptic one.

Willingness to have an eco-drive system, comparison between Pre and Post questionnaires
Before driving with the system, participants were not sure they would have liked to drive with an eco-driving system while, after tried it, they definitely wanted to (Figure 12).

Feedback evaluation
At the end of the test, participants were asked to choose between Visual only or Visual&Haptic interface. No differences emerged: 55% of participants preferred to drive with the Visual feedback only and 45% with the Visual&Haptic one.
Conclusion

The performance data results show that in particular Visual\&Haptic feedback give the driver the possibility to react more promptly and to reduce fuel consumption respect to the baseline condition. This is coherent also with the subjective data on impact on driving and perceived mental effort. The use of both eco-interfaces and in particular the Visual\&Haptic one seems to improve driver performances both in the Urban and Extra-urban scenario. Participants’ perception of their drive improves between the Baseline condition and the driving with the Visual\&Haptic interface, both on safety and on accuracy perception.

The eco-driving interface an in particular that with Visual\&Haptic feedback reduces participants’ perceived mental effort. Haptic feedback on the pedal is considered a good solution, even if too intrusive during the drive, as emerged from participant’s comments. Then it is necessary to develop it further in order to reduce the perceived intrusiveness.

The visual feedback, important to understand the haptic one, was well evaluated by participants. All information are understandable and simple to follow, the visual stimuli are understandable and easy to be used during the driving. There is no a clear preference between only Visual and the Visual\&Haptic type of feedback.

From a general overview of the obtained results arises a general positive evaluation of the tested eco-driving system HMI and participants declare their willingness to use it while driving. These results constituted the starting point for designing the CRF ecoDriver HMI which is tested with a long term controlled on-real roads study in 2014.

References

