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Learning eco-driving behaviour in a driving simulator: Contribution of instructional videos and interactive guidance system

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ABSTRACT

The present paper deals with how to design and test an eco-driving training tool in the form of a digital educational game, including a specific guidance system interface to teach eco-driving rules. We tested whether learners could reproduce the eco-driving behaviour and implement the rules once they were autonomous. We also aimed to validate the method as a relevant eco-driving teaching tool that does not distract drivers or affect safety behaviour. We examined the contribution of the guidance system to teach procedural skills compared with traditional teaching methods such as video instruction. Results reveal that both methods lead to reduced CO^2 emissions, but that the reduction is greater with the interactive guidance system. Further analysis and an eye-movement study revealed no increase in driving time or effect on safety.

1. Introduction

The aim of the study presented in this paper was to test the learning value of training programs to teach eco-driving in an immersive simulated environment and a multimedia learning tool interface embedded in the simulator.

Programs were designed in such a way that participants could complete the training on their own, without the presence of an instructor. The goal was to propose a complete training tool for eco-driving, enabling participants to learn autonomously how to apply each eco-driving rule efficiently and thus reduce their fuel consumption.

Two programs were tested, one based on instructional videos, the other combining instructional videos with an interactive guidance device embedded in the simulator. A baseline program was added for experimental control. The design principles of the interactive guidance device were based on recent research and the results of studies on multimedia learning in the field of educational psychology (Mayer, 2014).

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1.1. Eco-driving

"Eco-driving" is a concept used to describe energy-efficient use of vehicles. It is a driving strategy that aims at reducing fuel consumption, so that less fuel is used to travel the same distance. It is proven to be a driving style that encompasses road safety, consideration, comfort, and efficiency. It is also seen as an economic, environmentally friendly method that leads to reduced air and noise pollution, fuel savings for the individual and corporate organizations (UK Road Safety Lt, 2012).

There are several eco-driving operations referred to as "rules" that drivers can learn. Once acquired, their use could lead to significant fuel savings (e.g. Ericsson, 2001; Van der Voort, 2001). In a study by Ford Motor Company (2008) the authors claimed that implementation of rules improve by 25% fuel economy during short-term context situation (see also Hennig, 2008). While, in sustained, casual driving practices, others report that fuel savings are conservatively calculated at 10% (International Transport Forum, 2007).

However, this driving "style" is a complex activity, comprising over hundreds of separate tasks (Walker, Stanton, & Young, 2001). Previous studies tend to show that a full training (that includes theoretical learning, then practice with an observer) leads to higher improvement comparing to "classroom" teaching, that is to say theoretical learning only (Andrieu & Saint Pierre, 2012; Symmons, Rose, & Van Doorn, 2008).

Furthermore, even when drivers show immediate improvement, it had been reported that they will eventually return to their usual driving patterns on long-term period (Beusen et al., 2009).

The explanation could be that learning an eco-driving style requires acquiring and transforming declarative and procedural knowledge (the eco-driving rules) into practical skills (Anderson, 1993). A full training might be more prone to enable efficient integration of eco-driving behaviour into an operational mental model. Yet organizing periodic reminders requires time and the financial resources to afford the presence of an instructor.

To address this issue, an alternative teaching method we chose is providing training with the help of a multimedia educational interface, embedded in a high scale simulator for practice. Immersive simulation is mainly used for driving learning, experimental research on human behaviour, and automotive engineering (Parodi-Keravec et al., 2011; Azzi et al., 2010; Kemeny, Kelada, & Liano, 1997). Full scale driving simulation enables eco-driving skill acquisition with a practical experience in an interactive, dynamic environment. The drivers can exercise and reiterates the trials autonomously, without being apprehensive of physically damaging accidents. Moreover, elaborated road scenarios can support the learning of the targeted behaviour in a custom-built-way, and ultimate assessments can be objective, precise and extensive.

Numerous researches also experiment eco-driving learning efficiency with the help of eco-driving assistance systems embedded in the driving simulator's cockpit (Rakauskas, Graving, Manser, & Jenness, 2010; Voort et al., 2001), and highlighted their positive impact on fuel consumption and CO^2 emissions. That type of system contributes to reach higher eco-efficient behaviour by offering a more refined guided learning experience. Literature states that if the system is appropriately designed (Vicente & Rasmussen, 1992; Jamson et al., 2015; Vaezipour, Rakotonirainy, Haworth, & Delhomme, 2017), not only it can teach to the drivers "what" to do, it also enables to know "when" to implement the rules and "how much" (e.g. immediate feedback indicates how much emissions increase as more pressure is put on the accelerator), therefore it leads to a more comprehensive learning of eco-driving behaviour.

Although this raises the question of the impact eco-driving and other types of in-vehicle systems on driver's safety (Vaezipour et al., 2017). Any additional interaction with the drivers during driving activity may cause distraction due to the increased complexity of the task. As a result, it may be demanding regardless of whether or not it is designed for eco-driving or safe driving style (Oviedo-Trespalacios, Haque, King, & Washington, 2016). The increasing amount of visual information may compromise the driver's safety. Therefore, these concerns are taken into consideration during the design process and development of in-vehicle systems. The objective is that the eco-safe in-vehicle systems have minimal impact on driver's attention distribution processes. The driver's glance patterns must be recorded to evaluate this impact.

1.2. Eco-driving learning interface

Reinforcement of legislation and, for example, the banning of hand held mobile phone use (Young, Regan, & Hammer, 2003) is directed to help tackle the symptom of the distraction issue. However, a more ergonomic approach would be to treat the root cause of the problem by focusing on the instructional design of the interface. There's an important database in the field of ergonomics, transportation and Human Machine Interfaces (HMI) focusing on driver's distraction and driver's workload with the aim to generate guidelines to help integrate complex and real-time-changing information into onboard interfaces – namely design concepts based on Ecological Interfaces Design principles ("EID"; Burns & Hajdukiewicz, 2004).

In the context of our study, the training tool is not aimed at giving providing the drivers with assistance once he is on road. The objective is to teach eco-driving to the drivers with the perspective to allow them to implement the autonomously in their daily life, without any assistance. In addition to taking into consideration the EDI principles mentioned above to design our interface, we took the decision to base the design of the critical features of the interactive device on an approach usually used in cognitive educational psychology. More specifically, the researches on learning with multimedia supports offer relevant data for the elaboration of instructional design dedicated to help learning processes. The scientific basis for the design of the guidance system is The Cognitive Theory of Multimedia Learning ("CTML", Mayer, 2014). It states that any additional information is more information to process, even if it was intended to help (Mayer, 2005, 2014). The driver's environment is dynamic and transient. Learning a new behaviour, even within a familiar driving activity context, could be

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enhanced by providing a tool assisting learners to "filter" (e.g. select and focus) the complex flux of information. This approach has not been used yet in the area of learning to drive ecologically in a simulator.

To achieve this economical way of processing information, CTML suggests taking into consideration what is known as the "cueing principle" and the "feedback principle".

The "cueing principle" called also "signalling principle" is an instructional design technique (van Gog, 2014). It aims to reduce visual search by using cues embedded in the teaching aid in order to direct the subject's attention to specific locations on the learning support. "When cues are added, attention is guided to the relevant elements of the material or highlights the organization of the essential material" (De Koning, Tabbers, Rikers, & Paas, 2009; Mayer, 2005; see also Boucheix & Lowe, 2010; Boucheix, Lowe, Putri, & Groff, 2013; about dynamic cueing).

Adding cues allows to highlight the relevant information, at the right moment and in the right place. By this way, the process of selection of information is timely improved, and it fosters time locked processing of the relevant information. The visual search is reduced since the number of fixations, and cumulative time spent fixating on the material is reduced (Folker, Ritter, & Sichelschmidt, 2005; Ozcelik, Karakus, Kursun, & Cagiltay, 2009).

