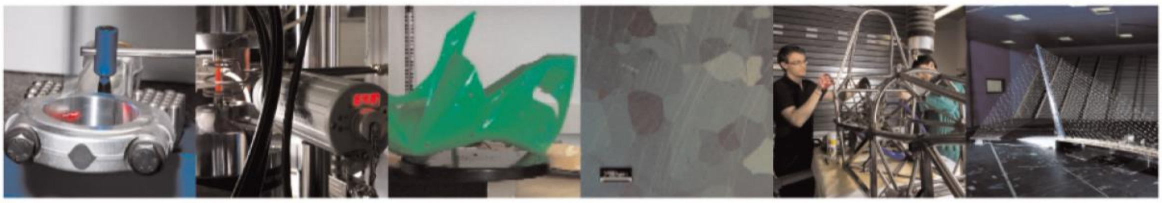

Eco-driving for the first time: The implications of advanced assisting technologies in supporting pro-environmental changes

Daniele Ruscio, Giandomenico Caruso, Lorenzo Mussone, Monica Bordegoni

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Eco-driving for the first time: the implications of advanced assisting technologies in supporting pro-environmental changes

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Abstract: Eco-driving assistance devices are being introduced to reduce CO_2 emissions, but the overall changes in the user behavior have not been sufficiently explored. While in-vehicle driver advanced systems are designed to support a single driving task (e.g. reducing emissions), they also imply the adoption of a different driving behavior and different driving attitudes in order to be efficient. Adopting for the first time a new driving style could affect driver's acceptance and undermine new technologies' efficacy. Purpose of the present research is to measure and evaluate the user's responses to first-time use of eco-driving assisting technology. Driver's performances in a virtual simulator were compared between experimental and a control group. The actual driving parameters and CO_2 emissions were recorded and compared to the optimal eco-driving style calculated by CarMaker software. The cognitive costs of the new driving style were measured by changes in the modulation of autonomic nervous system and NASA-TLX workload scale. Acceptance of the assisted driving style and general eco-friendly attitudes were analyzed by self-reported measures. Results show that being exposed for the first time to eco-driving technology produces a reduction of cumulate fuel consumption only due to speed reduction, and not to changes in the driving style parameters, as recommended by the assisting software. Overall CO_2 emissions of eco-driving group were not different from the control group. Rather, the first time use of the eco-driving assistance increases perceived fatigue and the physiological cardiac autonomic balance related to increased workload over time. These difficulties show that eco-driving style cannot be simply adopted by following the assistance device indications. It seems rather a process, which requires specific support during in the first driving-interaction with eco-driving technology. The design of assistance device that aims to change the driving style, could benefit from the measurement of the user's workload to avoid primacy effect that potentially undermine technology efficacy in supporting user-sustainable behaviors.

Keywords: Assistance technologies; CO2 emissions; pro-environmental behavior; human-machine interaction; acceptance; workload.

1. INTRODUCTION

Fuel consumption and CO_2 emissions are relevant topics in environmental research and mobility policies (Hunecke, Haustein, Bohler, & Grischkat, 2010). Eco-driving style is commonly estimated to induce a reduction of fuel consumption between 10-30% (Sivak & Schoettle, 2012). To support the driver in learning and maintaining eco-driving style, eco-driving assistance systems (EDAS / EDSS) are being introduced in new vehicles, to provide support-intervention and feedbacks (Hof, van der Weerdt, & Wijn, 2014).

The effectiveness of built-in or nomadic eco-driving devices are based on the assumption that the introduction of assisting technology will promote change in the driving style of the driver: smooth accelerations, steady speed, early gear change, efficient deceleration, and moderate brake behaviors. The implicit consideration is that the driver will be willing to follow the sufficiently good feedbacks (e.g. that will not distract nor affect drivers too much) of the device, in a proper way. However, the effective introduction of new assisting systems implies that the driver not only changes his driving style, but also accepts the new driving style and perceive the costs of the transition inferior to the perceived benefits (Af Wåhlberg, 2006). Since the driver needs to accommodate or change an already existing consolidated driving automation, the new eco-driving solutions should also consider the effects on the user of the modification of the driving style.

