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Haptic feedback in eco-Driver system: a field operational test with an electric vehicle.

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Abstract

Reducing energy consumption has become a matter of increasing concern for electric vehicle owners. EcoDriver is a project funded by the European Commission, searching for new eco-driving solutions for reducing energy consumption in private and public transport. EcoDriver's main purpose is to teach efficient driving strategies and facilitate drivers' decision-making processes through several feedback modalities, in order to help increase driving efficiency and therefore reduce energy consumption. In the present study, the Full ecoDriver System combined with a haptic feedback gas pedal was tested in real driving conditions to give answers to some questions about its effectiveness, efficiency, workload and acceptability in an electric vehicle. The sample profile was composed by thirty young but experienced drivers. They had to drive around an open road track which allowed several possible scenarios such as curves, intersection or roundabout, speed limit changes and preceding vehicles. Average speed, deviation standard speed and energy consumption were registered on each lap, likewise other subjective measurements. The main results suggest that the efficiency benefits achieved while driving depend on the event type and the feedback modality provided. For instance Haptic Gas Pedals seem to be especially indicated for roundabouts. In addition, the feedback provided by the FeDS nomadic device helps to save energy and learn eco-driving strategies. These outcomes indicate how several feedback modalities could facilitate the decision making process, changing driving behaviour, reducing energy consumption and increasing safety. These questions would help advance further research on eco-driving Intelligent Transport Systems and driving behaviour issues.

Key words: decision-making, eco-driving, electric vehicle, haptic gas pedals, workload.

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GLOSSARY

Terms	Description
CAN	**Controller Area Network**
CC	**Cruise Control**
EV	**Electric vehicle**
FeDS	**Full ecoDriver System**
FHGP	**Force Haptic Gas Pedal**
FOT	**Field Operational Test**
HGP	**Haptic Gas Pedal**
HUD	**Head-Up Display**
ICE	**Internal Combustion Engines**
SHGP	**Stiffness Haptic Gas Pedal**

1. INTRODUCTION

Global warning and greenhouse gas emissions are topics of great interest nowadays all around the world. Climate change could accelerate the irreversible reshaping of the earth's geography in a brief period of time. However, as it is known, geographical and climatic changes would also bring enormous social changes to our civilizations. After industry, the transportation sector is the second-largest contributor to greenhouse gas emissions in the European Union, accounting for around one fourth of the total CO_2 emissions (European Comission, 2012).

Owing to this, energy efficiency in the automotive sector is currently a focus of research and industry activities. Besides technological innovations, drivers' behaviour is a potential area of improvement in order to increase vehicles' efficiency. Eco-driving is a recent campaign originated in Switzerland and Finland (Birrell, Simpkin, Scridon, & Rollenitz, 2011) and promoted by some European institutions whose main objective is teaching drivers an efficient driving style which allows them to reduce energy consumption and greenhouse gas emissions. There are different eco-driving strategies for Internal Combustion Engine (ICE) vehicles and Electric Vehicles (EV) because the characteristics of their power train efficiency are completely different (Kuriyama, Yamamoto, & Miyatake, 2010; Miyatake, Kuriyama, & Takeda, 2011). Some eco-driving strategies for EV have been proposed in the Energy Efficient VEhicles for Road Transport project (EE-VERT) (Birrell et al., 2011) such as applying light but consistent pressure on the accelerator pedal, using the ECO mode for improved efficiency, applying early smooth braking which boosts regenerative braking, the use of Cruise Control (CC) to maintain steady speeds and using Re-circulate Mode when Climate Control is on. These eco-driving strategies have been shown to produce reductions in energy consumption in several studies (Beloufa, Vailleau, Boucheix, Kemeny, & Merienne, 2014; Felicitas, 2013). In particular, for EV, due to their limited battery power duration, saving energy to increase vehicle autonomy has become a mandatory issue that can increase anxiety and cognitive workload for EV drivers, a phenomenon known as "Range Anxiety" (Beloufa et al., 2014). Thus, EV owners are more concerned with their consumption. They fear that their vehicle will have insufficient range to reach its destination and would thus leave the vehicle's occupants stranded.

EcoDriver - supporting the driver in conserving energy and reducing emissions - is a four-year European project that supports the driver in adopting a eco-driving behaviour adapted to them and to their vehicle's characteristics through different feedback applications (for more details view Hibberd, Jamson, & Jamson, 2015; Hof et al., 2013; Jamson, Hibberd, & Merat, 2015; Jamson, Kappe, & Louw, 2014; Seewald & Stuiver, 2014).

The Automotive Technology Centre of Galicia (CTAG) for the implementation of new technologies and the encouragement of research, development and innovation, is an ecoDriver test site location that has designed different Field Operational Tests (FOT) (see *Table 1*) to validate the working of three configurations based on two ecoDriver systems: the Android ecoDriver System and the Full ecoDriver System (FeDS). One of these tests was carried out by the author of this project in close collaboration with CTAG. This study employed the Full ecoDriver System complemented by a haptic pedal to enhance the feedback provided to the user.

Type of test	ecoDriver system	Route	Participants	Vehicles
Naturalistic	Android ecoDriver System	Free driving	10	User vehicle
Controlled	Full ecoDriver System	Urban, interurban, rural and motorway	30	Leaf Scenic
Controlled	Full ecoDriver System + haptic pedal	Motorway	30	Leaf

Table 1 Tests developed in CTAG for ecoDriver project.

Smart driving systems, and particularly eco-driving systems, are a potentially achievable and efficient measure for private transport to contribute saving energy and consequently reducing greenhouse emissions without increasing drivers cognitive workload (Birrell, Fowkes, & Jennings, 2014). Several authors (Beloufa et al., 2014; Felicitas, 2013; Franke, Arend, McIlroy, & Stanton, 2016) have suggested that feedback from diverse eco-driving systems are recommendable to support users in changing their driving habits and reducing energy consumption in EV.

Currently, there are three different types of feedback eco-driving systems commercially available as Hammerschmidt & Hermann (2014) have suggested:

-*Visual online feedback of fuel consumption*: These systems provide direct feedback to the driver on the vehicle's fuel economy. They show either instantaneous consumption data, accumulated values (e.g. aggregated over a couple of minutes, one whole journey, the time between fuel stops), or a more detailed history of the vehicles fuel consumption.

-*Offline Feedback*: For this type of feedback, driving behaviour is first logged during operation of the vehicle and then saved onto a flash-drive. Later, this data can be analysed and reviewed on an external computer.

-*Haptic Feedback (Eco-Pedal)*: When pressed down, an Active Acceleration Pedal can increase its resistance in order to indicate excessive or wasteful acceleration and therefore improve fuel economy. Moreover, it can be used to help to enforce speed limits.

However, there is an important problem when designing new interface concepts: they require the user to accept the new technology in order to make it successful. Therefore, it is of great importance to discover at a very early stage of development which issues in system design are decreasing the acceptance of the new systems (Meschtscherjakov, Wilfinger, Scherndl, & Tscheligi, 2009).

When designing an eco-driving system in order to increase its acceptability, the rate of learning of eco-driving skills during experience with such a system is an important factor to consider. This will allow the delivery of information to be tailored to optimise learning, and will also allow identification of the point in time at which it is appropriate to reduce or eliminate the guidance to prevent the presentation of redundant in-vehicle information (Jamson, Hibberd, & Jamson, 2015). In fact, if advice is provided too frequently, this may become annoying for drivers, therefore influencing overall acceptance and ultimately engagement with the system. A key premise behind the ecoDriver project is that drivers who are able to learn eco-driving skills readily do not need constant eco-driving support.

Another important consideration when designing an eco-driving assistance system for prolonged use is the selection of the most appropriate - most effective and least distracting - modality for the system interface. Currently, the majority of the systems on the market rely on the provision of visual information to the driver (Graving & Rakauskas, 2010). Whilst this is an effective method for the transmission of detailed driving-related information, it also has the potential to overload drivers and distract them from the primary driving task (Hibberd et al., 2015). The negative impact of competing visual tasks on driving performance has been consistently reported, with impairment observed in driver reaction times (Muhrer & Vollrath, 2011; Summala & Lamble, 1998), event detection (Olsson & Burns., 2000) and lateral control (Östlund & Nilsson, 2004).

Whereas prior work has demonstrated a reduction in the distracting impacts of a visual eco-driving interface when combined with a complementary audio signal (Hibberd et al., 2015), there is substantial evidence in the literature of adverse effects of an auditory task on driving performance measures such as brake reaction time (Alm & Nilsson, 1995; Consiglio & Driscoll, 2003; Beede & Kass, 2006), longitudinal control (Rakauskas & Gugerty, 2004; Ranney & Harbluk, 2005), event detection (Beede & Kass, 2006) and steering performance (Reed & Green, 1999). This suggests a need to consider an alternative presentation modality: haptic feedback.

Haptic gas pedals have been used before in a number of in-vehicle applications such as forward collision warning systems (de Rosario & Louredo, 2010) and speed management systems (Várhelyi & Adell, 2008) to produce favourable effects on driving performance, as suggested by Hibberd et al. (2015). Birrell, Young, & Weldon (2013) also found positive changes to drivers' behaviour compared to baseline condition, when they evaluated a haptic accelerator pedal's effects on driving performance and perceived workload. They also reported a decrease in subjective workload when driving with the haptic pedal, thus concluding that haptic modality was beneficial in this context as it does not encroach on other attention resource pools that are used in driving (i.e. mainly visual). Furthermore, other modalities of haptic feedback have also been tested and showed similar results, for instance Spiessl & Hussmann (2011) assessing error recognition in automated driving used haptic steering-wheel feedback to provide the participant with useful information about the vehicle's trajectory. They found that participants required less time to redirect their attention towards the road after an automation error with haptic feedback. In other words, use of haptic feedback kept drivers more engaged in driving tasks.

Thus, the main objective in the present study is to test the efficiency, acceptance and workload of Force and Stiffness haptic pedals combined with the ecoDriver system. Expectations are that haptic gas pedals will help decrease energy consumption and reduce drivers' cognitive workload, which would also increase their acceptance (Birrell et al., 2013). It is expected that when using a different sensorial channel – the haptic channel -, information will be processed faster than when presented in visual modalities, as suggested by Wickens (2008) in his multiple resource theory, and consequently drivers' workload should be lower. Moreover, as seen in previously-mentioned literature, the ecoDriver system and haptic gas pedals should not affect general mean speed, but make speed steadier.

The main hypotheses are:

- I – Differences are not expected in average speed across all conditions.
- II – Experimental conditions should favour maintaining a steadier speed.
- III – Energy consumption should decrease in experimental conditions.
- IV – Speed differences are expected before events between baseline and experimental conditions.
- V - Speed during event should decrease in experimental conditions.
- VI – Speed during event should decrease with HGP modalities more than with FeDS.
- VII – HGP modalities should register equal or lower workload values compared to FeDS.
- VIII – FeDS should register higher general workload values compared to baseline conditions.
- IX – HGPs would obtain more favourable acceptance and satisfaction results compared to FeDS in the van der Laan Acceptance scale.

2. METHOD

The design of this research takes as a methodological reference the study conducted by Hibberd, Jamson, & Jamson (2015) at the University of Leeds. They focused on the interaction between the driver and their vehicle, looking at what type of eco-driving information is easy to use and learn whilst not compromising safety. They tested drivers' ability to follow eco-driving advice accurately; as well as their tendency to prioritise this over driving safety. FeDS (visual feedback) with FHGP and SHGP (haptic feedback) were tested in the Leeds University's driving simulator in order to evaluate both visual and haptic eco-driving feedback systems. They found that eco-driving advice improved driving performance, and that visual feedback was the most effective. However, this modality increased subjective workload as it reduced driving attention to the forward view. Although haptic force feedback's effect on subjective workload was lower, it was less effective than a visual feedback system.

For this reason, in the present study the main intention was to bring this test to a real-world driving situation and compare the main results of both studies. Speed parameters (in km/h) before, during and after each event (i.e. speed limit change, predecessor vehicle, curve and intersection) in both baseline and experimental conditions were registered. Average speed (km/h), speed standard deviation (km/h), and energy consumption (KW) were also registered for each lap.

2.1 PARTICIPANTS

Participants were 30 CTAG workers, of whom 26 were men and four were women. Their average age was 33 years old (M = 33.67; SD = 5.55). All of them received

20€ as an economic compensation when they finished the trials. None of the 30 participants were familiar with using haptic gas pedals, though 25 of them had already participated in a previous study with the ecoDriver system and had already driven the Nissan Leaf used in the present study. The other five participants were recruited later to replace other participants who were unable to be involved owing to reasons outside the research. These five newly recruited participants had no previous experience with the car, nor with the ecoDriver system, nor with the use of haptic pedals.

2.2 APPARATUS

2.2.1 Full EcoDriver System

The Full ecoDriver System (FeDS) is based on energy algorithms. The model uses data from the CAN bus of the vehicle, GPS, a map database and radar to provide guidance on how to achieve optimal energy efficiency through accelerator pedal usage and to create driving recommendations for the user linked to the functions to be tested. Generally, this advice recommends lifting the foot off the accelerator pedal. It is the driver's decision whether to obey the eco-driving guidance if it advises them to behave in a way which might compromise their safety. Once the event is finished, the system provides feedback about the driver's ecoDriver reaction, showing a score on the display by colouring from 0 to 5 stars.

In addition, at any time, the system provides:

- *Gear information*: the current gear engaged and the recommended gear shown through arrows
- *Speedometer information*: a blue needle represents the current speed and a green area with the eco speed is also shown. This best speed for an ecodriving style depends on the speed limits, vehicle configuration, power train and the vehicle ahead.

The functions tested in this controlled test are:

- *Preceding vehicle detection*: the system detects a vehicle ahead driving slower than the ecoDriver vehicle when the speed of the ecoDriver vehicle is higher than 40 km/h and the distance to the vehicle ahead is more than 20m.

The HMI application (see *Figure 1)* shows a pop-up on the screen for six seconds which recommends the driver to decrease pressure on the accelerator pedal. The aim of the system with this recommendation is to support the driver in a progressive deceleration using the engine brake.

Figure 1 *Advice and feedback for preceding vehicle detection.*

- *Approaching an intersection*: The use of a map database enables the system to receive data about the approaching horizon. This makes it possible to know when the ecoDriver vehicle is getting closer to the intersection (see *Figure 2*). The information on the pop-up recommends releasing the accelerator pedal for a progressive deceleration using the engine brake while approaching the intersection.

Figure 2 *Advice and feedback for approaching an intersection.*

- *Approaching a stretch of road with a lower speed limit*: the map database also offers information about the presence of speed limits and their position (see *Figure 3*). This makes it possible to know when the ecoDriver vehicle is getting closer to a speed limit. The HMI application shows the pop-up of the figure only when the speed of the ecoDriver vehicle is higher than the speed limit.