It also prevents from missing the important dynamic information, or processing the inexpedient information that replaced it instead (inattention blindness, see Boucheix & Lowe, 2010; Boucheix et al., 2013; De Koning et al., 2009). Thus, cueing technique prevents from generating extraneous cognitive processing and allows to release cognitive resources for the learner to focus on the task. It had been reported to enhance material processing (Folker et al., 2005; Ozcelik et al., 2009), and lower effort investment during learning process (Kalyuga, Chandler, & Sweller, 1999), resulting in a "deeper", more efficient understanding of the multimedia message.

In line with this previous development about cueing, or signalling, providing learners drivers with feedback is another guiding method which consists in notifying the learner with messages about his actual performance (Johnson & Priest, 2014). According to this theory, providing feedback messages contributes to learning by allowing learners to evaluate their own behaviour and performances relatively to the expected behaviour and performance level. They may better identify how to process the relevant information and adjust their behaviour in order to reach the expected performance. Effective feedback is aimed at support intentional effortful information processing. By prompting active processing of information, it might raise motivation and lead to a deeper processing of the information (Moreno & Valdez, 2005), thus improve learning performances.

1.3. Hypotheses

In sum, an efficient eco-driving training program must include the following key elements: (1) provide the trainee with prior procedural knowledge, combined with practical training in order to gain a deeper understanding of the eco-driving rules and ability to implement them; (2) the interactive guiding interface system must allow economical visual searching in order to select the relevant information rapidly and integrate it into a mental model; (3) the learning device must not lead to goal competition, which would distract the drivers and put their safety at risk; (4) it should reduce extraneous processing/cognitive load and effort.

The design of our interactive guidance system was based on the above-mentioned instructional design principles and models, grounded on, and conventionally used in, the educational area. In the present research, these principles were applied for the first time in the context of driving in a simulator.

We conducted a complete eco-driving training program. Training took place in a simulated environment, in which participants learnt eco-driving through instructional videos and practice in a driving simulatorequipped with the guiding signalling device, with the goal of being able to apply the rules independently at the end of the training. There were two experimental groups and a control group. One experimental group, the Non-Guided Video group (NGVg), only had access to instructional videos, in which an expert explained the eco-driving rules. The other experimental group, the Guided Video Group (GVg), was shown the same instructional videos but was additionally assisted by an interactive guiding system during the training phase. The Control group (Cog) had neither instructional video nor guiding device during the training sessions. The design of the interface was based on cueing and feedback principles, which are expected to improve eco-driving learning performance without generating extraneous information processing or distraction. Performance of all the participants was recorded and analysed in order to measure the contribution of the videos and interactive guiding system.

Our first hypothesis was that both training programs would impact the normal behaviour of drivers, and that a significant decrease in CO^2 emissions would be observed in both experimental groups but not in the control group. Our second hypothesis was that the group with the interactive guiding device would have higher eco-performance scores than the video-only group. Our third hypothesis concerned distraction and safety. The guiding system could provide extra information that needs processing in addition to the driving task. However, task-appropriate features of instructional material (Soemer & Schwan, 2016) can benefit the learner without generating extraneous cognitive load. We thus expected that the GVg would obtain the same safety scores as the other groups.

Finally, analysis of the eye-movement patterns should provide clues about potential differences in the visual search strategies of GVg and NVGg. In line with the CTML principles, GVg participants were expected to have fewer fixations, and spend less cumulative time fixating on the material.

2. Method

2.1. Participants

The study comprised 72 participants (45 men and 27 women), mean age 24.7 years (SD = 6.7, range 19–55 years). All participants had held a full driving license for at least one year with a mean of 5.9 years (SD = 6.1 and range 1–36 years). Their total reported mileage for the last twelve months was 150–40,000 km with a mean of 9429 km (SD = 8480). Groups were randomly assigned to the three groups, GVg, NVGg and Control. However, randomization was only partial because the characteristics of participants in each group were checked for comparability (via a questionnaire completed before the experiment) regarding three criteria: the same number of men and women in each group; similar computer gaming experience across groups; and comparable reported mileage for the last twelve months. All participants gave their informed consent and were offered a gift voucher. Finally, we checked that participants had normal (corrected) vision (colour-blind people were excluded).

2.2. Apparatus

The simulator was a one-person fixed-base simulator (Oktal Premium Simulator Eco² for RENAULT, see Fig. 1) with an adjustable seat, a wheel, a gear stick, clutch, accelerator and brake pedals. The participant was immersed in the simulated environment by means of three LCD screens, audio speakers located in front and behind the seat, and vibrators embedded in the seat. The eye-tracker was a faceLAB device (faceLAB eye-tracking system), and the simulation was generated by SCANeR (SCANeR™ studio; RENAULT-OKTAL). Eye-tracking and driving performance data were recorded at a frequency of 60 Hz. Precise temporal synchronization of the series of recordings was checked.

The dashboard provided the following information: revolutions per minute, speed, gear, position and it was equipped with an embedded GPS. Participants' eye movements were monitored while they were driving (the eye tracker was calibrated immediately after the practice scenario).

A specific data acquisition system comprising "driving style" measurement and analysis was incorporated in the simulator. First, this tool recorded precisely time-locked driving indicators (with data based on driver actions on the vehicle): pedal position, acceleration, speed, rpm, deviation from the centre line of the road, distance from other vehicles, brake inputs). Secondly, the computer program compiled and compared data for identical drives (by the same driver or by a learner and an eco-driving expert) in order to determine a global driving performance (cumulated braking time, duration of accelerations) and fuel consumption.

Fig. 1. Picture of the driving ECO² simulator.

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The CO^2 emission level of the vehicle was assessed by means of a realistic CO^2 emission model provided by the Renault Corporation.

2.3. Material

2.3.1. The eco-driving rules

The eco-driving rules were provided by Renault. For the experiment, they had been divided into two series (eco-driving rules 1, 2, 3 and eco-driving rules 4, 5, 6, see Table 1). These rules were given either verbally by a tutor in the training videos and/or through the online interactive guidance device. They were easy to understand, and the fact that they were not given at the same time but in two series (rules 1, 2, 3 and 4, 5, 6) could have facilitated their integration and memorization.

2.3.2. Road scenario design

The driving scenarios were instantiations of specific situations, in which the eco-driving rules had to be learnt and applied. There were four scenarios, one for each stage of the training program. They instantiated rural and urban areas, expected events (e.g. traffic lights) and unexpected events (e.g. pedestrians crossing the street, constructions, a car pulling out). Drivers encountered roundabouts, intersections, stops, high-speed roads, and low-speed roads in the city with more traffic (and risk of collision). The four scenarios were comparable, similar in the number and nature of relevant road situations, but were sufficiently different to avoid a potential repetition effect (see Fig. 2 for a plan of one of the two the training scenarios).

The scenarios were created in relation to the 6 eco-driving rules. They required specific actions by the drivers and corresponded to the instructions given to optimize reduction of CO^2 emissions. The 2nd and 3rd scenarios were designed for rules 1, 2, 3, and 4, 5, 6 respectively, and differed from scenarios 1 and 4 in order to avoid a repetition bias.

In the fourth stage, the scenario was designed to evaluate whether the participants could apply the six rules. Like the other scenarios, it comprised every road situation that could influence CO^2 emission level: total length of the route, number and length of straight and bend sections, radius of curvature of the bends, speed limits, and the events requiring the drivers to decelerate or stop (e.g. traffic lights, stop signs, and pedestrians crossing the road).