1.2 Considering the effects of introducing advanced assisting devices

The impact of introducing new device has been extensively studied in terms of effectiveness in reducing overall emission (Barkenbus, 2010), as well as for the effect on driver’s dual-task workload (Kircher, Fors, & Ahlstrom, 2014), safety (Young, Birrell, & Stanton, 2011) and acceptability (Vlassenroot et al., 2010).

The way drivers actually adapt to the first use of eco-driving devices and the related effects on workload and acceptance, are currently not certain. The question may be relevant especially considering that advanced driver assisting systems are rarely tried by drivers before use (Biassoni et al., 2016) and the potential side effects of assisting technologies are not always considered in the design manufacturing process (McLoone, et al., 2010). Several research works have shown that inadequate design and user experience, could affect user's satisfaction (Gaspar, Fontul, Henriques & Silva, 2014), perceived value of technology (Boztepe, 2007) and impact on risk management processes (Hood & Jones, 2003). In addition, the first impressions of the usability of a new device (Saadé & Otrakji, 2007) can be crucial to determine the willingness to buy the device (Park, & Han, 2013) and the intention to use again the device in the future (Steg, Lindenberg, & Keizer, 2016). If eco-driving assisting technologies can already provide good feedbacks for the driver, the question why correct eco-driving style is yet not easily being adopted by drivers on a wider scale and with long-term effects (Wåhlberg, 2007; Whitmarsh & O'Neill, 2010) remains still open (Rakotonirainy, Haworth, & Saint-Pierre, 2011), especially if considering that pro-environmental attitudes are increasing among the population (Ohtomo & Hirose, 2007). These open questions are suggesting that adopting an eco-driving style may be a complex process that involves several cognitive processes, which are maybe worth being better investigated in order to avoid the development of “not completely compelling” devices (Ahlstrom & Kircher, 2017).

1.3 Modelling the adoption of eco-driving behaviors

In a recent research Ahlstrom and Kircher (2017) reported that the visual behavior of ten drivers that interacted with eco-driving assisting device produced high amount of glances toward the system, looking for feedback on the driving style. At the same time, a considerable amount of relevant assisting feedback pop-ups (form 20% to 40%) were actually ignored by the drivers during the assisted driving. The researchers conclude that improvements to the already designed system should be made in order to avoid the disregard of important EDAS feedbacks. However, the research did not investigate the reasons behind this significant disregard of the assisting device feedbacks, nor the subjective feelings related the willingness to use the ecoDrive system, nor the actual changes in the drivers' behavior during the interaction. To better understand the nature of the interaction with assisted driving, a model of the user behavior can be proposed (Figure 1) to combine the Theory of Planned Behavior for advanced driver assistance systems (Biassoni, et al., 2016) and a cognitive taxonomy to explain the change (Bloom et al. 1956) to the eco-driving. According to the Theory of Reasoned Action (Fishbein and Ajzen, 1975) and the Theory of Planned Behavior (Ajzen, 1991), the best predictor of a person's behavior is the users' intention to use a technological device, which is based on two main features: 1) perceived usefulness of the device (defined as the extent to which a person believes that using the system will enhance his/her performance) and; 2) perceived ease of use (defined as the extent to which a person believes that using the system will be free of effort). In Figure 1, the *INPUT* of the process are the driving parameters required to be modified when EDAS feedback promote the adoption of an eco-driving style (e.g. adaptation of cruise speed and gears change frequency).