Figure 3 *Advice and feedback when approaching a lower speed limit.*

- *Approaching a curve*: The map database indicates the presence of curves and their position (see *Figure 4*). The system reacts to this event when approaching the curve if the speed of the ecoDriver vehicle is higher than the "safe speed" to approach the curve. The HMI application shows the pop-up of the figure only when the speed of the ecoDriver vehicle is higher than the "safe speed" of the curve. The information on the pop-up recommends releasing the accelerator pedal for a progressive deceleration using the engine brake approaching the curve. Once the driver has carried out the system's recommendation and the vehicle has entered the curve, the system gives feedback showing a score on the driver's behaviour.

Figure 4 *Advice and feedback when approaching a curve.*

In this study, the haptic gas pedal provides additional feedback and emphasises the information provided by the HMI. Two different stages are implemented:

- *Force mode*: applies a resisting force when some of the FeDS functions consider that the user should stop pressing the accelerator pedal.
- *Vibration mode*: the motor simulates a vibration when any of the FeDS demands it.

2.2.2 The Car

The present research was carried out with a 2010 Nissan Leaf full EV (*Figure 5*), which is part of the vehicle fleet used for research in CTAG. Although using an EV for testing reductions in energy consumption might seem inappropriate, Romm & Frank (2006) suggested that for hybrid and electric vehicles, driving style appears to have an even greater impact on energy consumption. Therefore it makes sense for this study to use an electric vehicle when analysing how driving style affects speed management and energy consumption.

The Nissan Leaf has the following main characteristics:

- Motor type: AC synchronous
- Maximum power: 109 hp (80 kW) / 2730-9800 rpm
- Maximum torque: 280 Nm / 0-2730 rpm
- Maximum speed: 10,390 rpm
- Battery type: Lithium ion laminated
- Voltage: 360 v
- Capacity: 24 kWh
- Gearbox: Automatic, unique relationship
- Drive: Front-wheel
- Maximum speed (km / h: 145 km / h

Acceleration 0-100 km / h: 11.9 seconds
Power consumption: 173 kWh / km

Figure 5 *Nissan Leaf used in the tests.*

2.2.3 FeDS Components

The Full ecoDriver system was integrated in this vehicle, of which the main components are:

- Radar: Front radar was integrated in the vehicle to implement the Preceding Vehicle Detection function.
- Car PC: with a map database and FeDS software.
- Smartphone: this device receives information from the car's PC via Wi-Fi and shows it in a visual and user-friendly way. It was attached to the front windscreen (see *Figure 6*).
- CTAG datalogger: this is the logging system. The datalogger is connected to the CAN bus of the vehicle, radar and a GPS antenna, and gathers all this information at 10Hz.
- Haptic gas pedal: an electric motor was attached to the accelerator pedal to simulate the behaviour of a haptic pedal. This motor is controlled by a PC that receives the ecoDriver messages from the Car PC. The pedal could be

turned on and off with a switcher (see *Figure 7*).

Figure 6 *Smartphone used as a nomadic device displaying FeDS.*

Figure 7 *HGP switcher.*

2.2.4 The Track

Trials had been carried out on an open road track combining motorway and inter-urban stretch which allowed several possible scenarios: curves, intersection/roundabout, speed limits and motorway stretch (see *Figure 8*).

Figure 8 *Track provided by Google Maps. (A) Start at a roundabout (B) Incorporation to traffic. (C) Dual carriageway driving with speed limited to 120 kilometres per hour. (D) Dual carriageway driving changing speed limit from 120km/h to 90km/h. (E) Leaving dual carriageway and incorporation to roundabout. (F) Making a U-turn on a conventional road. (G) Incorporation to dual carriageway back to point A. (H) Dual carriageway driving with speed limited to 120km/h. (I) Leaving dual carriageway and stopping at point A.*

2.2.5 Questionnaires and Scales

Questionnaires utilised included a battery of items to establish the profile of the sample relating to socio-demographic data such as age, gender, driver experience (years), annual mileage (km) and employment. It also included items related to in-vehicle technologies experience (e.g. using GPS navigation, ACC, etc.), willingness to use new technologies and attitudes towards efficient and green behaviour.

Secondly, they also included completing the NASA-Task Load Index after finishing each of five trials. This scale was primarily developed to evaluate workload in aviation. However, 20 years later it is being used in several fields and studies with the same purpose: namely, evaluating cognitive workload in humans while performing a task. In the transportation field it has also been used in many different studies, such as for evaluating driving distractions (Harbluk, Noy, Trbovich, & Eizenman, 2007; Horberry, Anderson, Regan, Triggs, & Brown, 2006; Strayer, Cooper, & Turrill, 2013) or assessing in-vehicle assistance systems (Birrell, Young, & Weldon, 2013; Hibberd et al., 2015; Jeon et al., 2009). In this case, workload is defined as "a term that represents the cost of accomplishing mission requirements for the human operator" (Hart & Sandra, 2006, p.904). NASA-TLX consists of six subscales that represent independent clusters of variables: *Mental demand, Physical demand, Temporal demand, Frustration level, Effort*, and *Performance* (see more details below in annex 2).

- *Mental demand* refers to how much mental and perceptual activity (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.) was required to perform the task.
- *Physical demand* evaluates how much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.).
- *Temporal demand* assesses how much time pressure the participant felt due to the rate or pace at which the tasks or task elements occurred.
- *Frustration level* investigates how insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent the participant felt during the task.
- *Effort* has reference to how hard the participant had to work (physically and mentally) to achieve the level reached in the performance of the task.
- Lastly, *Performance* refers to how successful and satisfied the participant thought s/he was in accomplishing the task's goals and their performance in accomplishing these goals.

In the experimental conditions, the Van der Laan acceptance scale (Van Der Laan, Heino, & De Waard, 1997) was included. It has been used and validated in several transport studies such as with a Tutoring and Enforcement system (De Waard & Brookhuis, 1997; De Waard, Brookhuis, Van der Hulst & Van der Laan, 1994; cited in Van Der Laan et al., 1997), Intelligent Cruise Control (Hogema, Van der Horst & Van der Laan, 1994; Rothengatter and Heino, 1994; cited in Van Der Laan et al., 1997) and with a Collision Avoidance System (Janssen, Brookhuis & Kuiken, 1993; cited in Van Der Laan et al., 1997). This scale is directed towards evaluation of user-acceptance of the system's ergonomics, and includes a set of items related with the FeDS system's perception. Individual item scores run from -2 to + 2, except items 3, 6 and 8 which are reversed compared to the other items. The first subscale contains an assessment in terms of useful, good, effective, assisting and raising alertness, and could be interpreted as denoting the system's usefulness (see *Figure 9*). The second subscale contains an assessment in terms of pleasant, nice, likeable and desirable, and could be interpreted as reflecting satisfaction with the system (see more details below in annex 2).

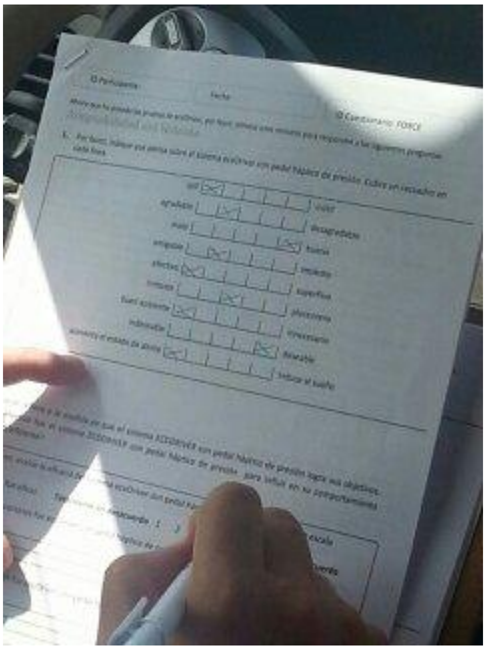

Figure 9 *Participant filling in the Van der Laan Acceptance scale after the trial.*

Lastly, a brief questionnaire to assess the overall study was filled in when participants had finished all the trials (see details below in annex 2).

2.3 RESEARCH DESIGN

A multifactorial repeated measures design was produced. Independent variables were: the FeDS with the traditional accelerator pedal; FeDS with Force Haptic Gas Pedal; and FeDS with Stiffness Haptic Gas Pedal. For each independent variable four events were proposed: speed limit, curve, intersection or roundabout, and predecessor vehicle. Dependent variables registered in each situation were the following: vehicle speed during event, vehicle speed five seconds before event, vehicle speed five seconds after event, mean speed after each trial, speed standard deviation, energy consumption, and participant's cognitive workload and system acceptance.

2.4 PROCEDURE

Before initiating each test a previous appointment had been made with each participant. Participants were welcomed in CTAG's garage. First they had to show they had their driving license in order. Next, when they entered the vehicle they were instructed how the vehicle and the ecoDriver system worked. After that, they were also informed about the nature of the study and that they were going to use a vehicle with a three-level haptic gas pedal: standard mode, force mode and stiffness mode. The test started once each participant had understood that the haptic pedal was in no way dangerous and that it could be disabled by pushing the brake pedal. The only instruction given was to drive as s/he usually did, respecting all traffic rules. When the participant was ready and had understood all the instructions, they proceeded to leave CTAG's garage and drove to point A (see *Figure 8*), always following the same route. Eventually, once point A has been reached, the car was stopped in order to initialise the data collection devices. This procedure was repeated in each trial and with each participant.

As with Hibberd et al., (2015) each of the five experimental trials lasted approximately 10 minutes and included the four events. Thus, participants took approximately one hour to complete the whole test. Participants performed the same circuit in each experimental condition (see *Figure 10*).

The first condition was a baseline (baseline 1). In this lap, participants only had to drive as they would usually do, without FeDS nor HGP.

The second lap was the first experimental condition. Participants had to drive as they would usually do, but this time using the FeDS, or using the FeDS with one of both HGP (this is Force gas pedal or haptic gas Stiffness pedal). Each lap's experimental conditions were counterbalanced across all participants.

Figure 10 *Participant during trials.*

The third lap was the second experimental condition. Participants had to drive as they would usually do; using the FeDS, or using the FeDS with HGP. Conditions were randomised, thereby avoiding the repetition of the previous condition in lap 2.

The fourth lap was the third experimental condition. Participants had to drive as they would usually do using the FeDS, or using the FeDS with HGP.

Conditions were randomised, so repeating the previous condition in laps 2 and 3 was again avoided.

The last lap was another baseline condition (baseline 2) introduced to investigate the possible appearance of learning effects. Participants only had to drive as they would usually do neither without the FeDS nor with HGP.

NASA-TLX questionnaires were filled out after each experimental condition in order to achieve greater reach higher accuracy with scores. Other questionnaires were filled out on the same day or on following days, at most one week later.

3. RESULTS

The need to register a type of widely differing variables during this study has been previously explained. A sample profile was composed with participants' socio-demographic data, drivers' experience using driving assistance technologies, participants' willingness to use technology and their attitude towards green behaviour.

Next, a set of objective measurements including average speed (km/h), speed standard deviation (km/h) and energy consumption (KW) was registered during each trial. Furthermore, driving speed (km/h) before, during and after the events detected by the FeDS was also registered. These events were curve, intersection, speed limit and preceding vehicle.

Lastly, a set of several questionnaires and scales was used to register participants' subjective information including workload (NASA-TLX), acceptance (Van der Laan Scale), effectiveness, usability, satisfaction and affordability. The main outcomes are presented itemised below.

3.1 SAMPLE PROFILE

Demographic data used in this study included participants' age, gender and annual mileage. Moreover, drivers' experience using driving assistance technologies such as route navigation, cruise control, parking aids, speed warnings, etc., participants' willingness to use technology and their attitude towards green behaviour was also included. This information will be helpful to better understand and interpret the main results.

3.1.1 Demographics

The sample was made up of 26 men and four women, their mean age being 33 years old (M = 33.67; SD = 5.55) as indicated previously in section 2 (see *Figure 11* for more sample distribution details). Furthermore, their mean annual mileage was 20600 km per year (SD = 8319.48), where the maximum was 40000 km per year and the minimum was 6000 km per year. This suggests that participants spent more time driving than the average Spanish driver, as the mean mileage in Spain in 2014 was 9126 kilometres per year (Heraldo, 2014). Moreover, participants' mean driving experience was M = 14.33 years (SD = 5.18), which suggests that the sample was primarily formed by young but experienced drivers. This information might be relevant to understanding the main results, as participants were used to driving regularly and had experience with some in-vehicle systems.

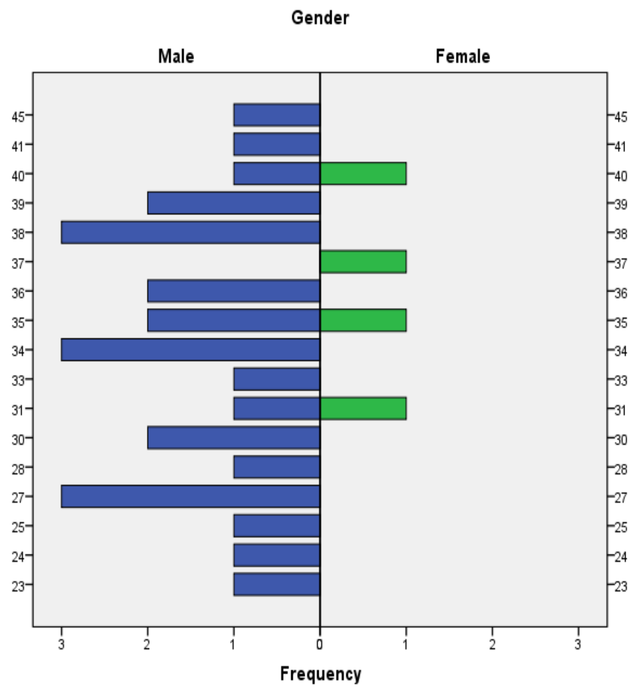

Figure 11 *Demographics: age and gender.*

3.1.2 Experience with technology

Participants were not novice drivers. They were young people who habitually drove more kilometres per year than the average driver in Spain, and they were also used to being involved with in-vehicle technology, as appears in *Figure 12*. Participants mainly had experience with route navigation, cruise control and reverse parking aid; as these are the most common systems installed in new vehicles over the last five or ten years. This suggests that participants were used to driving cars recently manufactured which incorporated the most recent in-vehicle technology. Other participants also had experience with other recently-developed systems such as speed limit change and fuel efficiency advisor, and which are especially related to the FeDS tested in the present study. Lastly, a few participants had experience with other brand-new technology, and although they represent one out of four participants, this suggests that the sample drivers in the present study are up-to-date with in-vehicle technology.