Improvement between the first and last driving scenario was assessed by a conventional Pre-test/Post-test paradigm. To guarantee reliable and fair comparison, the final scenario thus had to be strictly similar to the first scenario in terms of bends, straight lines, roundabouts, intersections, and specific events. Nevertheless, to avoid generating a learning-repetition bias, several (superficial) elements differed: the surrounding virtual world (e.g. buildings, trees, pedestrians' clothes and physical features), the nature of the events causing a stop or a deceleration (e.g. stop signs replaced by traffic lights turning red), the direction of the bends (e.g. right instead of left), and the order of the road sections with the associated events. Finally, the pre- and post-test scenarios (1 and 4) were counterbalanced across participants (i.e. half the participants in each group drove the initial and final scenarios in reverse order). Moreover, the initial scenario was the same as the final one in reverse, so that participants would not realize they were driving the same route (see Fig. 3). The two training scenarios were also different but similar to the initial and final runs in terms of events, routes and driving times, in order to prevent any learning bias.

2.3.3. Instructional videos

The instructional videos were designed and produced with the collaboration of a specialist driving school offering eco-driving courses to company employees and professionals ("KDC", Key Driving Competences). In the videos, the explanations of the eco-driving rules were given by an experienced and qualified instructor. The videos were displayed on the central screen of the simulator (see Fig. 4a–d).

One video was displayed prior to each stage of the training program. The goal was to provide the subjects with a theoretical knowledge of eco-driving and how to perform each eco-driving rule efficiently for optimal CO^2 emission reduction (Fig. 4, screen capture A and D).

The control group did not watch any videos. The two experimental groups, GVg and NVGg, followed different programs. The instructions provided in the videos were identical for both groups, but the GVg participants, whose training combined

Table 1
List of the 2 series of eco-driving rules as displayed to the subjects in the experiment.

Eco-driving rule #1	Change gear up before 2500 rpm (RPM). Score: mean rpm when participants changed gear.
Eco-driving rule #2	Drive in the highest possible gear. Score: mean difference between the participants' ratios and the 'ideal' gearbox ratio determined by the eco-driving expert.
Eco-driving rule #3	Maintain constant speed when the road is clear. Score: mean standard deviation in speed.
Eco-driving rule #4	Look ahead to anticipate decelerations. Score: mean position of the accelerator pedal (as a percentage) in the dedicated sections.
Eco-driving rule #5	To decelerate: (1) release the accelerator, (2) change to a lower gear, (3) brake if necessary (rule applicable in a non-emergency case only).
Eco-driving rule #6	Stop engine for stops lasting more than 30 s. Score: 1 point when participant stopped the engine and 0 if not.

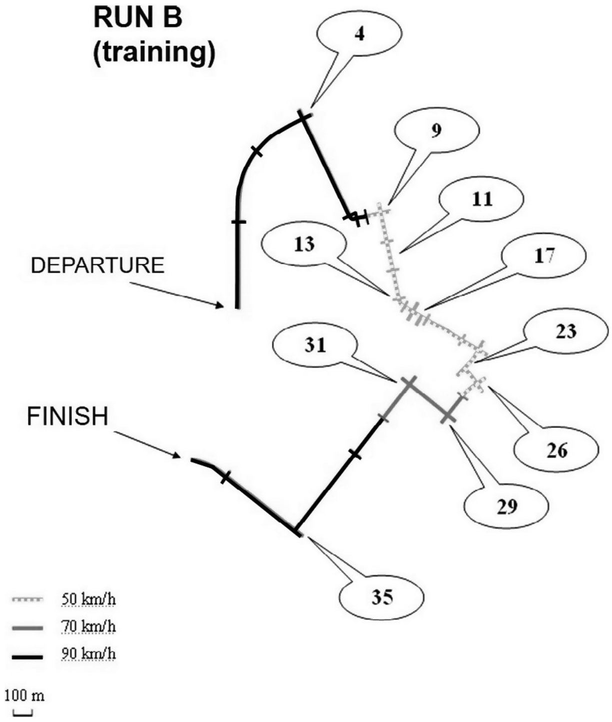

Fig. 2. Plan of one of the two training runs. The colors indicate the speed limit in each portion of the route. The numbers indicate the events. For example, event 4 corresponds to a 450 m straight line with a 90 km/h speed limit that offers the possibility to change gear up 5 times. Event 9 is a pedestrian crosswalk. Event 11 is a car pulling out without warning that can provoke a strong slowing down in a 50 km/h speed limit street with traffic.

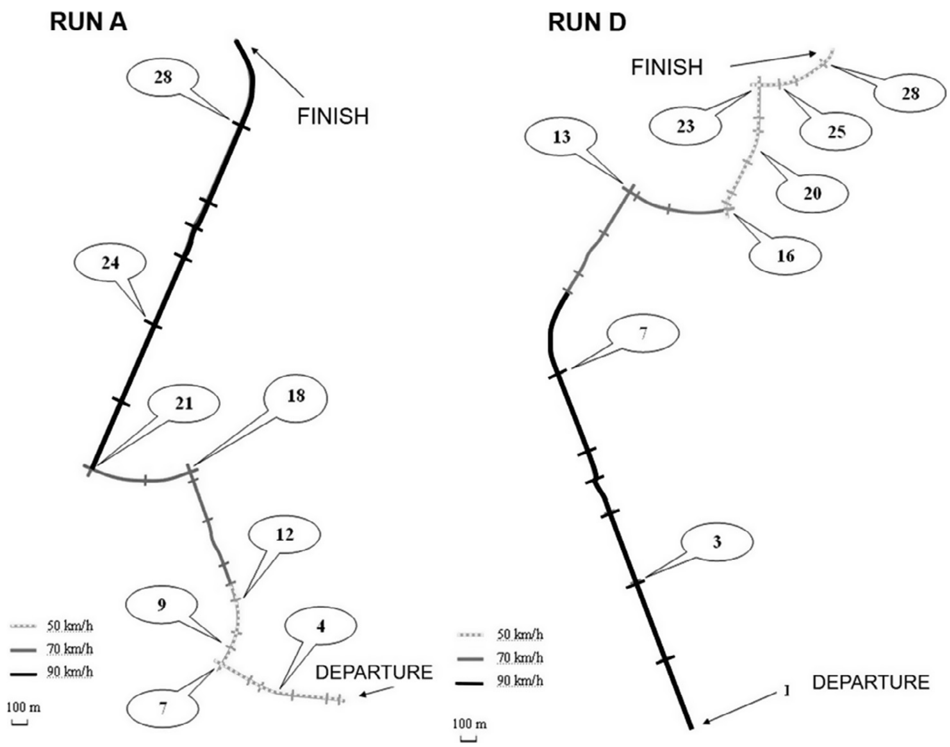

Fig. 3. Plans of initial and final runs. The numbers indicate the events; the colors indicate the speed limit in each portion of the route. It is in fact the same route reversed. Half the participants drove "Run A" in the initial assessment, and "Run D" for the final assessment. The situation was reversed for the other half.

Fig. 4. Screen Captures (from left to right, top to bottom: a, b, c, d) of the training videos.

videos and an interactive guiding system, were given additional information about the interactive multimedia material (Fig. 4, screen capture C, and D).

Prior to completing the first scenario, the video briefly introduced the concept of eco-driving. The first instruction was to drive in a natural, normal way.

In the second and third sessions, specifically aimed at training, the goal was to learn and apply rules 1, 2, 3 and 4, 5, 6 respectively. The participants were instructed about the purpose (declarative knowledge) of the rules and how to apply them correctly (procedural knowledge). The GVg participants were also instructed about which signalling element of the interactive guiding device was related to each rule and how it worked.

The aim of the 4th and last session was to assess what had been learnt (and CO^2 emission reduction). The instructions in the video was the same for both experimental groups. Participants were asked to apply all the eco-driving rules they had learnt, without assistance, cues or feedback.