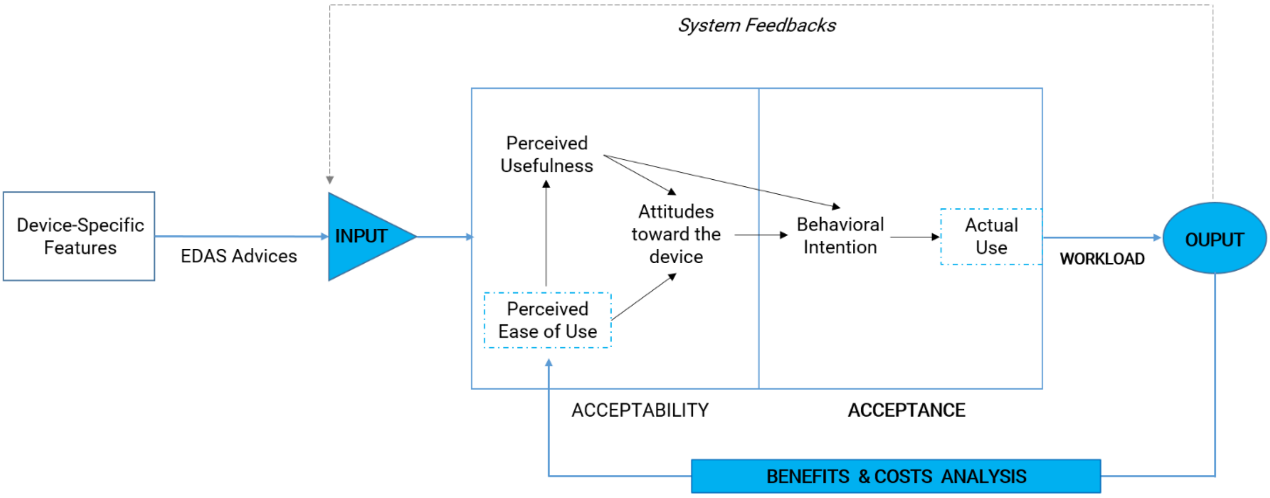

Figure 1. The model of user-behavior interaction with assisting technology, derived from the Technology Acceptance Model (Davis et al., 1989), used to explain the impact of using eco-driving assistance systems.

The *OUTPUT* of the transition represents the result of the modification of the driving style, in terms of application of the knowledge learned in the virtual training (Parmar, et al., 2016), which, in this case, can be measured as CO_2 emissions while following the assisting device. The initial *BENEFITS/COSTS ANALYSIS* associated to the use of the device is crucial to determine the user's acceptance and is dependent on the direct/indirect workload effects activated in this process (Backs, Rohdy, Barnard, 2005). User's initial *acceptance* can be measured as a judgment based on attitudes and behavioral experiences toward a system, which emerged after the actual use of the device (Beggiato and Krems, 2013). According to Malleable attentional resources theory (Young & Stanton, 2002), workload can accommodate according to the performance demand (Gaillard & Kramer, 2000) and this accommodation can be measured elaborating the autonomic nervous system modulations (Hoover, et al. 2012).

To achieve a global comprehension of the assisted modification toward eco-driving style, it may be helpful to understand the primacy effects (Todd, Provost & Cooper, G. 2011) of eco-driving feedbacks in the driver's behavior, initial acceptance and physiological indexes related to workload, while trying to adapt the driving style to reduce CO_2 emissions.

1.4 The present research

The purpose of the present study is to implement a simulation based on real-life sequence of urban driving situations, to test the effect of user-behavior interaction with advanced assisting device. Eco-driving training and eco-driving assistance feedbacks were implemented into a driving simulator to measure changes in drivers' behavior as well in the initial acceptance and workload costs in a group of naïve drivers, never been exposed before to eco-driving training.

We hypothesize that after the first-time use, the drivers could benefit from the presence of eco-driving feedbacks, but that the initial modification of the spontaneous driving behavior would have some costs in terms of acceptance and workload, compared to a control group. In particular, we expect to: (1) measure the effects of eco-driving on the user's driving behavior and workload; (2) understand if changes in the driving style produce functional outputs (i.e. less CO_2 emissions), accordingly to the EDAS feedbacks; (3) understand how the eco-driving transition could potentially affect user's initial acceptance.