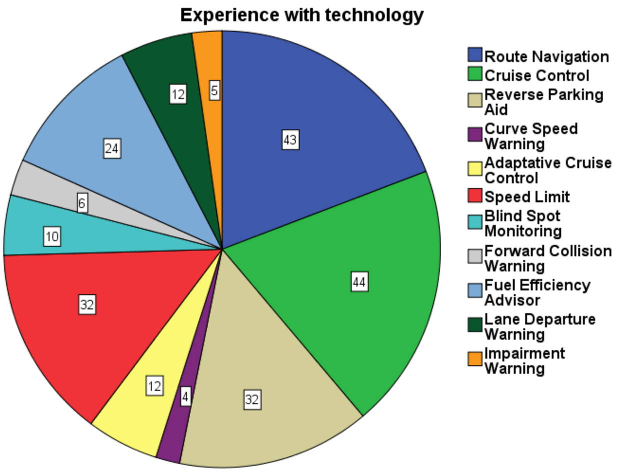

Figure 12 *Frequency experience with technology.*

3.1.3 Technology readiness

This scale is part of the pre-exposure questionnaire pack and was previously used by Jamson et al. (2014) in the ecoDriver D42.1 - *Evaluation of effectiveness subproject* -. It contains items formed by sentences describing people's attitudes towards willingness to use technology. Participants used the rating scale opposite each phrase to describe how accurately each statement described them. Items were rated between 1 (strongly disagree) and 5 (strongly agree). Items 3 (M = 4.03; SD = 0.67), 5 (M = 4.47; SD = 0.63), 6 (M = 4.30; SD = 0.60), 8 (M = 4.03; SD = 0.72), 16 (M = 4.07; SD = 0.79), 26 (M = 4.17; SD = 0.75) and 35 (M = 4.63; SD = 0.49) show the strongest agreement between participants (M > 4). Conversely, the strongest disagreement was reached by items in which M < 2.5. These items were: 12 (M = 2.27; SD = 0.69), 23 (M = 2.47; SD = 1.14), 29 (M = 2.13; SD = 1.20), 31 (M = 2.23; SD = 1.19) and 32 (M = 2.23; SD = 1.28).

3.1.4 Attitudes towards green behaviour

This scale again forms part of the pre-exposure questionnaire set and was also used by Jamson et al. (2014) together with the *Technology readiness* scale with the purpose of classifying drivers regarding their driving style and habits. The scale contains items formed by sentences describing people's attitudes towards environmentally-friendly behaviour. Participants used the rating scale opposite each phrase to describe how accurately each statement described their behaviour. Items were rated between 1 (strongly disagree) and 5 (strongly agree). Items 1 (M = 4.07; SD = 0.91), 2 (M = 4.07; SD = 1.08) and 12 (M = 4.37; SD = 0.72) reach the strongest agreement between participants (M > 4). On the contrary, the strongest disagreement was reached by items 4 (M = 2.20; SD = 0.81) and 13 (M = 2.33; SD = 0.88), in which M < 2.5.

3.2 LAP PARAMETERS

Given that data did not meet the normality assumption, a non-parametric test for multiple related variables was performed to investigate differences between average speed (km/h), speed standard deviation (km/h) and energy consumption (KW) within baseline 1, FeDS condition, FeDS + FHGP condition, FeDS + SHGP condition, and baseline 2. The rating data were analysed using Friedman's ANOVA, whereas Wilcoxon tests were used for the post hoc tests of means. Statistical testing was completed using SPSS 23.0 and significance was accepted at $p < 0.05$.

However, no statistically significant differences were found across conditions.

3.2.1 Average Speed

Inspection of the median values (see *Table 2*) showed little difference from baseline 1 (Md = 75.79) to FeDS (Md = 75.03), and SHGP (Md = 75.06). However, major differences were observed with FHGP (see *Figure 13*), which registered the lowest average speed median values (Md = 74.19), while baseline 2 registered the highest scores (Md = 76.08).

Average Speed (km/h)	Median	Standard Deviation
Baseline 1	75.79	5.89
FeDS	75.03	4.89
FeDS + FHGP	74.19	5.06
FeDS + SHGP	75.06	4.53
Baseline 2	76.08	7.01

Table 2 *Average Speed descriptive values.*

As hypothesised, speed did not differ so much across conditions and these minor differences could be explained by the nature of the track.

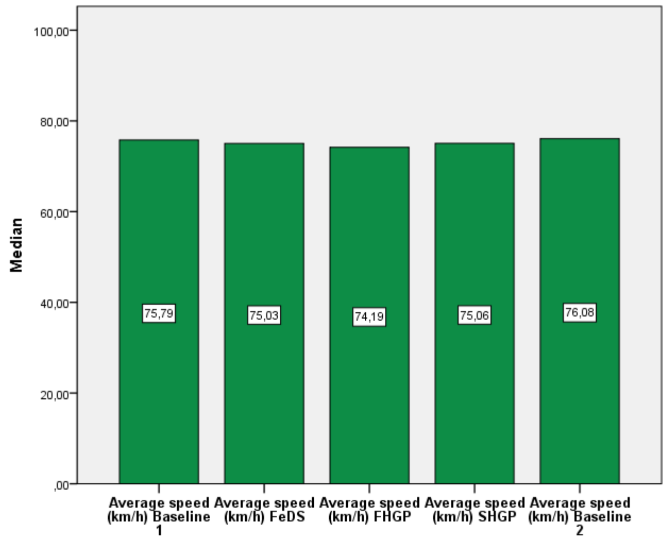

Figure 13 *Average speed median values.*

No statistically significant differences were found between average speed in baselines and experimental conditions.

3.2.2 Speed standard deviation

Speed standard deviation median values (see *Table 3*) showed analogous scores from baseline 1 (Md = 33.19) to FHGP (Md = 33.15), and SHGP (Md = 33.78). Main differences were found in FeDS (Md = 30.61), and baseline 2 (Md = 32.81).

Speed standard deviation (km/h)	Median	Standard Deviation
Baseline 1	33.19	3.94
FeDS	30.61	5.02
FeDS + FHGP	33.15	4.04
FeDS + SHGP	33.78	4.69
Baseline 2	32.81	4.01

Table 3 *Speed standard deviation descriptive values.*

No statistically significant differences were found between speed standard deviation values in baselines and experimental conditions.

3.2.3 Energy Consumption

Median values for energy consumption (see *Table 4*) showed similar scores between haptic pedals energy consumption: FHGP (Md = 33165.12), and SHGP (Md = 33649.05).

Consumption (KW)	Median	Standard Deviation
Baseline 1	34167.26	3558.68
FeDS	32610.07	3070.41
FeDS + FHGP	33165.12	3257.55
FeDS + SHGP	33649.06	2650.04
Baseline 2	32358.38	4330.51

Table 4 *Consumption descriptive values in Kilowatts (KW).*

The main differences were found between baseline 1 (Md = 34167.26) and baseline 2 (Md = 32358.38). FeDS energy consumption values were lower than with haptic pedals (Md = 32610.07) and comparable to baseline 2 (see *Figure 14*).

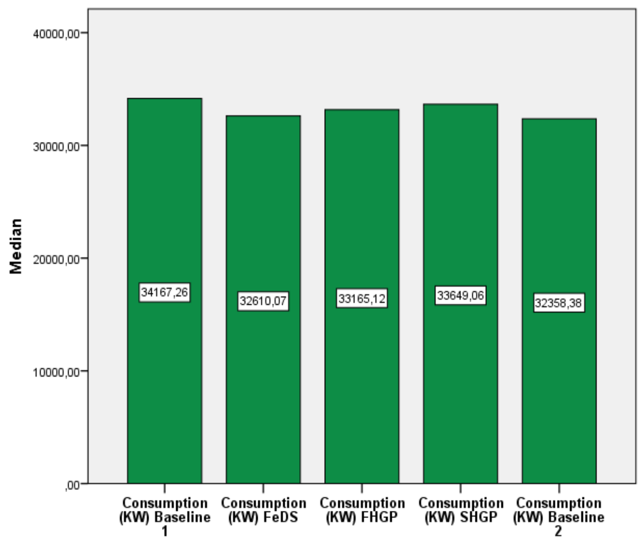

Figure 14 *Consumption (KW) median values.*

No statistically significant differences were found between energy consumption across conditions.

3.3 EVENTS

A one-way intra-groups multivariate analysis of variance was performed to investigate speed differences in the following events: curve, speed limits, predecessor vehicle and intersection. Three dependent variables were used: speed before event, speed during event and speed after event. The independent variable was the FeDS modality. Preliminary assumption testing was conducted to check for normality, linearity and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity, with no serious violations noted.

3.3.1 Curve

Mean speed scores showed that before the event, mean speed (see *Table 5*) was slower (M = 19.67; SD = 5.86) than during the event (M = 25.34; SD = 2.10); and then increased after it (M = 37.97; SD = 4.99). These data are as expected, as they are in accordance with the natural way of taking a curve when driving: reducing speed when approximating, and then increasing speed progressively.

Curve	Mean (km/h)	Standard Deviation
5s Before event	19.97	5.86
During event	25.34	2.10
5s After event	37.97	4.99

Table 5 *Mean speed values before, during and after curve event.*

Mean values (see *Figure 15*) for each condition separately showed a similar pattern across all conditions. Speed in baseline 1 was always higher than other conditions, while experimental conditions showed lower values especially after the event. FHGP registered the lowest mean speed during: M = 24.17 (SD = 1.22); and after: M = 34.87 (SD = 4.97). The second baseline behaved differently compared to others; before and during the curve its speed was similar to experimental conditions, but after the event it was almost equal to the first baseline.

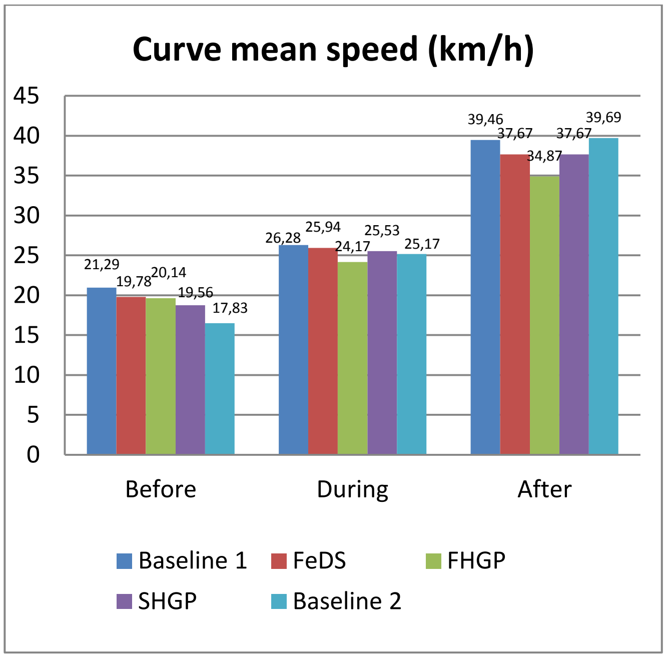

Figure 15 *Mean speed values before, during and after curve event for each condition.*

No statistically significant differences were found between system modalities' mean speed five seconds before, during, and five seconds after curve event.

3.3.2 Speed limit

An inspection of the mean scores indicated that speed during event reported slightly higher levels of mean speed (M = 113.05, SD = 10.92) than before event (M = 111.52, SD = 9.93) and after event (M = 110.90, SD = 12.62). This can be explained by the fact that the driver was increasing his speed until reaching the limit, and following slowed down. These differences are more appreciable in *Figure 16* where mean speed values are represented for each condition. As the reader may see, the FeDS registered the slowest speed value across all conditions, followed by baseline 2, except after the event, where surprisingly it registered the top speed. HGPs registered speeds faster than the first baseline, except after the event.

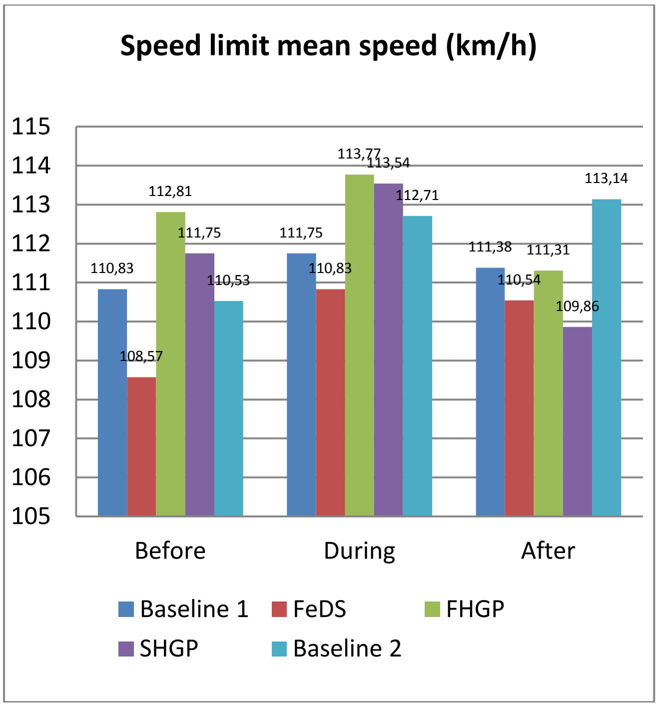

Figure 16 *Mean speed values during, before and after speed limit event.*

There were statistically significant differences, F (12, 572) = 4.42, $p < 0.05$; Wilks' Lambda = 0.79; partial eta square = 0.08; between FeDS and other modalities before: M = 108.57 (SD = 12.76); and during: M = 110.82 (SD = 12.14).

3.3.3 Predecessor vehicle

A descriptive statistical analysis showed that mean speed values (see *Table 6*) were higher before *Predecessor vehicle* event (M = 91.37; SD = 17.35), then decreased during event (M = 84.27; SD = 24.89) and following increased a little (M = 87.21; SD = 20.26), as expected for this situation. When the driver detected the preceding vehicle he reduced his speed to avoid the collision, and when the distance with the following car was safe the driver accelerateed again.

Predecessor vehicle	Mean (km/h)	Standard Deviation
Before event	91.37	17.34
During event	84.27	24.89
After event	87.21	20.26

Table 6 *Mean speed values before, during, and after Predecessor vehicle event.*

Mean values for each condition (see *Figure 17*) reflect this pattern with more details. FHGP registered the lowest speed across all conditions: before M = 87.77 (SD = 17.44); during M = 81.21 (SD = 23.94); and after M = 82.53 (SD = 20.30). Followed by FeDS and SHGP, which appear to be less effective. Otherwise, the second baseline shows values more similar to experimental conditions than to baseline 1.