2.3.4. Interactive guiding system

An innovative interactive guiding device for eco-driving was constructed and used (see Fig. 5). "Metaphors" had to be interactive, easy to understand and not too heavy in terms of cognitive load. They included visual messages, sounds and tactile feedback. These graphic "metaphors" were connected to the vehicle data acquisition module and interacted in real time with the participant. Visual information concerned CO^2 emissions, gear engaged, recommended gearbox action (with an arrow indicating when a gear change was required), ideal RPM level, and speed limit, and also messages concerning use of clutch and brake pedals. An illustration of the visual feedback system is shown in Fig. 5. Visual messages were accompanied by sounds in the form of beeps, spatialized 3D sounds, and/or verbal messages. As explained in introduction section, the feedback and cueing messages were designed on the basis of CTML feedback, cueing and modality principles. In other words, messages were distributed across auditory and visual sensory channels so as not to overwhelm one sensory channel.

In the first training scenario, interactive visual cues gave immediate feedback to the VGg participants on their CO^2 emission level and their compliance with each of the eco-driving rules. The CO^2 emission level of the vehicle was updated in real time (averaged over a three-second period) and displayed on a CO^2 emission gauge (in green on the left of the dashboard, see Fig. 5). Additionally, specific feedback was given for each eco-driving rule. As illustrated in Fig. 5, a green flashing area in the tachometer indicated when the participants had to change gear to comply with eco-driving rule #1. If the tachometer needle went past this area, the green light started to flash. For eco-driving rule #2, a blue arrow on the right of the dashboard indicated that the participant should change to a higher gear. For eco-driving rule #3, the figures in the digital speedometer turned red when the road was clear and the participants were not maintaining a constant speed.

During the second training scenario, participants were also given immediate feedback on their CO2 emission levels and on their compliance with the eco-driving rules. The CO2 emission gauge was again displayed on the dashboard. As eco-driving rule #4 required particular attention to be paid to the road (and not the dashboard), auditory messages rather than visual cues were used to give feedback on participants' compliance with all the eco-driving rules. A common feedback was given for eco-driving rules #4 and #5 because they were interdependent – both required release of the accelerator. When the participant did not release the accelerator sufficiently in advance when approaching a stop sign, a red light or traffic jam for instance, a 'look ahead' message was triggered. If the participant did not decelerate in the next three seconds, a 'release the

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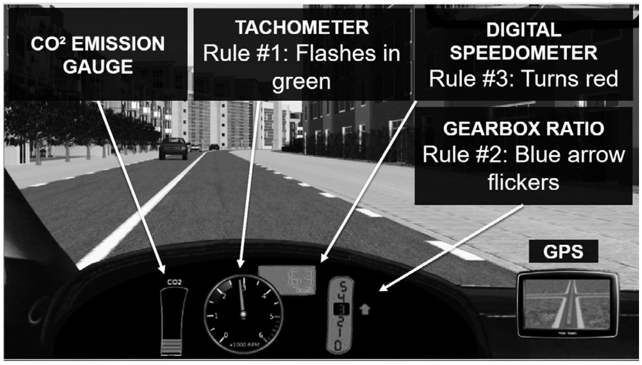

Fig. 5. Screen capture of the simulated dashboard while driving with interactive guidance system. The dashboard provided visual and/or auditory cues giving immediate feedback on the participant's performance.

accelerator pedal' message was triggered, and was repeated every three seconds if the participant did not comply. With regard to eco-driving rule #6, a 'stop the engine' message was triggered when the participant did not cut the engine at a predictably long stop for a bicycle race.

2.3.5. Scoring feedback during training

"Outcome feedback" is defined as "a feedback message that provides information about the learner's overall score" (van Gog, 2014). Like "informative feedback", it enables learners to evaluate their own behaviour and responses, and to identify and repair a gap in their knowledge.

At the end of each scenario, the participants were informed of their CO^2 emission levels, with a score expressed in grams per kilometre. During the 1st and 4th scenarios, the participants were informed of their global CO^2 emission performance. After the 4th scenario, their performance before /after the training (i.e. in 1st and 4th scenarios) was displayed so that they could see their overall improvement. This was also designed to give the training program a game mode aspect so as to prompt intentional, active participation, and increase participants' motivation and desire to improve their performance.

2.4. Experimental design details and procedure

The learning value of the training sessions was assessed by means of a pre- /post-test, control group/experimental group design. The experimental design included three main steps, as shown in Fig. 6: pre-test, training scenarios, and post-test.

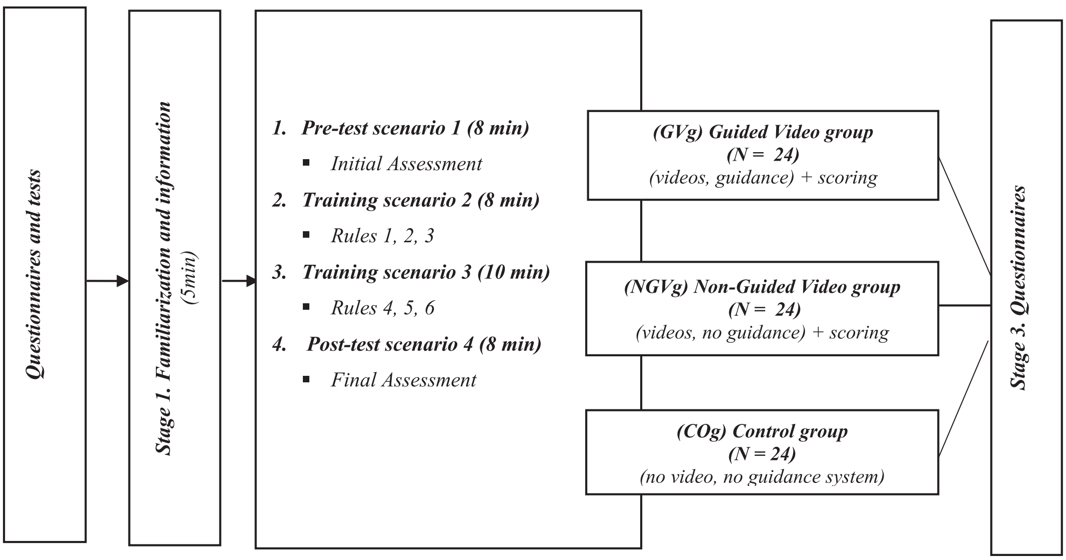

Fig. 6. Description of the experimental procedure.

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2.4.1. Preliminary questionnaires

First, the participants were asked to complete a questionnaire with information about their age, gender, and education, time since they had obtained a driving license, number of kilometres driven per year, car use, and time spent playing video games per day. They were also asked to rate their knowledge about eco-driving and CO^2 emissions. They then completed a spatial ability test (DAT IV), a Stroop test, and an N-Back test, in order to avoid potential bias related to individual differences in the capacity to perceive the environment. No significant difference between groups was observed in performance on these tests, or in data on the initial questionnaire.

2.4.2. The training programs and the instructions given to participants

As described above, the training programs had 3 main stages. In stage 1, participants were informed about eco-driving, and the experimental groups were told how to apply eco-driving rules properly. The participants in the control group were informed that they were participating to a study about eco-driving, but that they were assigned to the group that do not learn the rules. Thus they were not provided at all with information about eco-driving techniques. In stage 2, participants were trained to apply the rules while driving, with or without an interactive guidance system. Each participant drove the four scenarios: one for the pre-test, two for training, and one for the post-test. Finally, in stage 3, all the participants completed a questionnaire about their subjective experience and evaluation of the training phase.

Before using the driving simulator, participants watched an instructional video, in which a professional trainer explained how, why and when to implement the eco-driving rules. The simulation brought together this prior theoretical knowledge and skill-based knowledge (see Fig. 4).

As described above, and shown in Fig. 6, the practical training sessions were split into 4 driving simulation modules. The aim of the second and third was to acquire the rules, while the first and the fourth assessed the participants' eco-performance before and after training.

At the beginning of the experiment, participants drove a practice scenario for 5 min in order to become familiar with the apparatus and were informed about the purpose of the task. This familiarization phase also enabled us to identify any participants suffering from "simulation sickness". Based on the information in the preliminary questionnaires, participants were then quasi-randomly assigned to the GVg, NGVg and Control group (Cog).