2. METHODS

2.1 Testing Scenario

The software CarMaker (IPG Automotive) has been implemented on the iDrive driving simulator (Politecnico di Milano) to recreate a complex real urban scenario, useful to measure the effect of different driving styles on fuel efficiency and CO_2 consumption. The experimental scenario was comprised of 3.75 km of urban driving. The scenario was built importing into CarMaker the Google Earth coordinates and topography of an urban portion of the city of Milan - Italy (Figure 2). The scenario was built to present a series of driving interactions where the driver was required to adjust the driving style to face different road interactions. In particular, five right of way situations were included [A, B, C, F, J in Figure 2], two roundabouts [D, N], one underpass with and without traffic [E, M] and one traffic light [I]. In addition, three hazardous situations were created in order to see the effects of braking and decelerations on fuel consumption: two slow vehicles were introduced in front of the driver [G, K]: one with an overtake opportunity during a stop of the bus after a series of bumps [H] and one where overtaking was not allowed.

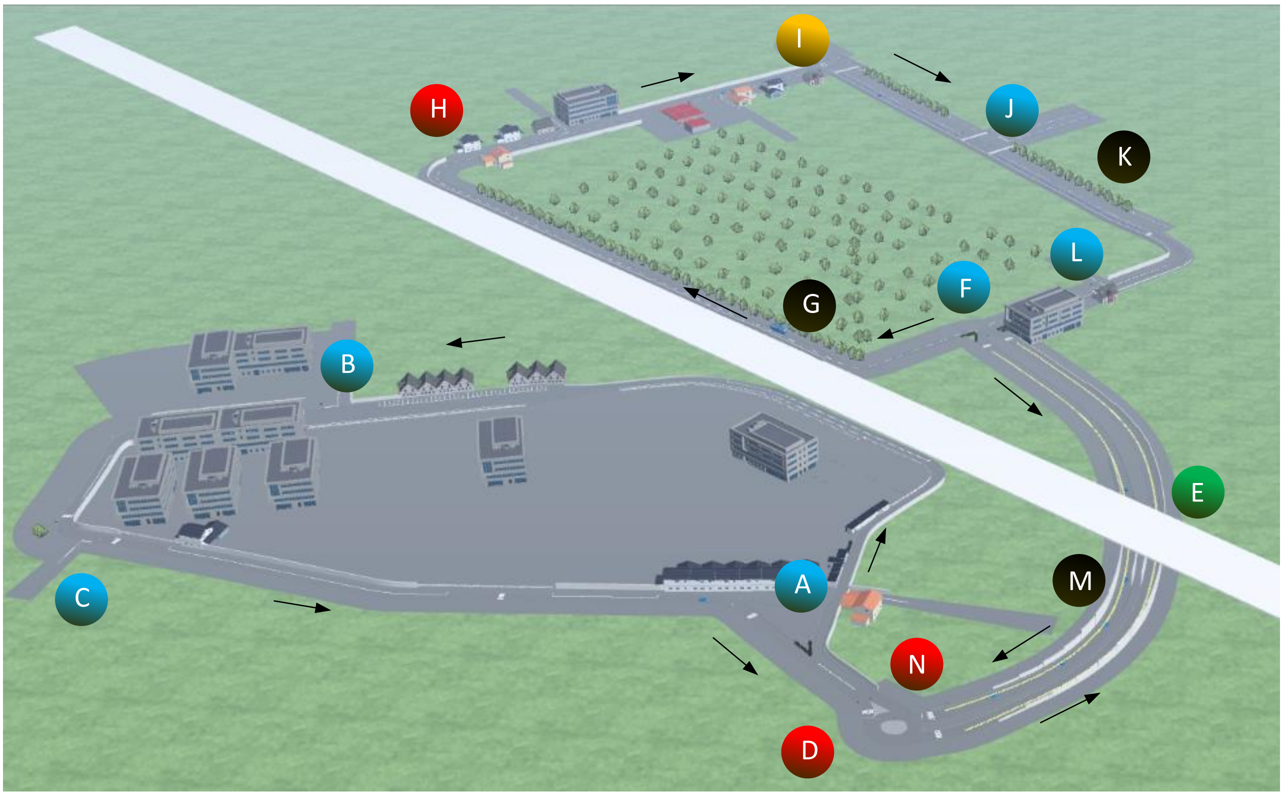

Figure 2: Map of the urban scenario with the sequence of intersections. The route was considered to compute the most accurate eco-driving style required to face the different intersections and to measure the effect of eco-driving information on driver's behavior and workload.