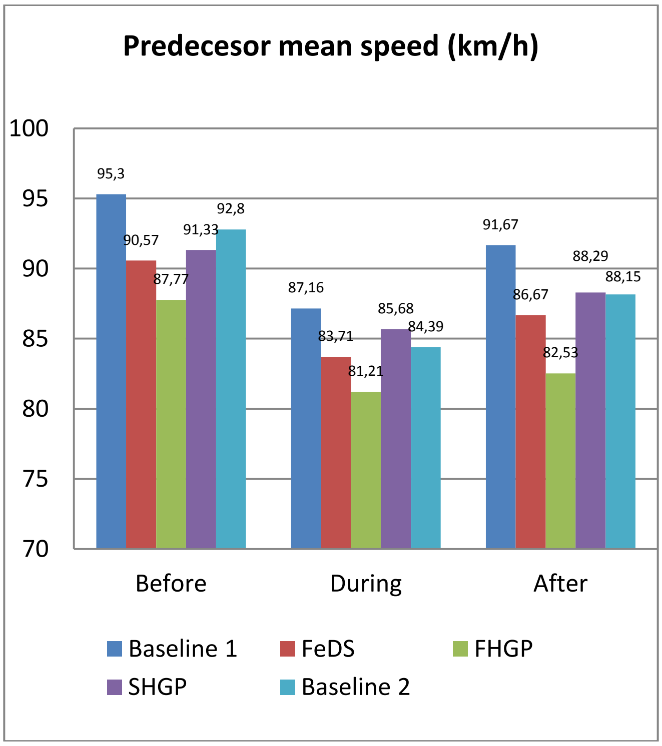

Figure 17 *Mean speed values during, before and after predecessor vehicle event for each condition.*

In *Predecessor vehicle* event condition the data does not fulfil on MANOVA main assumptions, as there is a high correlation between 0.8 and 0.9 between dependent variables, and covariance matrices Box test is lower than < 0.001. This is why an ANOVA for each dependent variable has been carried out. No statistically significant differences were found across conditions.

There were statistically significant differences between FHGP and other modalities, F (12, 997.74) = 3.51, $p < 0.05$; Wilks' Lambda = 0.90; partial eta square = 0.04. It reached the lowest speed across conditions: before M = 40.06 (SD = 12.80), during M = 37.10 (SD = 6.44), and after M = 31.55 (SD = 17.43).

3.3.4 Intersection

The analysis of the mean scores suggested that speed before the event reported slightly higher levels (M = 42.32, SD = 14.75) than speed during (M = 37.89, SD = 6.25) and after event (M = 34.92, SD = 16.83). The general speed pattern is as it was expected for this event type. Drivers reduce their speed when reaching the roundabout, and five seconds later they may continue to reduce or maintain a low speed to negotiate it. In *Figure 18* more details on each condition may be found. The FHGP seems to be the most effective modality for reducing speed in advance and then maintaining a slow speed during and after the event. Baseline 2 registered very similar values to FeDS and SHGP, except after the event.

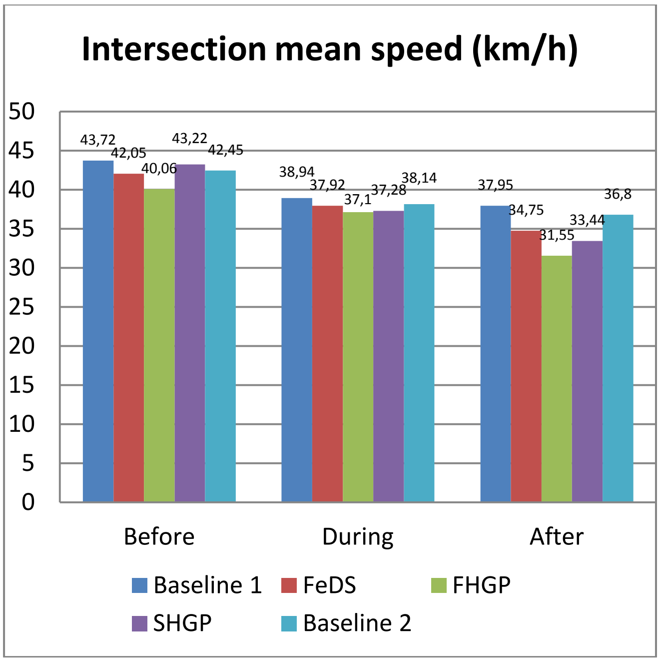

Figure 18 *Mean speed values during, before and after intersection event for each condition.*

3.4 SUBJECTIVE MEASUREMENTS

In this case data failed to meet the normality assumption, so a non-parametric test for multiple related variables was performed to investigate differences between NASA-TLX variables within baseline 1, FeDS condition, FeDS + FHGP condition, FeDS + SHGP condition, and baseline 2. The rating data were analyzed using Friedman's ANOVA and Wilcoxon tests were used for the post hoc tests of means.

3.4.1 NASA-TLX

NASA-TLX total score was low in all conditions, as the maximum score was 14.5 out of a total of 60 (Hibberd et al., 2015). Total median scores were analysed for each condition separately (see *Figure 19*). Experimental conditions reported the highest workload values, especially those with HGPs (FHGP Md = 14.5; SHGP Md = 14.2). FeDS median workload values (Md = 12.7) were similar to those observed in Baseline 1 (Md = 12.2). Baseline 2 reached the lowest total workload values (Md = 9.15).

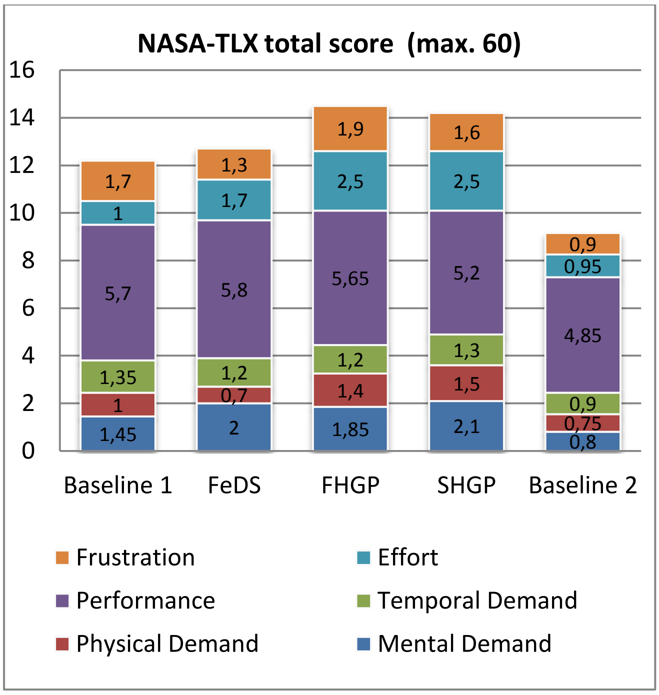

***Figure 19** NASA-TLX median total scores for all conditions.*

NASA-TLX median scores (see *Table 7*) were also examined for each subscale. For the first one, an increase was observed in *Mental demand* scores from baseline1 (Md = 1.45) to FeDS (Md = 2.00), FHGP (Md = 1.85), SHGP (Md = 2.10) and a further decrease at baseline 2 (Md = 0.80).

Mental demand	Median	Standard Deviation
Baseline 1	1.45	0.96
FeDS	2.00	1.81
FeDS + FHGP	1.85	1.84
FeDS + SHGP	2.10	1.94
Baseline 2	0.80	1.52

***Table 7** Mental demand scores.*

Physical demand median scores (see *Table 8*) were higher for haptic gas pedal conditions (Md = 1.40 in FHGP condition; Md = 1.50 in SHGP condition), and lower in baseline 1 (Md = 1.00) and baseline 2 (Md = 0.75.). The lowest value was in FeDS condition (Md = 0.70).

Physical demand	Median	Standard Deviation
Baseline 1	1.00	1.05
FeDS	0.70	0.90
FeDS + FHGP	1.40	1.24
FeDS + SHGP	1.50	1.50
Baseline 2	0.75	0.81

***Table 8** Physical demand scores.*

Within *Temporal demand* scores (see *Table 9*) the lowest values were in baseline conditions (Md = 1.35 in baseline 1; and Md = 0.90 in baseline 2); while in the experimental conditions they were higher: Md = 1.20 in FeDS, Md = 1.20 in FHGP and Md = 1.30 in SHGP condition.

Temporal demand	Median	Standard Deviation
Baseline 1	1.35	1.12
FeDS	1.20	1.76
FeDS + FHGP	1.20	2.33
FeDS + SHGP	1.30	1.74
Baseline 2	0.90	0.59

***Table 9** Temporal demand scores.*

Performance scores (see *Table 10*) decreased during the trials, as in baseline 1 median values were higher Md = 5.70) then increased in FeDS (Md = 5.80), but decreased when participants tested the haptic pedals: FHGP (Md = 5.65), SHGP (Md = 5.20) while in baseline 2 median values (Md = 4.85) were lower compared to the first baseline.

Performance	Median	Standard Deviation
Baseline 1	5.70	1.89
FeDS	5.80	2.16
FeDS + FHGP	5.65	2.37
FeDS + SHGP	5.20	2.20
Baseline 2	4.85	2.38

***Table 10** Performance scores.*

Frustration level scores (see *Table 11*) were higher in the first baseline 1 (Md = 1.70) than in baseline 2 (Md = 0.90); and higher using FHGP (Md =1.90) than SHGP (Md = 1.60) and lower in FeDS condition (Md = 1.30).

Frustration level	Median	Standard Deviation
Baseline 1	1.70	0.82
FeDS	1.30	1.19

FeDS + FHGP	1.90	1.92
FeDS + SHGP	1.60	1.90
Baseline 2	0.90	0.84

Table 11 *Frustration level scores.*

Finally, *Effort* values (see *Table 12*) followed similar patterns as *Mental demand, Temporal demand*, so median values were lower in baseline conditions (Md = 1.00 in baseline 1; Md = 0.95 in baseline 2) than in experimental conditions. Values were mainly high for HGP conditions (Md = 2.50 in FHGP; Md = 2.50 in SHGP) compared to FeDS condition (Md = 1.70).

Effort	**Median**	**Standard Deviation**
Baseline 1	1.00	1.31
FeDS	1.70	1.83
FeDS + FHGP	2.50	2.06
FeDS + SHGP	2.50	2.24
Baseline 2	0.95	1.24

Table 12 *Effort scores.*

Variable *Effort* showed statistically significant differences X^2 (4, n = 19) = 10.75, $p < 0.05$). Thus a Wilcoxon test was applied to explore the size effect with a Bonferroni alpha adjustment between variables *effort in FHGP condition* and *effort in baseline 2*; and *effort in SHGP condition* and *effort in baseline 2.* The Wilcoxon test showed statistically significant differences ($p < 0.016$) between variables *effort in FHGP condition* and *effort in baseline 2*; and *effort in SHGP condition* and *baseline 2*.

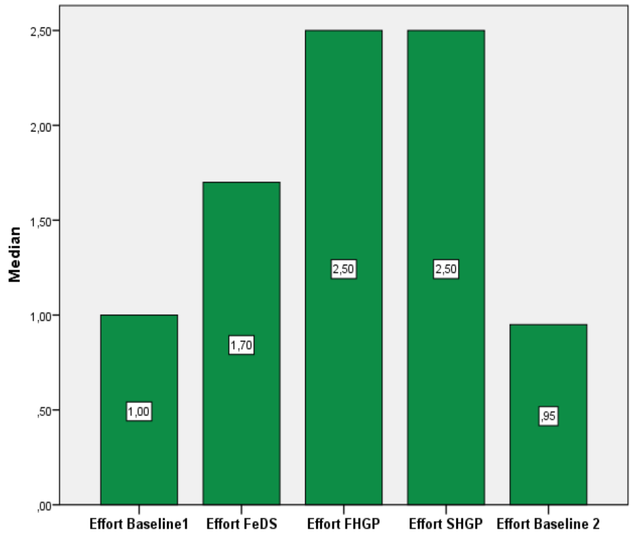

Figure 20 *Effort median scores.*

3.4.2 Van der Laan Acceptance Scale

Below, the means of *Acceptance* subscales of FeDS and HGPs are presented for items *Useful, Effective, Assisting, and Undesirable* (see *Figure 21*, *Figure 22*, and *Figure 23*). First, FeDS + FHGP was found to be the most useful system modality (M = 0.82; SD = 0.95), followed by FeDS (M = 0.70; SD = 0.72) and FeDS + SHGP (M = 0.59; SD = 0.97).

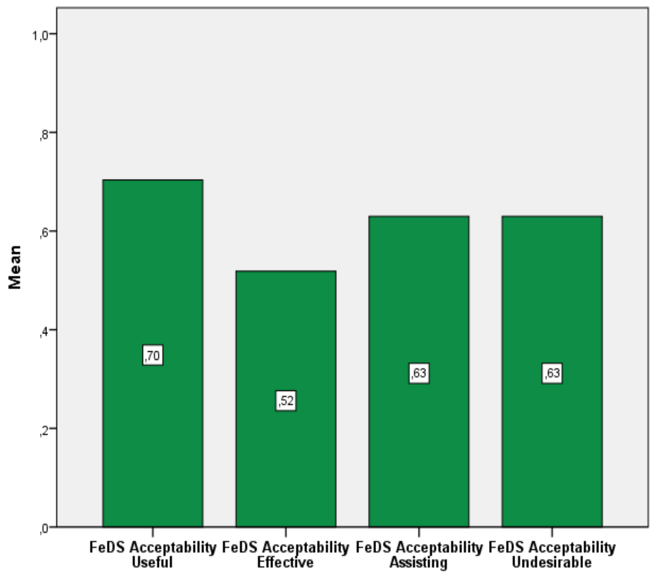

Figure 21 *FeDS Acceptance mean scores.*

Secondly, FeDS + FHGP was found to be the most effective system modality (M = 0.86; SD = 0.85), followed by FeDS+ SHGP (M = 0.79; SD = 0.97), and FeDS (M = 0.52; SD = 0.80).

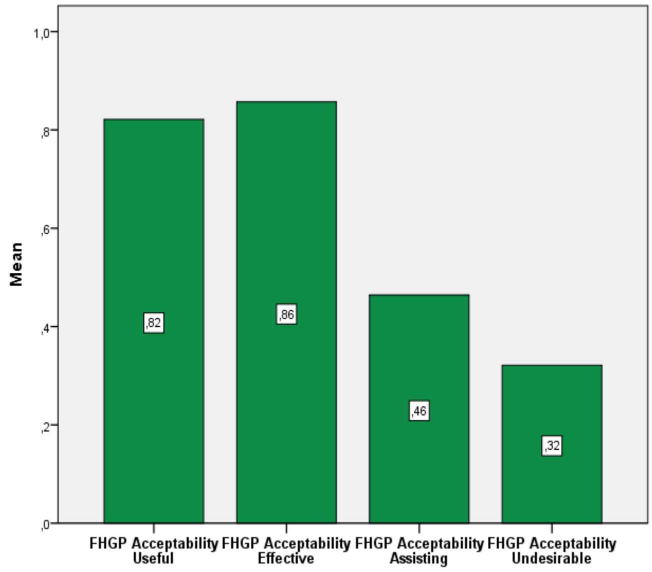

Figure 22 *FeDS + FHGP Acceptance mean scores.*

Third, FeDS + SHGP was the most assisting system modality (M = 0.70; SD = 0.91), followed by FeDS (M = 0.63; SD = 0.79), and FeDS + FHGP (M = 0.46; SD = 0.92).