At the end of each scenario, the participants received feedback summarizing their eco-performance by means of a score screen (Fig. 7).

2.4.3. Subjective evaluation

At the end of the study, participants were asked to rate the experiment on 7-point scales concerning: (i) overall enjoyment, (ii) motivation, (iii) perceived quality of the simulation task (control of the vehicle, general gameplay), (iv) the feeling of having learned about eco-driving, (v) the effort required to apply the rules during the simulation, and (vi) the desire and subjective ability to use the eco-driving rules on their own in the future.

2.5. Measures

Several measures were developed and carried out: (i) eco-driving performance; (ii) safety; (iii) driving time in each session; (iv) eye movement, and (v) subjective evaluation.

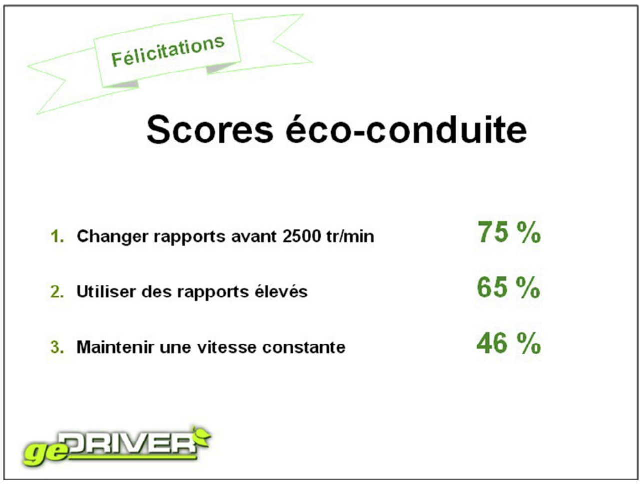

Fig. 7. Screen capture of a scoring screen at the end of the first training scenario (Run b). The 3 scores indicates to the participant, his performance on applying the 3 first eco-driving rules taught in the first training session (run b).

2.5.1. Eco-driving performance

For global eco-driving performance, CO^2 emissions were calculated by a data engine embedded in the software for each scenario. Reduction in CO^2 emissions was calculated as the difference between pre-test/post-test scores, i.e. between the initial and final drives. This measure was referred to as overall "eco-performance".

A score was also calculated for each rule. The measures used to calculate the score for each rule are presented in Table 1.

2.5.2. Safety

Safety was measured as: (i) time spent with eyes off the road, (ii) lateral control performance, (iii) minimum time headway, and (iv) minimum distance maintained behind a vehicle braking unexpectedly.

2.5.3. Driving time

The driving time was the number of minutes and seconds spent driving in each scenario, i.e. for each run.

2.5.4. Eye-tracking

As described in the introduction and hypotheses section, in order to investigate the effects of the instructional videos and interactive guidance system on the focus of attention while driving in each scenario, we recorded the duration and number of eye fixations on Areas Of Interest (AOIs) of the dashboard.

3. Results

3.1. Statistical analyses

Each dependent measure was analysed using a mixed 2 (Scenario: initial assessment, final assessment) x 3 (Group: GVg, NGVg, Cog) analysis of variance (ANOVA) with Scenario as the within-subject independent variable and Group as the between-subjects independent variable. For Scenario x Group interactions, post hoc tests were performed to determine the effect of the Scenario factor for each of the experimental/control groups (i.e. three *t* tests with Bonferroni correction).

3.2. Eco-performance

The results of the CO^2 emission measure are presented in Table 2.

A repeated measure ANOVA with group as the between-subjects factor and scenario (initial vs. final drive) was performed on CO^2 emissions. This analysis revealed a significant Scenario x Group interaction (F (2, 69) = 12.59, $p < .001$, $\eta p^2 = 0.27$). A significant training effect, F (1,69) = 49.82, $p < .00001$, $\eta p^2 = 0.42$, was also observed. Post-hoc tests indicated that the CO^2 emission levels were significantly lower during the final assessment scenario than during the initial scenario for GVg (197 g/km versus 225 g/km; F (1,69) = 55.53, $p < .00001$, $d = 1.26$) and for NGVg (205 g/km versus 222 g/km; F (1,69) = 19.31, $p < .00004$, $d = 0.69$), whereas there was no difference for the control group (F (1,69) = 0.15, $p = .70$, $d = 0.08$). Detailed analyses of the means indicated that the real-time feedback contributed to the 12.4% cut in CO^2 emissions in the unaltered version of the simulation. Thus, the interactive guidance system added 5% to eco-driving performance after training, compared to learning with videos. Further analysis corroborated this difference in eco-performance between GVg and NVg (F (1,69) = 4.67, $p < .05$, $d = 0.46$). Moreover, a one-factor ANOVA conducted on the initial scenario scores (pre-test) showed that there was no difference between the three groups for the initial run, F (2,69) = 0.42, $p = .66$, $\eta p^2 = 0.012$. The repeated measure ANOVA with group as the between-subjects factor and scenario (initial vs. final run) performed on CO^2 emissions in the initial and final runs did not show an overall main effect of group, F (2,69) = 0.92, $p = .40$, $\eta p^2 = 0.03$, because of the mix of pre- and post-test scores in this analysis. However, the one-factor ANOVA conducted on the difference in CO^2 scores between the final (post-test) and the initial (pre-test) scenario scores showed a main effect of group, F (2,69) = 12.6, $p = .00002$, $\eta p^2 = 0.027$. The VGg outperformed the NVGg (F (1,69) = 4.67, $p = .034$) and the control group (F (1,69) = 25.01, $p = .0001$), and the NVGg outperformed the Control group (F (1,69) = 8.06, $p = .006$). In sum, these results suggest that the simulation familiarization session alone could not account for the cut in CO^2 emissions, as there was no difference for the control group.

3.3. Contribution of eco-driving rules

The learning scores for the eco-driving rules are shown in Table 3.

Table 2
CO^2 emission during initial and final assessment scenarios for each group.

Experimental group	Initial assessment	Final assessment	Eco-performance (%)
(GVg) Guided Video group	225.18 (22.7)	197.29 (21.5)	12.38
(NGVg) Non-Guided Video group	221.74 (25.2)	205.29 (22.4)	7.42
(COg) Control group	219.29 (18.4)	217.88 (15.7)	0.64

Table 3
Mean scores for each rule during initial and final assessment scenarios for the Guided Video group (GVg), Non-Guided Video group (NGVg) and Control Group (COg).

	Guided Video group		Non-Guided Video group		Control group	
	Initial assessment	Final assessment	Initial assessment	Final assessment	Initial assessment	Final assessment
Score rule #1	2733	2288	2719	2295	2586	2593
(mean rpm)	(330.5)	(222.3)	(326.1)	(194.9)	(331.5)	(344.1)
Score rule #2	1.78	1.83	1.64	1.71	1.67	1.63
(mean difference between participants' gear box ratio and ideal ratio)	(0.27)	(0.34)	(0.23)	(0.34)	(0.26)	(0.25)
Score rule #3	5.11	3.84	4.69	4.21	4.74	5.00
(mean standard deviation in speed)	(1.32)	(0.92)	(1.5)	(1.07)	(1.52)	(1.17)
Score rules #4/#5	0.21	0.14	0.20	0.17	0.21	0.19
(mean accelerator position as%)	(0.05)	(0.05)	(0.04)	(0.05)	(0.03)	(0.05)
Score rule #6	0.00	0.75	0.04	0.92	0.00	0.00
(% of stopping engine)	(0.00)	(0.44)	(0.2)	(0.28)	(0.00)	(0.00)

Eco-driving rule #1 advised participants to change into a higher gear before 2500 rpm. The score for this rule was the mean rpm when participants changed gear. As expected, the repeated measure ANOVA with group as the between-subjects factor and scenario (initial vs. final run) performed on rule #1 scores revealed a significant Scenario x Group interaction, F (2,69) = 20.52, p < .00001; ηp^2 = 0.37. The main effect of scenario, initial vs. final run, was large, F (1,69) = 78.09, p < .00001, ηp^2 = 0.53. Post-hoc tests indicated that the GVg participants changed gear at a lower rpm in the final scenario than in the initial scenario (2288 rpm versus 2733 rpm (F (1,69) = 62.46, p < .00001, d = 1.58). The post hoc tests for the NGVg indicated a similar effect (F(1,69) = 56.65, p < .0001, d = 1.57), whereas there was no difference for the Cog (F (1,69) = 0.05, p = .90, d = −0.02). This indicates that the eco-driving training successfully taught participants to change gear before 2500 rpm.