The scenario allowed a maximum speed of 50 km/h, it included different slopes of the road and a wide range of turning amplitude and roadway width that required the driver to slow down, stop, adjust speed to face safely the intersection before going back to cruise speed.

2.2 Experimental Design

The ideal eco-driving style, was calculated by the software CarMaker, which provided the exact information on the driving style required to approach the different intersections with the least CO_2 emissions possible. The optimal driving style was used as the ideal reference to compare the drivers' driving style after the first-time approach to eco-driving. A between groups design was used, to test the change in driving style and its effect on workload of young drivers that were never exposed to any eco-driving training or EDAS before. The experimental group was: 1) briefed with an introduction to the “Golden Rules” of eco-driving (ecodrive.org, 2013; United Nations 2013); 2) it was exposed to a video-description generated by the software that show the ideal eco-driving style on the considered urban route; 3) it was informed about the head up information coming from the inbuilt EDAS on real-time fuel consumption and; 4) it was asked to try to voluntarily adopt the EDAS suggestion in the driving test. The control group, instead, was just briefed with a general didactic video about new intelligent vehicle technologies, without any introduction of the golden rules, nor any explanation about the functionality of the inbuilt EDAS and without any mention on the driving style that they were required to maintain in the urban scenario.

2.3 Procedure

After reading the consent form, drivers were introduced to the questionnaire battery, followed by the application of physiological sensors (Blood Volume Pulse, Electrodermal activity and respiration). An adaptation scenario consisted of a straight empty road to help the driver experience the basic vehicle controls and mitigate potential effects of motion sickness. Participants drove until they felt habituated to the virtual simulator and were confident in controlling the virtual vehicle.

After the adaptation scenario, the sample was divided into two groups by random selection. 12 drivers were assigned to the experimental group, which included the eco-driving training, while the 12 drivers of the control group did not attend any training on eco-driving. After the experiment, participants were thanked for their time and a debriefing session concluded the experiment, including measurement of subjective workload indexes about the simulated driving.

2.4 Sample

24 young male drivers voluntarily participated in the experiment. The mean age of participants was 22.2 years old (SD = 3.2), they had the driver license for a mean of 3.8 years (SD = 3.0) and declared a mean driving experience of 7,357 km/year (SD = 7,179). All the participants declared that they did not participated in any eco-driving training course and never used an EDAS before the test. Only male drivers were considered in this preliminary study, in order to keep the variability of the sample constant for gender. Demographic information and attitude towards green behaviors were also collected, along with a measurement of the Barratt Impulsiveness Scale (BIS-11; Patton & Stanford, 1995), in order to control the individual distribution between the experimental groups of the personality/behavioral construct of impulsiveness that could affect the susceptibility towards pro-social behaviors (Stanford, et al., 2009). The experimental group and the control group were considered comparable, as no significant differences emerged for age $F(1,24) = 1.526$, $p = .233$, $\eta_p^2 = .078$, years of driving experience $F(1,24) = 2.350$, $p = .143$, $\eta_p^2 = .115$, and km/year $F(1,24) = 2.891$, $p = .106$, $\eta_p^2 = .138$. No differences were also found in the BIS-11 overall scale $F(1,24) = .080$, $p = .780$, $\eta_p^2 = .004$, nor in the subscales: Cognitive Instability $F(1,24) = .567$, $p = .461$, $\eta_p^2 = .031$; Attentional Impulsiveness $F(1,24) = .019$, $p = .892$, $\eta_p^2 = .001$; Motor Impulsiveness $F(1,24) = .003$, $p = .957$, $\eta_p^2 = .001$; or Non-planning $F(1,24) = .029$, $p = .867$, $\eta_p^2 = .002$.

2.5 Measurement

The Dependent Variables are reported in Table 1. Measures of the driving style parameters, the perceived effort, the physiological reactions and the way the two groups faced the driving situation, were recorded and compared to the ideal driving style produced by the software.

Table 1: Dependent variables measured between groups.