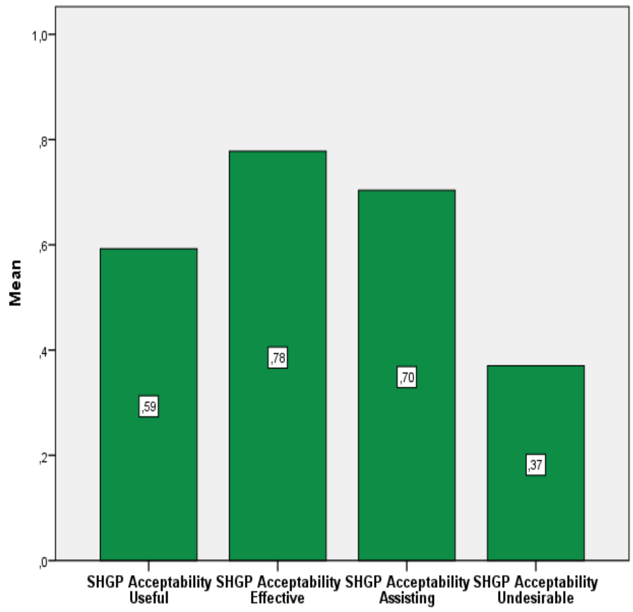

Figure 23 *FeDS + SHGP Acceptance mean scores.*

Lastly, the most desirable system modality was FeDS (M = 0.63; SD = 0.57), followed by SHGP (M = 0.37; SD = 0.82) and (FHGP M = 0.32; SD = 1.09)

The remaining Van der Laan Acceptance Scale items are presented below in median values. In *Pleasant* median values (see *Table 13*), FeDS showed the higher median punctuations (Md = 1.00), followed by SHGP (Md = 0.50), and FHGP (Md = -0.50).

Pleasant	Median	Standard Deviation
FeDS	1.00	0.64
FeDS + FHGP	-0.50	1.18
FeDS + SHGP	0.50	1.19

Table 13 *"Pleasant" scores.*

Bad scores (see *Table 14*) were equal for FeDS and FHGP (Md = 1.00) and lower for SHGP (Md = 0.00).

Bad	Median	Standard Deviation
FeDS	1.00	0.75
FeDS + FHGP	1.00	0.83
FeDS + SHGP	0.00	0.96

Table 14 *"Bad" scores.*

Nice median values (see *Table 15*) were higher for FeDS (Md = 1) and lower for FHGP and SHGP (Md = 0).

Nice	Median	Standard Deviation
FeDS	1.00	0.68
FeDS + FHGP	0.00	1.08
FeDS + SHGP	0.00	1.02

Table 15 *"Nice" scores.*

Irritating median values (see *Table 16*) were equal in FeDS, and SHGP conditions (Md = 1; Md = 1, respectively). FHGP median values were Md = 0.

Irritating	Median	Standard Deviation
FeDS	1.00	0.57
FeDS + FHGP	0.00	0.86
FeDS + SHGP	1.00	0.72

Table 16 *"Irritating" scores.*

Alertness medians (see *Table 17*) were higher for HGP conditions (Md = 1 in both cases) than in FeDS (Md = 0).

Alertness	Median	Standard Deviation
FeDS	0.00	0.75
FeDS + FHGP	1.00	0.74
FeDS + SHGP	1.00	0.71

Table 17 *"Alertness" scores.*

The results of the Friedman Test showed that there was a statistically significant difference in variables: *Pleasant* X^2 (2, n = 26) = 7.79, $p < 0.05$); *Bad* X^2 (2, n = 26) = 8.85, $p < 0.05$); *Nice* X^2 (2, n = 26) = 14.10, $p < 0.05$); *Irritating* X^2 (2, n = 26) = 12.23, $p < 0.05$); *Alertness* X^2 (2, n = 26) = 14.86, $p < 0.05$). Thus a Wilcoxon test was applied to explore the size effect with a Bonferroni alpha adjustment to 0.016 (0.05/3) between these variables. There were statistically significant differences ($p < 0.016$) between *Pleasant, Nice and Irritating* values in FeDS condition and FHGP condition; and in FeDS condition and SHGP condition. There also were statistically significant differences ($p < 0.016$) in item *Alertness* between FeDS condition and SHGP condition.

3.4.3 Other subjective measurements

The remaining questionnaire items medians' were also examined for the three system modalities. Inspection of *Effectiveness* median (see *Table 18*) values showed an increase in scores from FeDS (Md = 3) to FHGP (Md = 4) and SHGP (Md = 4).

Effectiveness	Median	Standard Deviation
FeDS	3.00	1.02
FeDS + FHGP	4.00	1.13
FeDS + SHGP	4.00	1.14

Table 18 *"Effectiveness" scores.*

Usefulness median values (see *Table 19*) showed a decrease in scores from FeDS (Md = 4) to FHGP (Md = 3), and a further increase in SHGP (Md = 4).

Usefulness	Median	Standard Deviation
FeDS	4.00	0.97
FeDS + FHGP	3.00	1.03
FeDS + SHGP	4.00	1.03

Table 19 *"Usefulness" scores.*

Satisfaction median values (see *Table 20*) showed equal scores in all conditions (Md = 3).

Satisfaction	Median	Standard Deviation
FeDS	3.00	0.86
FeDS + FHGP	3.00	1.02
FeDS + SHGP	3.00	1.11

Table 20 *"Satisfaction" scores.*

Affordability scores (see *Table 21*) were also similar, equal in FeDS (Md = 2) and FHGP conditions (Md = 2); but increased in SHGP (Md = 2.5).

Affordability	Median	Standard Deviation
FeDS	2.00	1.12
FeDS + FHGP	2.00	1.29
FeDS + SHGP	2.50	0.99

Table 21 *"Affordability" scores.*

No significant differences were found among these variables.

3.4.4 Free text responses

Participants also filled in some free text gaps with their opinion about the effectiveness, usefulness and satisfaction of the several FeDS modalities tested in trials. Bar charts presented below represent a qualitative response analysis, where each bar represents response frequencies accumulation, that is, number of inter-related comments or opinions. There were some recurring features through participants' opinions that should be pointed out.

As it is shown in *Figure 24*, participants suggested that FeDS in all modalities was especially effective for speed management when noticing speed limit changes while driving. HGP do not seem to increase the effectiveness of this feature. Where HGP stand out as more effective is when for maintaining the safety distance with a preceding vehicle. Furthermore, surprisingly, participants thought that HGP do not increase the FeDS' energy-saving effectiveness. Lastly, SHGP seems to be more effective as an early warning system than FHGP.

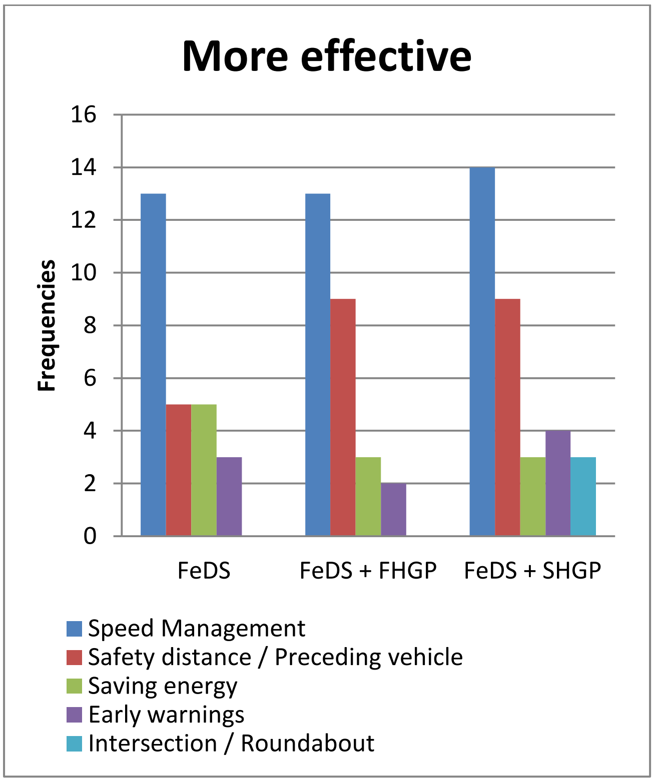

Figure 24 *Effectiveness frequencies. "More effective" free text responses.*

Figure 25 represents participants' reports related to less effective FeDS tested modalities. As the reader may see, all modalities, and especially with both HGP, are seen as less effective in intersections and roundabouts. Participants reported that the system is not effective when following vehicles at low speeds and it may make overtaking manoeuvres difficult when the HGP turns on. They also reported that the feel of the SHGP is not as intuitive as the FHGP, although its early warnings were rated as being more effective (see *Figure 24*). The reason may be, as participants declare, because SHGP only "warns to", meanwhile FHGP "orders to".

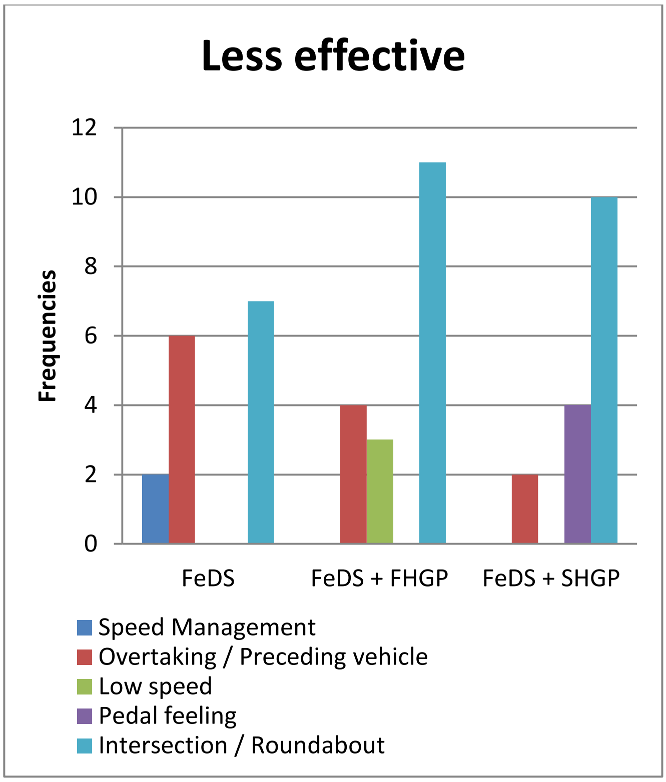

Figure 25 *Effectiveness frequencies. "Less effective" free text responses.*

Figure 26 displays what participants reported as more useful in each system modality. In this case, speed management is rated as the most useful feature in FeDS, and especially with both HGP. FHGP seems to be more useful in maintaining safety distance with a preceding vehicle. Moreover, participants also reported that all FeDS modalities were primarily useful in motorway driving and during long journeys. Another relevant issue is that participants declared that visual feedback was necessary and very useful for understanding the functioning of FeDS with FHGP. This suggests that when drivers are not used to haptic feedback, they need another kind of feedback more familiar to them (visual) in order to guide and support their eco-driving learning. In this case, FeDS without HGP seems to be seen as more useful when it comes to saving energy.

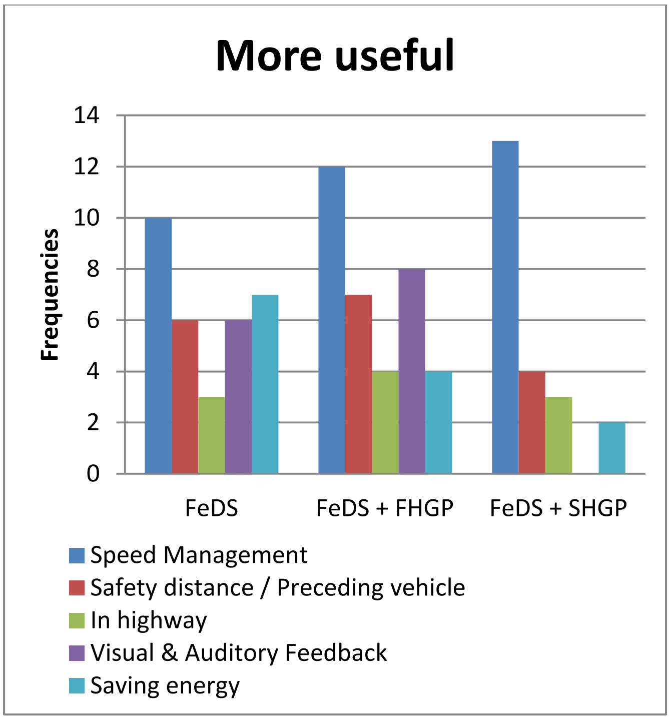

Figure 26 *Usefulness frequencies. "More useful" free text responses.*

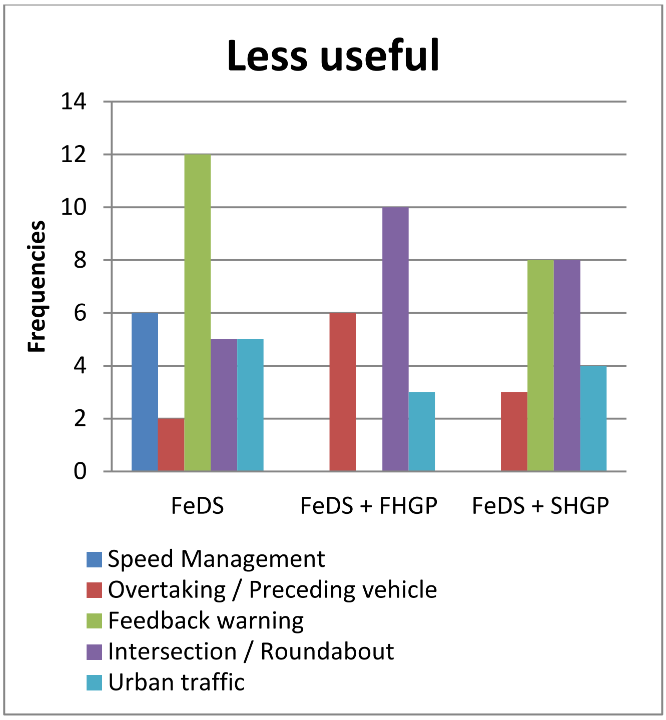

Figure 27 *Usefulness frequencies. "Less useful" free text responses.*

On the other hand, "Less useful" ratings are shown in *Figure 27*. As the reader may see, participants thought that FeDS with HGP modalities was less useful at intersections and roundabouts. FHGP seem to be the least useful in this scenario and also for overtaking when following other vehicles. This, together with ratings of urban traffic, suggests that FeDS modalities are not useful in urban driving for these purposes. Moreover, participants also complained that FeDS visual feedback warnings (e.g. curve warnings and behavioural feedback) were not at all accurate, and sometimes confusing. Furthermore, they also suggested that a HUD or an integrated display would be a better solution for presenting this visual information without taking their attention from the roadway. In addition, they reported that the HGP response was too early in some cases and that it should be configurable. They also reported that HGP sensation was less informative than a standard pedal, and it lacked real perceptible information.