The one-factor ANOVA showed no difference between groups for the initial run only, F(2,69) = 1.44, p = .024, ηp^2 = 0.04, but a similar analysis between groups on the final run revealed a significant effect of group, F (2,69) = 10.65, p = .00009, ηp^2 = 0.23. Post-hoc comparisons revealed no difference between GVg and NGVg (F(1,69) = 0.008, p = .92). Finally, a one-factor between-groups ANOVA conducted on rule 1 scores between pre-test and post-test scenarios indicated a main effect of group, F (2,69) = 20.52, p = .00001, ηp^2 = 0.37, with similar scores for VGg and NVGg (F (1,69) = 0.70, p = .79), both experimental groups scoring higher than the control group: VGg, F (1,69) = 32.21, p = .0001, and NVGg, F(1,69) = 29.26, p = .00001.

Eco-driving rule #2 recommended driving in the highest possible gear. Ideal gearbox ratios were determined for all the scenarios with the help of an eco-driving expert. Scores were the mean difference between the participants' and the 'ideal' gearbox ratios. The ANOVA did not yield any significant effect (all p > .1), and the main effect of group was not significant, F (1,69) = 0.57, p = .56.

Rule #3 recommended maintaining a constant speed when the road was clear. As the road was always clear in three specific sections of the initial and final scenarios, there was no reason not to maintain a constant speed. Scores were the mean standard deviation in speed. The repeated measure ANOVA with group as the between-subjects factor and scenario (initial vs. final run) conducted on this measure revealed a significant Scenario x Group interaction (F (2, 69) = 6.01, <0.004, ηp^2 = 0.15). The main effect of scenario (initial vs. final run) was significant, indicating a training effect, F(1,69) = 7 .58, p = .007, ηp^2 = 0.10. Post-hoc tests indicated that the standard deviation in speed was lower in the final scenario than in the initial scenario for the GVg (3.84 versus 5.11; F (1,69) = 16.57, p = .0002, d = 1.12), whereas there was no reliable difference between the initial and final scenarios for the other two groups: NGVg, F(1,69) = 2.34, p = .13, d = 1.04, and control group F (1,69) = 0.69, p = .41, d = −0.19. This indicates that the training successfully taught this eco-driving rule and that the real-time feedback was helpful. A one-factor ANOVA showed no difference between groups for the initial run only, F(2,69) = 0.58, p = .056, ηp^2 = 0.01, but a similar analysis of the final run indicated a significant difference, F(2,69) = 7.59, p = .001, ηp^2 = 0.18. Post-hoc comparison revealed that the difference between GVg and NGVg failed to reach significance (F(1,69) = 1.50, p = .22, d = −0.38).

Rules #4 and #5 both concerned the use of the accelerator pedal. Rule #4 advised participants to look ahead to anticipate decelerations. Rule #5 recommended decelerating by releasing the accelerator pedal before changing to a lower gear and braking (in a non-emergency situation). As both rules applied to the use of the accelerator pedal and were interdependent, a common score was designed. Seven specific sections of the initial and final scenarios involved anticipation of a deceleration (e.g. a stop sign or a red traffic light). The score for these two rules was the mean position of the accelerator pedal (as a percentage) in these sections. The analyses performed on this measure revealed a reliable Scenario x Group interaction, F(2, 69) = 6.51, p < .002, ηp^2 = 0.16. The main effect of scenario (Initial vs. final run) was significant (F(1,69) = 41.35, p < .00001, ηp^2 = 0.37) showing a training effect. Post-hoc tests indicated that the mean position of the accelerator pedal was lower in the final scenario than in the initial scenario for GVg (14% versus 21%; F(1,69) = 41.58, p < .00001, d = 1.39), and for the NGVg (F(1,69) = 10.87, p = .002, d = 0.66), but there was no significant effect for the control group (F(1, 69) = 1.94, p = .17, d = 0.44). These results indicate that the training successfully taught this eco-driving rule and that the real-time feedback contributed. A one-factor ANOVA showed no difference between groups for the initial run only, F(2, 69) = 0.041, p = .95, ηp^2 = 0.001; the same analysis for the final run indicated a significant difference, F(2,69) = 7.74, p < .001, ηp^2 = 0.18. Post-hoc comparison revealed that the difference between GVg and NGVg reached significance (F(1,69) = 5.07, p = .03, d = −0.6).

Rule #6 advised the participants to stop the engine when stopping for more than 30 s. This was the case in one section of the initial and final scenarios, one for a bicycle race and the other for a train crossing. The score for this rule was 1 if the participant stopped the engine and 0 if not. Irrespective of group, almost no participant stopped the engine in the initial scenario (just one player out of 24 in the NGVg). Conversely, the majority of participants in the GVg and NGVg (18 and 22 respectively) stopped the engine in the final scenario, but none of the Cog participants did. Although no particular statistical analysis was performed on this measure, the results suggest that training in the simulator successfully taught this rule.

3.3.1. Regression analysis

In order to investigate which dimensions of driving behaviour contributed most to the CO^2 emission score levels, a multiple linear regression analysis was performed on the CO^2 emission level recorded in the final scenario as the dependent variable, and the scores obtained for each rule during the same scenario (irrespective of group) as the predictive factors. As shown in Table 4, the analysis revealed a significant contribution effect of rules #1, #3, and #4 on the reduction of CO^2 emissions.

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Table 4
Multiple regression shows the contribution of each rule to CO^2 emission reduction.

Coefficients					
Model	Non-standardized coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
(Constant)	0.413	3.06		1.12	0.27
Score rule #1	0.02	0.007	0.26	2.62*	0.01
Score rule #2	7.71	5.57	0.14	1.38	0.17
Score rule #3	2.82	1325	0.22	2.13*	0.04
Score rule #4	141.96	36.299	0.4	3.91*	0.00

Dependent variable: CO^2 emission.

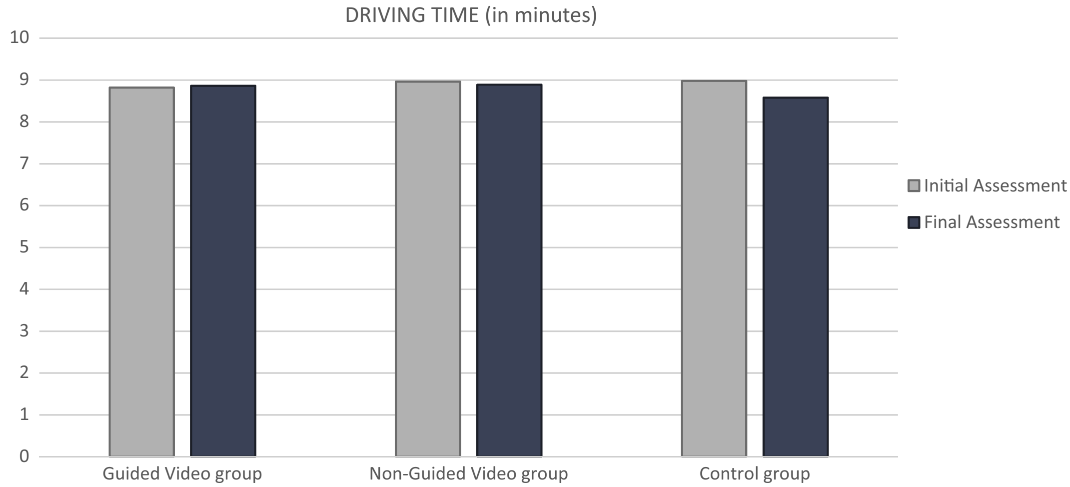

Fig. 8. Impact of scenario on driving time (in minutes). difference between initial and final assessment in each group.