Satisfaction reports represented in *Figure 28* were in line with those previously mentioned, as FeDS was primarily more satisfactory for speed management on a dual carriageway. HGP, and in particular FHGP modality, was especially satisfactory for this purpose, followed by maintaining safety distance with preceding vehicle, where SHGP was rated as the most satisfactory modality. Furthermore, as in previous "Effectiveness" reports (see *Figure 24*), HGPs were not perceived to be as satisfactory as FeDS for saving energy. Regarding feedback warnings, FeDS visual warning was stated to be very precise and clear, visually friendly, easy to learn and not intrusive. Moreover, FHGP feedback was more intuitive than SHGP feedback

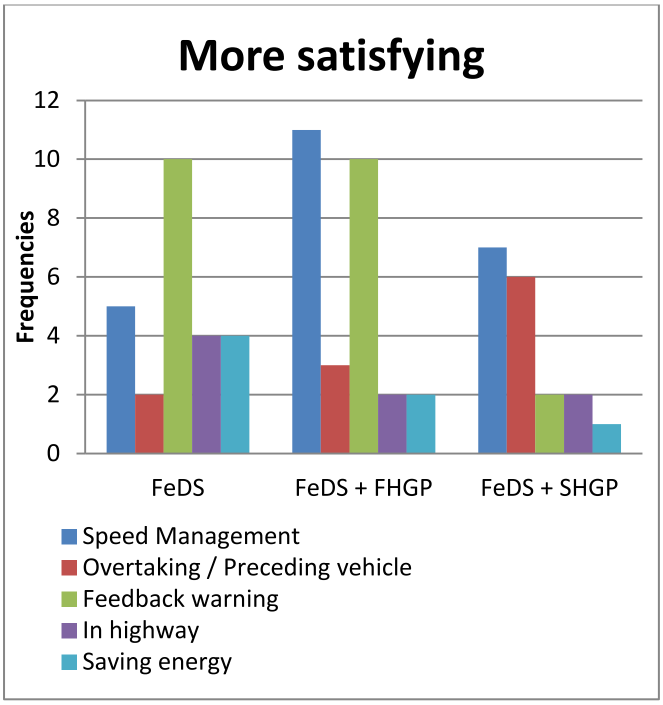

Figure 28 *Satisfaction frequencies. "More satisfying" free text responses.*

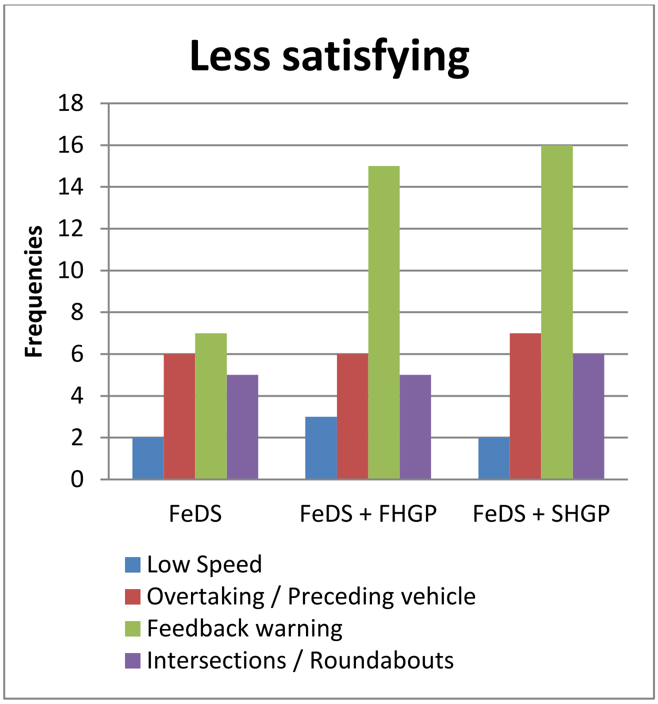

Figure 29 *Satisfaction frequencies. "Less satisfying" free text responses.*

Lastly, reports of "Less satisfying" features are represented in *Figure 29*. In all modalities, FeDS and HGPs were unsatisfactory neither in inter-urban traffic or low speed driving, at intersections and roundabouts nor, in particular, when accelerating to the dual carriageway with preceding vehicles. In this situation the HGP turns on abruptly and unnecessarily, making the manoeuvre disturbing. Thus, participants suggested that both HGP feedback warnings should be revised to improve their haptic feel and their operation. They also suggested that FeDS visual feedback should be more intuitive and clear, offering alternative driving strategies.

The main conclusions drawn from these results will be discussed in depth in the following section.

4. DISCUSSION

The initial purpose of the present paper was to test and validate the effectiveness of the FeDS combined with HGPs. In other words, to observe whether FeDS combined with HGPs helps to increase energy efficiency in terms of maintaining steadier speed values without altering average speed, and decreasing energy consumption. In addition, it was also designed to assess whether HGPs help to reduce subjective workload, as the haptic information presented through the pedals should lower visual information overload and therefore decrease subjective workload. Finally, there was also the need to test its acceptance by the users, which would indicate if the product is desirable and affordable for their daily use in real life.

In the present study the **sample profile** was mainly characterised by young men with broad driving experience and really up-to-date with using in-vehicle technology. Furthermore, the highest-rated items in the *Technology readiness* scale were statements related with the freedom and flexibility that technology offers; how technology can help to increase efficiency, and also the concept of technology as a personal challenge to enjoy, as well as learning how to use it. This indicates that participants were also willing to use new technology. On the other hand, the items rated with the strongest disagreement are statements related to the consequences of misusing technology, such as the dangers of carrying out financial operations on line. This is in accordance with the highest rated items in this scale, indicating that participants were really familiar with the latest technology as they knew quite well how technology can be misused nowadays.

Regarding the *Attitudes towards green behaviour*s scale, participants strongly agreed that they had a good knowledge of environmentally-friendly behaviour and that they were interested in saving as much energy as possible while driving. This result indicates that participants were susceptible and motivated to follow the advice provided by FeDS. In contrast, they did not think that eco-driving was currently a common practice with drivers; perhaps participants thought that environmentally-friendly behaviour is not often ingrained in most drivers' minds. This suggests that in future actions increasing the interest in being an eco-driver should be taken into account.

In conclusion, it seems that the sample profile was suitable for the purpose of the present study, those taking part had wide driving experience, were willing to use new technology and had a positive attitude towards environmentally-friendly behaviour.

Regarding laps driven by participants, the **objective data** analysed was average speed (km/h), speed standard deviation (km/h) and energy consumption (KW), registered during **each lap** of the trials in baseline and experimental conditions.

Significant differences were not expected at **average speed**; however, as it was a relatively short track, with frequent speed changes due to the changing road conditions, average speed differences may appear because of the event's nature, especially in HGP conditions.

Therefore, in agreement with initial main assumptions, no differences were found between average speed in baseline conditions and in experimental conditions; which suggests that using FeDS, plus its HGP modalities, did not affect average journey speed.

However, median speed values were lower across all experimental conditions than compared to baseline conditions. These results may be a point to bear in mind for future studies, to analyse if previously-mentioned route changes and the using of FeDS modalities, could increase differences in speed values. So, these variations could be caused by external factors like the mere nature of the track, or could be because the sample was made up by drivers who already employed eco-driving strategies. Future research should focus on longitudinal studies in order to clarify whether FeDS modalities affect average journey speed or the median differences obtained here are due to other factors which were not controlled.

Regarding **speed standard deviation**, differences were expected in experimental conditions, where speed should be steadier than in baselines, because of the effect of the FeDS. Despite the initial assumptions, no differences were found between speed standard deviation values in baseline and experimental conditions. Speed standard deviation similarities across all conditions may be because of the nature of the track, as happened in average speed. As it was a short and irregular track, it was hard to register clear speed standard deviation differences across modalities. For further research it would be interesting to test these over a longer track, or in a longitudinal study with limited and more homogenous scenarios such as motorway, urban track or rural route, in conditions that have been controlled as much as possible.

On the other hand, differences were also expected in **energy consumption** values between baselines and experimental conditions. Baseline conditions should report higher energy consumption than experimental conditions. Otherwise, differences between experimental conditions may be expected between FeDS and HGP conditions, as pedals should facilitate lifting the foot from the pedal sooner than while using the visual display, since the visual information overload is greater than with haptic information and thus haptic information is processed more quickly.

Energy consumption values showed a similar pattern to that observed before in average speed and speed standard deviation scores, namely, that no differences were found across conditions. A FeDS design limitation may explain this lack of differences. The modality tested here was initially designed for ICE vehicles with gearbox, but the vehicle used in the present study was full electric and had no gearbox. It is therefore mandatory for future research with ecoDriver to develop a system exclusively for EVs. Furthermore, it would be recommendable to test them in a sample which is less interested in green driving behaviour as the one used here.

Another possible explanation might be related to the type of feedback provided. There are modalities of feedback which are more useful and effective than others, depending on the scenario, the stimuli, the driver, etc. Thus, haptic feedback may not be the most suitable feedback modality when teaching eco-driver strategies, due to the nature of the learning process and the behaviour to be learnt. In fact, participants reported in free text responses that HGPs were perceived neither as effective, nor as useful, nor as satisfying as FeDS for saving energy.

However, there were participants who suggested that one of the advantages of using HGP was that they could keep their eyes on the road, whereas the FeDS forced them to look at the display screen. This would indicate that haptic feedback could be really useful and effective for warnings in other situations. Therefore further research is needed to elucidate which could also benefit from this type of feedback.

To continue discussing objective measurements, it was expected that FeDS and HGPs advice would help drivers to anticipate different **events** and assist them with the decision-making process, reducing speed progressively before reaching the given event, in order to drive at the recommended speed while negotiating it.

Firstly, in the event ***Curve***, speed differences were expected between baselines and system modalities before the event. However, no differences were found when analysing data. Nevertheless, it has to be said that in free text responses, participants replied that the curve warning signal displayed in the FeDS device was confusing and actually did not fulfil in its purpose. The problem was that the warning always a signalled a curve turning to the right, so that when in fact it turned to the left, the alert could confuse the driver. Further studies should improve the way of displaying curve information in order to resolve this problem.

Taking these results into consideration, there is no clear evidence as to which is the best feedback modality for curves.

Secondly, for the ***Speed limit*** event it was expected that FeDS modalities would help participants to detect speed limitations and avoid exceeding them.

As expected, speed was higher during the event than before and after the event, once when drivers reached the top speed allowed on the dual carriageway, the system alerted them and they then slowed down immediately.

Moreover, differences between the FeDS and HGP modalities were found before, during and after the event. Before and during the event, FeDS registered the lowest value, whereas, after the event it was the SHGP which reached the lowest value, followed by the FeDS. Taking these data into consideration, it is clearly suggested that FeDS seems to be the most effective warning in order to avoid exceeding legal speed limits. Furthermore, subjective free text responses support this statement. Participants agreed that FeDS was really effective and useful for speed management and, especially when combined with HGPs, it was also more satisfying.

Thirdly, in the ***Predecessor*** event, speed differences were expected between the first baseline and experimental conditions, and also between FeDS and HGPs. HGPs should help to accelerate driver response on the gas pedal; thus speed after the event with HGPs should be lower than FeDS and baseline 1. Before the event it was expected that speed would be quite similar across all conditions; but during the event it should be lower in experimental conditions because of the FeDS and HGPs effect.

However, no differences were found across conditions. Further research is also needed in this area, as participants' subjective evaluations suggest that FHGP was really effective and useful for maintaining the safety distance. Nevertheless, many of them also agreed that it was not useful when they tried to overtake a vehicle, or when moving to the fast lane from the slow lane. So in further investigations this should be taken into account and modified in order to avoid these disturbing situations.

Finally, in the event ***Intersection***, speed differences before the event were expected between the first baseline and experimental conditions; as FeDS, and specially HGPs, should help to advise drivers about an imminent intersection and therefore reduce their speed before reaching the event.

Some interesting differences were found across conditions. FHGP registered the lowest values across all conditions, evidencing its effectiveness above the rest. This phenomenon may be explained because FHGP was more intrusive and "forced" drivers to reduce their speed during the event. Meanwhile, the last baseline showed a similar pattern to experimental conditions so maybe in future studies the question of whether participants learnt to anticipate the event and took the roundabout slower could be investigated.

Taking this data into consideration, it seems that FHGP is the most recommendable feedback modality for intersection or roundabout events in terms of safety and efficiency. Assuming that a roundabout should be taken at under 40km/h, the FHGP was the only feedback modality which helped drivers to maintain this speed. Nevertheless, it has to be said that participants complained that FHGP was actually less effective and useful in roundabouts as it hampered the natural manoeuvre, hindering acceleration while negotiating the roundabout. So in forthcoming investigations, the pedal needs to be fine-tuned and reviewed in other to avoid disturbing situations, allowing the driver to have full control over the gas pedal during the roundabout manoeuvre.

Having dealt with the main objective data, subjective measurements will now be discussed. It was expected that subjective data would support the main findings in objective data previously discussed, and furthermore that it would help to understand the principal limitations and suggestions found in users' opinions.

The first scale to be discussed here is the **NASA-TLX** scale. It was administered in the expectation of equal or higher values for FeDS compared to baseline conditions. Furthermore, it was expected that HGP modalities would obtain lower workload values compared to FeDS, as HGP should help to reduce visual overload produced by FeDS' displayed information.

Actually, no significant workload differences were found between baseline and experimental conditions, and total workload values were really low, as the highest median was 14.5 out of 60 in FHGP condition. However, given that the system tested is a prototype, the feedback provided had its limitations when turning on/off, and the haptic sensation provided may not be the most suitable nor comfortable for drivers. Participants suggested that their workload might be reduced after increased time exposure to HGPs. So, further long-term research with a similar sample is needed to ascertain how FeDS and HGPs increase or reduce workload.

Analysing the subscales independently, subscale *Effort* showed statistically significant differences between HGP conditions and baseline 2. This outcome implies that using HGPs required a little more effort from drivers compared to driving without any system. However, the reader should remember that haptic feedback's main purpose was also to raise drivers' attention, so it has to be a demanding modality. It is possible that drivers mistook attention changes for overload, when they were simply more aware of their environment as a result of the haptic feedback. Therefore, after driving three laps with experimental modalities, it seems reasonable that participants should rate their perceived effort on the last baseline run so low when compared to HGP conditions.

Thus, before making definitive conclusions about whether HGPs workload in real driving conditions would be counterproductive, a longitudinal further investigation on drivers' habituation on HGP while driving is needed. In fact, one of the main purposes of HGP, as stated before, is to catch drivers' attention and cause an immediate behavioural response. The results indicate that there are statistical effort differences between HGPs conditions and baseline 2, which suggests that if HGPs were really effortful and demanding, they could also be truly effective in their purpose.

The second scale used for gathering subjective data was the **Van der Laan Acceptance scale**. It was considered that HGPs would help increase FeDS acceptability, as pedals supported the information provided by the visual channel and made it easier to follow the eco-driving counsels displayed. Indeed, the tendencies observed indicate that the FeDS was in many aspects more acceptable than both HGPs. Significant differences observed between system modalities suggested that FeDS was more *pleasant*, *nice*, *desirable* and less *irritating* than both HGPs, implying that the HGPs should be improved to make them less annoying for users.

As an alternative, making turning on the FHGP smoother and less abrupt would help to increase its acceptance. In fact, FHGP was the most useful and effective feedback modality for eco-driving. This indicates that although the FHGP was an adequate feedback modality for learning eco-driving strategies, its main limitation was in its tuning. Thus, improving the force feedback in further investigations in order to make it more acceptable for drivers would be a good solution as an eco-driving aid.

Regarding irritability differences, one reason why FHGP was perceived as more *Irritating* may be because its way of turning on and off was really abrupt. Some participants pointed out in free text responses that such an aggressive pedal movement with no previous warning, made this way of turning on confusing, leading them to think that the pedal was broken.

On the other hand, *Alertness* differences between FeDS and SHGP suggest that SHGP is a better solution than FeDS for raising drivers' alertness, which is in agreement with the initial purpose of this feedback modality. Moreover, SHGP was the most *assisting* feedback modality, which is in agreement with the reports provided by some participants in free text replies. They felt that SHGP was more effective as a warning system than other feedback modalities, but not when learning eco-driving strategies. This suggests that SHGP might be a good system to implement in terms of safe driving as a rapid warning system. However, similarly to FHGP, its main limitation in the present study resides in its tuning. SHGP was considered as a *bad* system modality compared to others. Indeed, some participants pointed out in the free text responses that employing a different vibration pattern, similar to that used in currently smartphones, would make the SHGP friendlier and more intuitive.

Finally, there are other subjective items which also assess *Effectiveness*, *Usefulness*, *Satisfaction*, and *Affordability* to complete the gathering of subjective data.

Both HGPs were perceived as more effective than FeDS; FeDS and SHGP were felt as more useful than FHGP. All three were equally satisfying in a neutral way; i.e. the system was neither totally satisfying nor completely disturbing.

However, in terms of affordability, participants manifested that they would not want to pay extra to install those systems in their own car. But they also claimed that if the system were improved in certain aspects, they would be happy to have it in their car.

But as mentioned previously, on balance, each feedback modality had its particularities and was specifically recommendable for different situations. For instance, FeDS was experienced as the best modality for saving energy whilst FHGP was good for maintaining safety distance and speed management and SHGP was recognised as offering excellent warning feedback.

By contrast, HGPs were not good for saving energy, neither when driving slowly nor in roundabouts. Additionally, their haptic feel should be improved in many aspects in order to make it less disturbing. On the other hand, FeDS visual feedback would be better if integrated into a HUD in order to avoid restricting the view of the road, as the nomadic device is sometimes hard to read. Moreover, additional behavioural advice or instructions could be given (by auditory signals for instance) in order to facilitate eco-driving strategies, because sometimes the visual feedback is confusing and drivers do not know what are they doing wrong.

5. CONCLUSIONS

To sum up: this was a first study performed to test and validate the FeDS and its haptic gas pedal modalities in real driving conditions in terms of energy efficiency and, ultimately, driving safety. Finding significant differences in a sample of participants so accustomed to trying out new in-vehicle systems suggests that in any future research with samples of quite average drivers, these differences could prove to be even more remarkable.

Overall, the main results evidence that the FeDS and its FHGP modality provide the best guidance feedback for saving energy and in many cases it can also increase safety. The FeDS visual feedback is the most recommendable feedback modality for speed management and energy efficiency, as it provides a helpful aid to decision-making and eco-driving strategies learning processes. However, the FHGP feedback modality is mainly recommendable at intersections or roundabouts. Moreover, participants' subjective assessments clearly support these main findings. Workload measurements evidence that despite the need to improve some features, the visual feedback provided by the FeDS and the haptic feedback provided by the FHGP do not substantially increase perceived workload. Furthermore, those feedback modalities were well accepted in terms of effectiveness and usefulness. Despite that, the main system design limitations resulted in neither unfavourable Satisfaction nor Affordability results. However, being optimistic, system improvement is possible, so it is to be expected that in further research drivers would eventually be satisfied and requesting installation of these systems in their own vehicles as another on-board aid system.

One more relevant result that cannot be ignored is regarding the learning effect observed in the second baseline. It is very promising for FeDS to generate a learning effect in drivers after approximately just one hour driving with it. But in fact, some drivers showed an eco-driving learning process in the second baseline. This effect was also observed previously in Beusen et al. (2009) who studied the impact of long-term exposure to an eco-driver system and observed large differences among drivers, most of whom improved their driving habits in the long term. Although such longitudinal differences have not been studied here, they clearly support the main findings in the present study. In this sense, the present research contributes to bringing new evidence to support FeDS' main purpose, which is to teach efficient driving strategies and facilitate drivers' decision-making processes through several feedback modalities, in order to help increase driving efficiency reducing by energy consumption.

All in all, the main results discussed here are in agreement with previous ecoDriver research that tested the FeDS system in driving simulators and obtained similar results; Hibberd et al. (2015) and Jamson et al. (2015b) found that FHGP was the most effective modality for energy efficiency in scenarios where drivers were required to decelerate, while Jamson et al. (2015a) demonstrated the benefits of visual and haptic systems for providing eco-driving feedback on efficient accelerator pedal usage.

The next step in further research is to compare other feedback modalities in real driving conditions. For instance, testing the FeDS with visual and auditory feedback modalities, as auditory information may be useful in some circumstances where the visual information causes overloaded. Moreover, it would also be interesting to carry out a longitudinal FOT comparing both HGPs specifically for different events. The FHGP could be used in situations where it has shown its effectiveness, but SHGP could be tested in new scenarios as a warning feedback modality.

In conclusion: at present, the main objective for road and transport researchers in eco-driving solutions should be to concentrate their efforts on performing FOTs in order to validate the most recommendable feedback modalities and try to integrate them in production vehicles, bringing these solutions into our daily life on the road.

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ANNEXES

Annex 1. Sample profile

The reader may find below the charts regarding scales used to describe the sample profile in the present study. As the scales were extensive, the author had to subdivide them into several smaller charts to make it clearer for the reader. In each chart the mean scores for each item are represented in their natural order. From *Figure 30* to *Figure 35* the items from the *Technology readiness* scale are represented in groups of six.

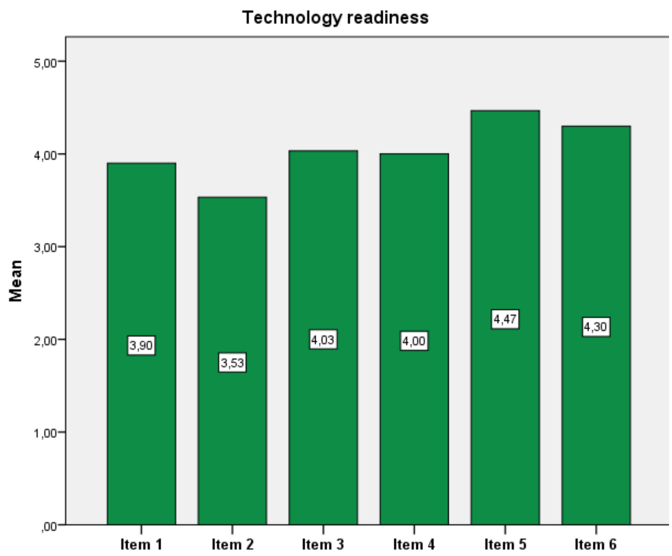

Figure 30 *- Technology readiness. Items 1 to 6.*

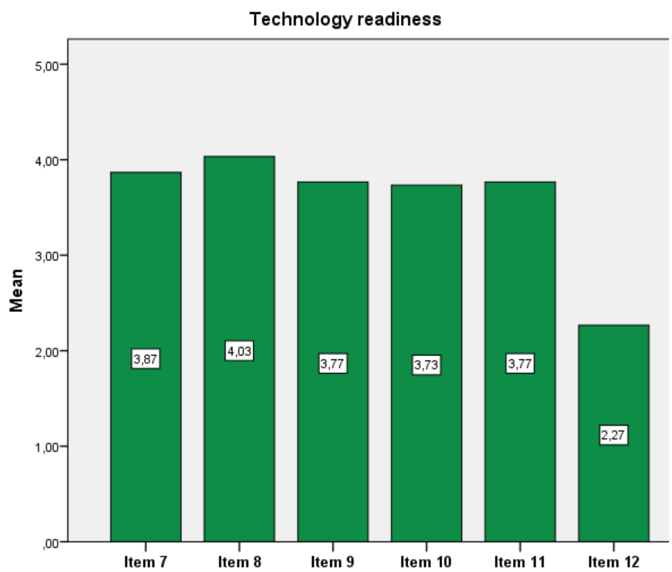

Figure 31 – *Technology readiness. Items 7 to 12.*

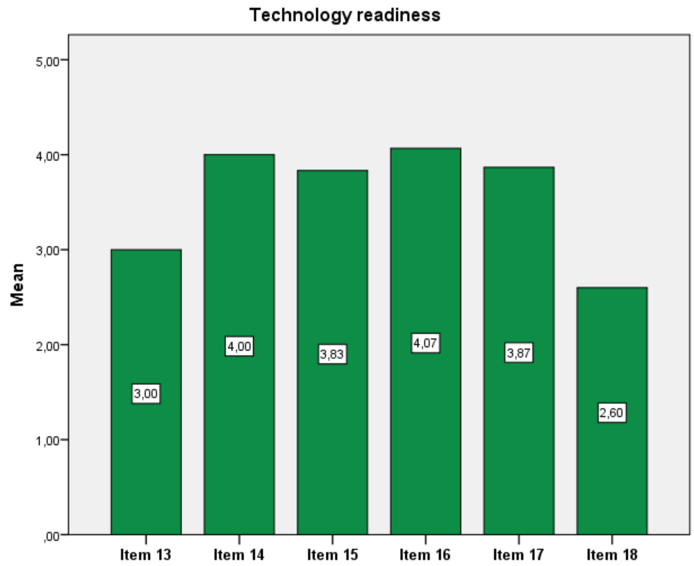

Figure 32 *– Technology readiness. Items 13 to 18.*

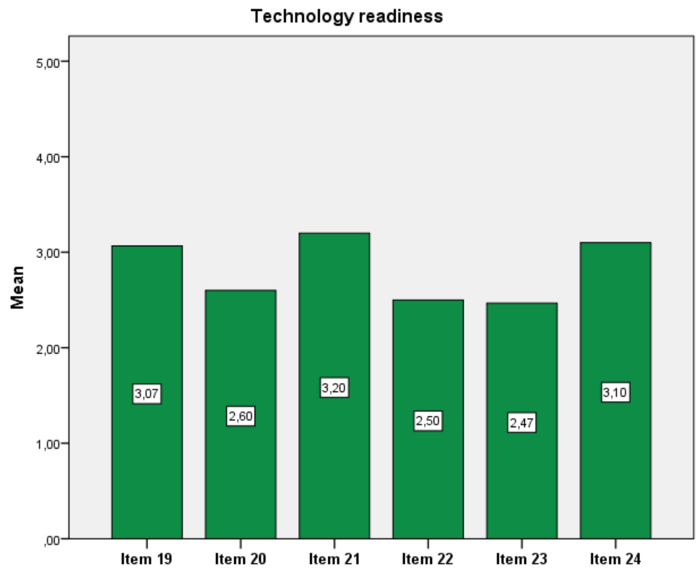

Figure 33 *– Technology readiness. Items 19 to 24*

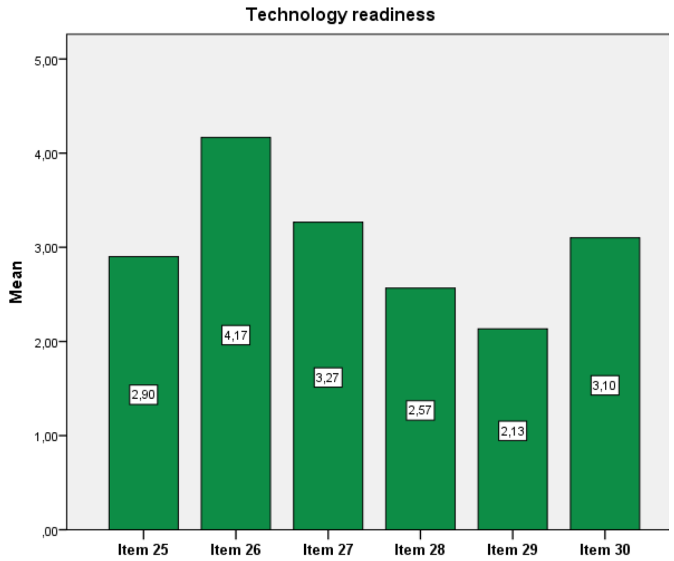

Figure 34 *– Technology readiness. Items 25 to 30.*

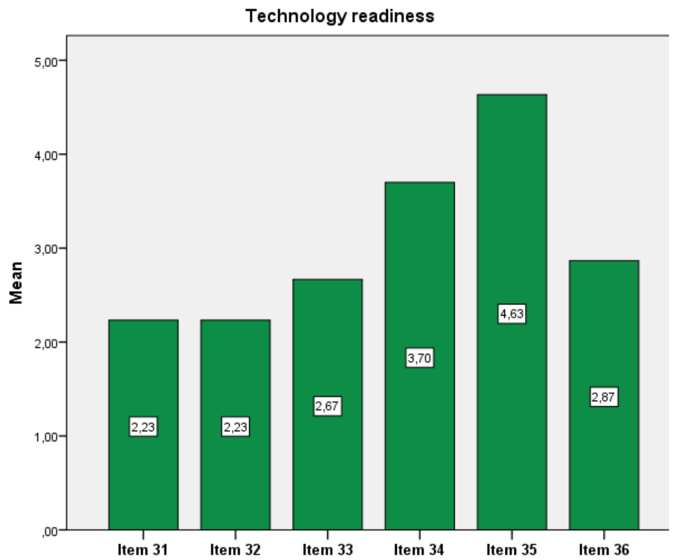

Figure 35 – *Technology readiness. Items 31 to 36.*

Moreover, the same has been done with the scale *Attitudes towards green behaviours*, where items are represented in groups of five in their natural order from *Figure 36* to *Figure 38*.