3.4. Measures of safety

Measures of safety included time spent with eyes off the road, lateral control, minimum time headway, and minimum safe distance to allow for a lead vehicle braking unexpectedly. None of the ANOVAs performed on these measures yielded a significant effect of either the scenario factor or the group factor, and no significant interaction was observed (all $ps > 0.1$ in the post hoc tests). In other words, we found no evidence that the significant decrease in CO^2 emission elicited by the simulation training had any downside effect regarding the participants' safe driving behaviour. For example, time spent with eyes off the road was 15% in the initial scenario versus 16% in the final scenario for the GVg, and 17% in both scenarios for the NGVg, indicating that eco-driving rules could be applied without spending significantly more time looking at the dashboard.

3.5. Driving time

Driving times are presented in Fig. 8. The repeated measures ANOVA on driving times, with group as the between-subjects factor and scenario (initial vs. final run) as the within-subject factor, did not reveal a significant impact of either scenario (between initial and final assessment, $F(1,69) = 1.78$, $p = .19$, $\eta p^2 = 0.02$) or group ($F(2,69) = 0.27$, $p = .76$, $\eta p^2 = 0.01$). There was no significant interaction between group and scenario ($F(2, 69) = 1.83$, $p = .17$, $\eta p^2 = 0.05$). Finally, there was no difference between groups for the final scenario assessment only ($F(2,69) = 1.67$, $p = .20$, $\eta p^2 = 0.05$). Participants in all the groups drove approximately the same amount time in the initial and final scenarios. This result shows that it is possible to modify driving behaviour in a way that reduces CO^2 emissions without losing time.

3.6. Subjective measures

Effort was chosen as the most interesting subjective measure. An analysis of subjective effort only was performed. In the short questionnaire handed out at the end of the experiment, participants rated the mental effort required to apply the rules on a 7-point scale. The one-factor ANOVA with group as the between-subjects factor showed a significant effect of group, $F(2,66) = 3.79$; $p = .028$; $\eta p^2 = 0.10$. More precisely, there was no significant difference in perceived effort between GVg and

Table 5
Duration and number of eye fixations on dashboard during final assessment in each group.

	Final assessment		
	Guided Video group	Non-Guided Video group	Control group
Mean fixation duration (sec)	0.38 (0.17)	0.42 (0.18)	0.30 (0.16)
Number of gazes at dashboard	215.5 (105.54)	210.73 (83.90)	177.3 (106.24)
Gaze at dashboard (%)	15.9 (10.6)	17.4 (9.5)	10.6 (6.6)

NGVg (respectively 4.92/7 and 4.63/7; $F(1,66) = 0.41$, $p = .52$), whereas the differences between GVg and Cog, and between NGVg and Cog, were significant, respectively, $F(1,66) = 7.03$, $p < .01$, $d = 0.75$, and $F(1,66) = 4.14$, $p = .046$, $d = 0.63$. This indicates that applying eco-driving rules after a very short training could involve an increase in mental effort. However, there was no difference between the two training methods.

3.7. Eye-tracking results

We analysed three eye-movement indicators in the final assessment: mean fixation duration (in milliseconds), number of fixations on dashboard, and percentage of gazes at the dashboard. Eye-fixation duration is the time eyes focus on a particular point. Mean fixation duration is the average fixation time; this measure is used to assess the processing length of fixations, e.g. processing depth, on the area of interest on the dashboard. The number of eye fixations is the number of times the eyes focus on an area of interest (the dashboard) then leave. Finally, the percentage of time spent looking at the dashboard during the scenario assessed the overall time attention was directed toward the information given on the dashboard while driving. The eye movement results are presented in Table 5.

Regarding the mean fixation duration in the final assessment, the one-factor ANOVA revealed a marginal effect of driving condition, $F(2,69) = 2.79$, $p = .07$, $\eta p^2 = 0.075$. The was no difference between GVg and Cog ($F(1,69) = 2.19$, $p = .14$, $d = 0.44$), a significant difference between NGVg and Cog, ($F(1,69) = 5.47$, $p = .02$, $d = 0.68$), and no difference between the two experimental groups ($F(1,69) = 0.73$, $p = .39$, $d = -0.24$). This result is interesting, indicating that it was easier to process the relevant feedback information and apply the rules with the added guidance system than with the instructional video only. Regarding the percentage of fixations on the dashboard, the one-factor between-subjects ANOVA also showed a marginal effect of driving condition ($F(2,69) = 2.80$, $p = .07$, $\eta p^2 = 0.07$). Furthermore, there was a significant difference between GVg and NGVg together and Cog, $F(1,69) = 4,86$, $p < .05$. This could indicate that the experimental groups looked at the dashboard longer than the control group since they were focused on applying the rules, and maybe more visual processing was needed. However, further analysis also showed no significant difference between GVg and Cog. By contrast, there was a significant difference in the percentage of time spent looking at the dashboard between NGVg and Cog ($F(1,69) = 5.47$, $p < .02$, $d = 0.68$). Thus, learning with instructional videos only resulted in more visual search to apply the rules, while the additional guidance system reduced visual searching, to the point that eye-fixation durations were the same as under a normal driving situation.

Finally, the one-factor between-subjects ANOVA showed no significant effect of group on the number of eye fixations ($F(2, 69) = 1.04$, $p = .35$, $\eta p^2 = 0.03$), indicating that neither the interactive guidance system nor instructional video made participants look more often at the dashboard.

4. Discussion

The main goal of this experiment was to design and measure the contribution of a real-time interactive guidance system to teach eco-driving using immersive simulation. Our main hypothesis was that teaching eco-driving would positively impact CO^2 emissions, then that the method used to teach would make the improvement vary. This hypothesis is confirmed, since participants in both GVg and NGVg significantly reduced their CO^2 emissions (i.e. fuel consumption) by 12,38% and 7,42% respectively. In the last scenario, used to calculate the reduction in CO^2 emissions, participants were given no extra information about applying eco-driving rules. This shows that the VGg participants had successfully acquired the eco-driving rules and were able to implement them on their own. This is a very positive result, as it shows it is possible to teach eco-driving using immersive simulation to relatively autonomous participants in a one-hour training session.

Our second hypothesis concerned the contribution of the interactive guiding system. The results are in line with our hypothesis. While NGVg showed a 7.42% decrease in CO^2 emissions, GVg performed significantly better, with a decrease of 12.4%. Statistical analysis also revealed a significant difference in terms of eco-performance between GVg and NGVg, the interactive guidance system leading to better eco-performance than the instructional videos only. The meta-analysis by Andrieu and Saint Pierre (2012) suggests that the methodology used to teach eco-driving has only a slight impact on eco-performance. Both lead to reduced fuel consumption, but learners perform better after training.

Our third hypothesis was related to extraneous cognitive processing. According to the distraction hypothesis, the NGVg should behave more safely than the GVg, and their scores on safety and driving time should thus be closer to those of the control group. Our results support this hypothesis as no difference was found in safety or driving time between GVg, NGVg, and Cog. By following the CTML guidelines for instructional design of multimedia material, one can create an effective system to teach eco-driving without impacting important goals such as safety.