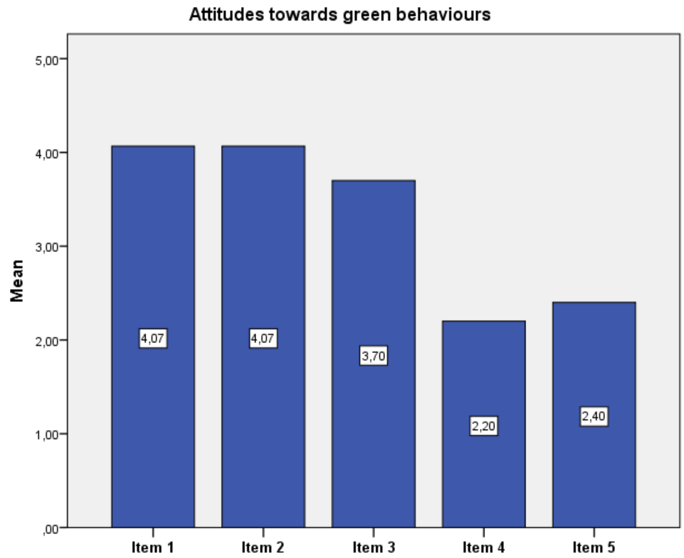

Figure 36 – *Attitudes towards green behaviours. Items 1 to 5.*

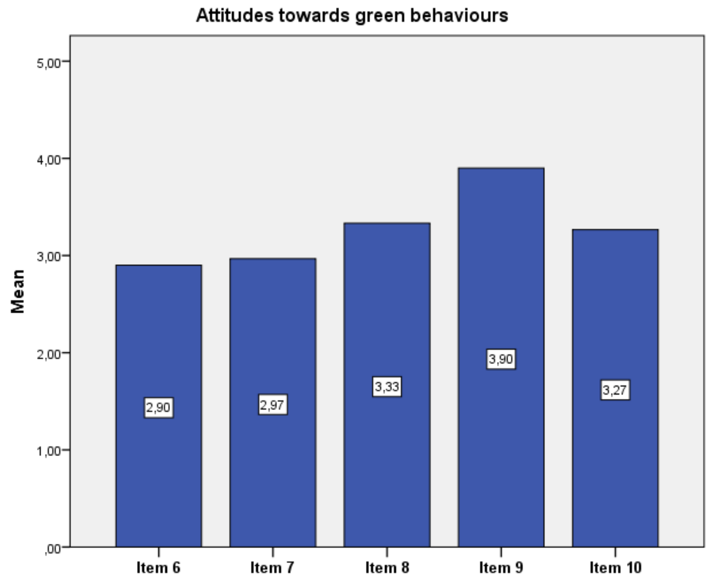

Figure 37 - *Attitudes towards green behaviours. Items 6 to 10.*

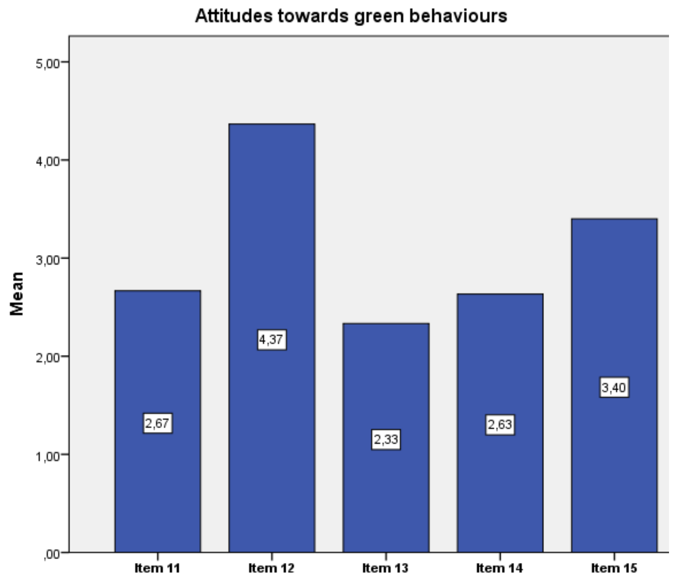

Figure 38 *- Attitudes towards green behaviours. Items 11 to 15.*

Annex 2. Questionnaires

Participant ID:	Date:	Questionnaire ID: PreBaseline

Thank you for volunteering to take part in this study. We would be grateful if you could take a few minutes to answer the following questions. The questions provide us with information about you, your driving experience and your attitude towards technology. All of the information you provide will be kept confidential.

About you

1. Are you? Male ☐1 Female ☐2
2. What is your date of birth? DD / MM / YYYY
3. What is your employment status?

Employed full time	☐1	Employed part time	☐3	Retired	☐5
Unwaged/not looking for work	☐2	Student	☐4	Unemployed	☐6

4. Do you hold a valid licence to drive a [car, bus, truck]? Yes ☐1 No ☐2
5. In which year did you obtain your [car, bus, truck] licence? ________
6. On average, how many kilometres do you drive a [car, bus, truck] a year? ________kilometres/year

Experience with technology

7. Please indicate how much practical experience you have with these in-vehicle technologies (tick one box per line):

	None, never used	Some, brief experience	Prolonged experience
Route navigation	☐	☐	☐
Cruise control (maintains a steady speed as set by the driver)	☐	☐	☐
Reverse parking aid (detects obstacles behind to aid parking)	☐	☐	☐
Curve speed warning system (warns the driver about inappropriate speed when approaching a bend)	☐	☐	☐
Adaptive cruise control (automatically adjusts the speed to ensure the vehicle does not get too close to the one in front)	☐	☐	☐
Speed limiter (controls the maximum speed of the vehicle)	☐	☐	☐
Blind spot monitoring (detects when a car or motorcycle has entered the driver's blind spot)	☐	☐	☐
Forward collision warning (monitors distance to the vehicle in front and alerts the driver when they are too close)	☐	☐	☐
Fuel efficiency advisor (provides advice regarding fuel	☐	☐	☐

consumption)			
Lane departure warning system (assists the driver in maintaining lane position, giving a warning if the vehicle crosses lane markings unintentionally)	☐	☐	☐
Impairment warning system (alerts tired and distracted drivers by monitoring car's movements between the lane markings)	☐	☐	☐

Technology Readiness

8. Below there are phrases describing peoples' attitudes to technology. Please use the rating scale opposite each phrase to describe how accurately each statement describes *you*.

Please read each statement carefully, and then circle for each statement the appropriate response that describes you.

	Strongly disagree				Strongly agree
Technology gives people more control over their daily lives	1	2	3	4	5
Products and services that use the newest technologies are much more convenient to use	1	2	3	4	5
You like the idea of doing business via computers because you are not limited to regular business hours	1	2	3	4	5
You prefer to use the most advanced technology available	1	2	3	4	5
You like computer programs that allow you to tailor things to fit your own needs	1	2	3	4	5
Technology makes you more efficient in your occupation	1	2	3	4	5
You find new technologies to be mentally stimulating	1	2	3	4	5
Technology gives you more freedom of mobility	1	2	3	4	5
Learning about technology can be as rewarding as the technology itself	1	2	3	4	5
You feel confident that machines will follow through with what you instructed them to do	1	2	3	4	5
Other people come to you for advice on new technologies	1	2	3	4	5
It seems your friends are learning more about the newest technologies than you are	1	2	3	4	5
In general, you are among the first in your circle of friends to acquire new technology when it appears	1	2	3	4	5
You can usually figure out new high-tech products and services without	1	2	3	4	5

help from others					
You keep up with the latest technological developments in your areas of interest	1	2	3	4	5
You enjoy the challenge of figuring out high-tech gadgets	1	2	3	4	5
You find you have fewer problems than other people in making technology work for you	1	2	3	4	5
Technical support lines are not helpful because they do not explain things in terms you understand	1	2	3	4	5
Sometimes, you think that technology systems are not designed for use by ordinary people	1	2	3	4	5
There is no such thing as a manual for a high-tech product or service that is written in plain language	1	2	3	4	5
When you get technical support from a provider of a high-tech product or service, you sometimes feel as if you are being taken advantage of by someone who knows more than you do	1	2	3	4	5
If you buy a high-tech product or service, you prefer to have the basic model over one with a lot of extra features	1	2	3	4	5
It is embarrassing when you have trouble with a high-tech gadget while people are watching	1	2	3	4	5
There should be caution in replacing important people-tasks with technology because new technology can breakdown or get disconnected	1	2	3	4	5
Many new technologies have health or safety risks that are not discovered until after people have used them	1	2	3	4	5
New technology makes it too easy for governments and companies to spy on people	1	2	3	4	5
Technology always seems to fail at the worst possible time	1	2	3	4	5
You do not consider it safe giving out a credit card number over a computer	1	2	3	4	5
You do not consider it safe to do any kind of financial business online	1	2	3	4	5
You worry that information you send over the Internet will be seen by other people	1	2	3	4	5
You do not feel confident doing business with a place that can only be reached online	1	2	3	4	5
Any business transaction you do electronically should be confirmed later with something in writing	1	2	3	4	5
Whenever something gets automated, you need to check carefully that	1	2	3	4	5

the machine or computer is not making mistakes					
The human touch is very important when doing business with a company	1	2	3	4	5
When you call a business, you prefer to talk to a person rather than a machine	1	2	3	4	5
If you provide information to a machine or over the Internet, you can never be sure it really gets to right place	1	2	3	4	5

Attitudes towards green behaviours

9. To what extent do you agree or disagree with the following set of statements? Please circle the appropriate number.

	Strongly disagree				Strongly agree
I have a good understanding of which driving behaviours are environmentally friendly	1	2	3	4	5
It is important to me that I save as much fuel as possible while driving	1	2	3	4	5
I care whether my driving style is negatively impacting on the environment	1	2	3	4	5
Drivers generally drive with the environment in mind.	1	2	3	4	5
Most drivers think it is a good idea to drive with the environment in mind.	1	2	3	4	5
I buy certain products specifically because they are better for the environment	1	2	3	4	5
I avoid products packaged in excessive packaging	1	2	3	4	5
If distance allows, I walk or ride a bike to my destination	1	2	3	4	5
I have a good understanding of which driving behaviours lead to saving fuel	1	2	3	4	5
It is important to me that my driving style has minimal impact on the environment	1	2	3	4	5
Drivers generally know how to get the most out of a tank of fuel.	1	2	3	4	5
Most drivers think it is a good idea to spend less on fuel.	1	2	3	4	5
I am happy to pay a bit more for fuel if it means I can drive the way I want	1	2	3	4	5
I wash laundry in cold water specifically to save energy	1	2	3	4	5
I keep the heating or cooling in my home or workplace at low settings to save energy	1	2	3	4	5

Participant ID:	Date:	Questionnaire ID: PostExposure

We would be grateful if you could answer the following questions. The questions provide us with information about your attitudes and expectations of the system. All of the information you provide will be kept confidential.

System acceptability

1. Imagine driving with the system and how it might affect your driving. Tick one box on each line.

useful						useless
pleasant						unpleasant
bad						good
nice						annoying
effective						superfluous
irritating						likeable
assisting						worthless
undesirable						desirable
raising alertness						sleep-inducing

Effectiveness

Effectiveness relates to the extent to which the system achieves its objectives. How effective was system in influencing your eco-friendly/fuel-efficiently behaviour?

1. Please rate how effective you found the system on the scale below.

The system was effective	**Strongly disagree**	1	2	3	4	5	**Strongly agree**

2. In which situations was the system most effective?

____
____
____

3. In which situations was the system least effective?

____
____
____

Usefulness

Usefulness relates to how well you think the system improves your own driving performance. How much you think you would need such a system in order to be able to drive more eco-friendly/fuel-efficiently?

4. Please rate the system using the scale below

The system was useful	**Strongly disagree**	1	2	3	4	5	**Strongly agree**

5. In which situations was the system most useful?

____
____
____
____

6. In which situations was the system least useful?

____
____
____
____

Satisfaction

Satisfaction relates to your approval of the system, how desirable or likeable you find the system. Think about whether the system was pleasant and likeable or irritating and annoying.

7. Please rate the system using the scale below.

The system was satisfying to use	**Strongly disagree**	1	2	3	4	5	**Strongly agree**

8. In which situations was the system most satisfying?

____
____
____
____

9. In which situations was the system least satisfying?

____
____
____

Affordability

Affordability relates to whether you are willing to pay to purchase, install and maintain the Full ecoDriver System.

10. Please rate if you would be willing to pay extra for the Full ecoDriver System on the scale below

If the system was an optional feature on a new car, I would be willing to pay extra to have it fitted	**Strongly disagree**	1	2	3	4	5	**Strongly agree**

Study evaluation

21. We are interested in finding out about your experience of taking part in the study. Please rate the following aspects of the study on the scales provided.

	Poor				**Excellent**
Explanation of the ecoDriver system	1	2	3	4	5
Explanation of the study requirements	1	2	3	4	5
Administration of the questionnaires	1	2	3	4	5
Level of support provided for system difficulties	1	2	3	4	5

22. Please provide below any other comments on the study organisation, administration and communication.

____

____

____

____

____

____

____

Thank you for taking the time to complete this questionnaire

THE TLX QUESTIONNAIRE

The initials TLX stand for Task Load indeX and this questionnaire is designed to assess your own feelings and perceptions about the difficulty and mental workload associated with the drive you have just completed.

The questionnaire divides workload into a number of contributing factors and all these factors add up to the total difficulty of the drive. Please read the definitions of each factor carefully before completing the questionnaire.

DEFINITION OF 6 FACTORS WHICH DESCRIBE THE LOADS PLACED ON AN INDIVIDUAL DURING THE DRIVING TASK

MENTAL DEMAND
This refers to the 'thinking' component of the driving task. For example, consciously making decisions about the traffic environment or deciding how to respond to the scenarios. How much of this type of thinking, deciding, calculating, remembering, looking, searching, etc. did you need to do? Was the task easy or demanding, simple or complex in this respect?

PHYSICAL DEMAND
How much physical activity was required (e.g. operating brake, clutch and accelerator, steering the vehicle, using the indicator, etc.)? Was the drive easy or demanding, slow or brisk, slack or strenuous in this respect?

TIME PRESSURE
Did you feel you had enough time to adequately perform the driving task?

PERFORMANCE
How satisfied were you with your performance in achieving the goals of the driving task i.e. safe driving?

EFFORT
How hard did you have to work (mentally and physically) to achieve your level of performance? Did you feel stretched or comfortable during the drive?

FRUSTRATION LEVEL
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the driving task?