Another effect based on this hypothesis concerns the impact of instructional design guidelines on information processing and distraction phenomena. Our analysis showed no significant difference in number and duration of eye fixations, even between GVg and Cog. Combined with the other results on safety behaviour and perceived mental effort, this suggests that the material did not significantly distract participants from road events, or even add extraneous cognitive load during activity, and that it is appropriate for teaching eco-driving as it improved eco-performance by 5% without modifying participants' goal prioritization or driving time.

As a conclusion, this study shows that there's a significant contribution of the guidance system to learning eco-driving, comparing to learning with instructional videos and practice only. The guidance system leads to higher eco-performance than learning with instructional videos only. It seems that it helps merging procedural knowledge with the implementation of practical skills. Videos and practice alone also lead to significant performances, but it seems like the guidance system leads to a deeper learning or a more understanding integration of the rules.

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References

Anderson, J. R. (1993). *Rules of the mind*. Hillsdale, NJ: Lawrence Erlbaum Associates.
Andrieu, C., & Saint Pierre, G. (2012). Comparing effects of eco-driving training and simple advices on driving behavior. *Procedia-Social and Behavioral Sciences, 54*, 211–220.
Azzi, S., Reymond, G., Kemeny, A., & Mérienne, F. (2010). Eco-driving performance assessment with in-car visual and haptic feedback assistance. In *Trends in driving simulation design and experiments, Proceedings of the driving simulation conference Europe*, pp. 181–190.
Beusen, B., Broekx, S., Denys, T., Beckx, C., Degraeuwe, B., Gijsbers, M., ... Panis, L. I. (2009). Using on-board logging devices to study the longer-term impact of an eco-driving course. *Transportation Research Part D: Transport and Environment*, 514–520.
Boucheix, J. M., & Lowe, R. K. (2010). An eye tracking comparison of external pointing cues and internal continuous cues in learning with complex animations. *Learning and Instruction, 20*(2), 123–135.
Boucheix, J. M., Lowe, R. K., Putri, D. K., & Groff, J. (2013). Cueing animations: Dynamic signaling aids information extraction and comprehension. *Learning and Instruction, 25*, 71–84.
Burns, C. M., & Hajdukiewicz, J. (2004). *Ecological interface design*. CRC Press.
De Koning, B. B., Tabbers, H. K., Rikers, R. M. J. P., & Paas, F. (2009). Towards a framework for attention cueing in instructional animations: Guidelines for Research and design. *Educational Psychology Review, 21*, 113–140.
Ericsson, E. (2001). Independent driving pattern factors and their influence on fuel-use and exhaust emission factors. *Transportation Research Part D: Transport and Environment, 6*(5), 325–345.
faceLAB eye-tracking system. <http://www.ekstremmakina.com/EKSTREM/product/facelab/index.html>.
Folker, S., Ritter, H., & Sichelschmidt, L. (2005). Processing and integrating multimodal material: The influence of color coding. In B. G. Bara, L. Barsalou, & M. Bucciarelli (Eds.), *Proceedings of 27th annual conference of the cognitive science society* (pp. 90–95). Mahwah, NJ: Lawrence Erlbaum.
Ford Motor Company (2008). Ford tests show eco-driving can improve fuel economy by an average of 24 percent, August 27.
Hennig, W. (2008). Ford eco-driving: Best practice training and evaluation, November 12.
International Transport Forum (2007). *Workshop on ecodriving: Findings and messages for policy makers, November 22–23*.
Jamson, A. H., Hibberd, D. L., & Merat, N. (2015). Interface design considerations for an in-vehicle eco-driving assistance system. *Transportation Research Part C: Emerging Technologies, 58*, 642–656.
Johnson, C. I., & Priest, H. A. (2014). 19 the feedback principle in multimedia learning. *The Cambridge handbook of multimedia learning*, p. 449.
Kalyuga, S., Chandler, P., & Sweller, J. (1999). Managing split attention and redundancy in multimedia instructions. *Applied Cognitive Psychology, 13*, 351–371.
Kemeny, A., Kelada, J. M., & Liano, J. P. (1997). Un simulateur de conduite pour la formation des conducteurs de véhicules poids-lourds. In *Proceedings of the SIA Normandie, Rouen, Oct. 1997*.
Key Driving Competences. <http://www.keydriving.com/>.
Mayer, R. E. (2005). Principles for reducing extraneous processing in multimedia learning: Coherence, signaling, redundancy, spatial contiguity and temporal contiguity principles. In R. E. Mayer (Ed.), The *Cambridge handbook of multimedia learning* (pp. 183–200). New York: Cambridge University Press.
Mayer, R. E. (2014). Cognitive theory of multimedia learning. In: *The Cambridge handbook of multimedia learning*, p. 43.
Moreno, R., & Valdez, A. (2005). Cognitive load and learning effects of having students organize pictures and words in multimedia environments: The role of student interactivity and feedback. *Educational Technology Research and Development, 53*(3), 35–45.
Oktal Premium Simulator. <http://www.oktal.fr/en/automotive/range-of-simulators/range-of-simulators>.
Oviedo-Trespalacios, O., Haque, M. M., King, M., & Washington, S. (2016). Understanding the impacts of mobile phone distraction on driving performance: A systematic review. *Transportation Research Part C: Emerging Technologies, 72*, 360–380.
Ozcelik, E., Karakus, T., Kursun, E., & Cagiltay, K. (2009). An Eye-tracking study of how color coding affects multimedia learning. *Computers and Education, 53*, 445–453.
Parodi-Keravec, A., Azzi, S., Filliard, N., Vailleau, B., Icart, E., Kemeny, A., . . ., Martinez, J. L. Eco-driving performance assessment with in-car visual and haptic feedback assistance. In *Proceedings of virtual reality international conference (VRIC 2011), 6–8 April 2011, Laval, France*.
Rakauskas, M. E., Graving, J. S., Manser, M. P., & Jenness, J. W. (2010). Determining the accuracy and acceptance of using driver interface display components and fuel economy information types. In *Proceedings of the human factors and ergonomics society annual meeting* (Vol. 54, No. 19, pp. 1536–1540). Sage CA: Los Angeles, CA: SAGE Publications.
SCANeR™studio: For research and engineering. <http://www.oktal.fr/en/automotive/range-of-simulators/software>.

Soemer, A., & Schwan, S. (2016). Task-appropriate visualizations: Can the very same visualization format either promote or hinder learning depending on the task requirements? *Journal of Educational Psychology, 108*(7), 960.

Symmons, M. A., Rose, G., & Van Doorn, G. H. (2008). The effectiveness of an ecodrive course for heavy vehicle drivers. In *2008 Australasian road safety research policing and education conference*, pp. 187–194.

UK Road Safety Lt. Report by annie canal – Energy and transport European commission.

Vaezipour, A., Rakotonirainy, A., Haworth, N., & Delhomme, P. (2017). Enhancing eco-safe driving behaviour through the use of in-vehicle human-machine interface: A qualitative study. *Transportation Research Part A: Policy and Practice, 100*, 247–263.

Van der Voort, M. C. (2001). *Design and evaluation of a new fuel efficiency support tool*, Ph.D. dissertation, University of Twente.

van Gog, T. (2014). 11 The signaling (or cueing) principle in multimedia learning. *The Cambridge handbook of multimedia learning*, p. 263.

Vicente, K. J., & Rasmussen, J. (1992). Ecological interface design: Theoretical foundations. *IEEE Transactions on Systems, Man, and Cybernetics, 22*(4), 589–606.

Voort, M., Dougherty, M. S., & Maarseveen, M. (2001). A prototype fuel-efficiency support tool. *Transportation Research Part C, 9*, 279–296.

Walker, G. H., Stanton, N. A., & Young, M. S. (2001). Hierarchical task analysis of driving: A new research tool. In M. A. Hanson (Ed.), *Contemporary ergonomics* (pp. 435–440), Taylor & Francis Ltd.: London.

Young, K. L., Regan, M. A., & Hammer, M. (2003). And sub-title. *Public Health, 81*, 102–106.

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