Variable	Measure	Unit
Driving Behavior	Fuel consumption.	L
	Gear Changes	frequency/number
	Speed (mean and SD)	km/h
Driver’s acceptance	Assisting device acceptance scale	1-7 Likert Scale
Driver’s workload	Mean Heart Rate	bpm
	High Frequency power	15-40 Hz
	Blood Volume Pulse amplitude	V
	Cardiac Autonomic Balance (CAB)	PSNz-(SNSz)
	Subjective workload (NASA-TLX)	Weighted scores

2.5.1 Fuel Consumption. The algorithm used to define the ideal driver’s behavior to save fuel consumption was derived by a specific manipulation of the software CarMaker (Figure 3). The software provided for all intersections the values of: cruising speed, corner cutting coefficient, dt change of pedals, longitudinal acceleration, lateral deviation, time to change gear, engine speed RPM and distance from lead vehicle. For the purposes of the present research, only for fuel consumption, fuel efficiency and speed were considered.

Figure 3. Virtual reconstruction of the urban environment and EDAS equipped dashboard, used to compare drivers to the optimal eco-driving style, using CarMaker software (IPG).

2.5.2 Driver’s Acceptance and pro-environment attitude. In order to measure user’s acceptance of assisting device, a questionnaire was derived from the acceptance scale of Vlassenroot, et al. (2010). The Italian adaptation was taken from Biassoni, et al. (2016), that included a selection of factors, measured on a 1-7 Likert scale: (1) trust in the assisting device, (2) perceived difficulty of use, (3) perceived fatigue, (4) perceived frustration derived from potential distraction, (6) perceived pleasantness of driving while using the assisting device and (7) perceived irritation. Attitudes toward the environment were taken from the scale used in the European Project: Ecodriving, to measure user’s green attitudes (Hof, van der Weerdt, & Wijn, 2014).

2.5.3 Driver’s Workload. To measure the autonomic nervous modulations related to workload, mean heart rate, high frequency power of heart rate variability and Blood Volume Pulse amplitude were considered. High frequency (HF) power of heart rate variability represent a good estimation of parasympathetic activity on vagal efferents, as it reflects the high frequency component of heart rate variations (.12/.15 - .40 Hz) in relation to the respiratory cycle regulated by the parasympathetic system (Berntson, et al., 1997). Blood Volume Pulse (BVP) measures changes in blood volume using infrared light through the fingers’ tissues. It is a measure that result from sympathetic neuronal activity related to the autonomic activation (Peper, Harvey, Lin, Tylova, & Moss, 2007). Using a combined analysis of HF and BVP amplitude, Cardiac Autonomic Balance (CAB) was calculated as the difference between the normalized parasympathetic and sympathetic reactivity scores to provide a synthetic measure of autonomic balance (Berntson, Norman, Hawkley & Cacioppo, 2008). Physiological data were calculated in two one-minute windows during two similar road segments (centered on turn C vs. L in Figure 1) in order to see differences in facing a turn toward the beginning and the end of the driving session, and avoid motion artifacts. To contextualize physiological variables, subjective scores of perceived workload and effort were recorded using the NASA-TLX (Hart & Staveland, 1988), which is a standardized test commonly used to measure validate subjective metal effort.

2.6 Calculation

Repeated measures ANOVA between groups [with eco-driving training vs. without eco-driving training] for all the dependent variables (Table 1) was performed to measure statistical differences between experimental group for attitudes, driving style, perceived cognitive workload and physiological measurement. Correlations between subjective measures and weighted NASA-TLX workload were also performed between two groups, to determine what subjective elements remain correlated to the driving style after the experimental driving.

3. RESULTS

3.1 Driving behavior

The ideal eco-driving style did not prevent reaching high speeds: the mean speed was 24 km/h, the maximum speed was 42.26 km/h and during the turns, the software suggested keeping the speed greater than 20 km/h, using mainly the third gear. The ideal eco-driving speed profile did not present intense accelerations and decelerations: the maximum acceleration reached 1 m/s^2 after the stops while it was kept constant for the rest of the driving parts. The experimental group and the control group presented different values of speed profile, with the experimental group keeping a slower speed (M=17.0 km/h, SD = 1.85), compared to the control group (M=20.4 Km/h, SD = 3.69), and the difference was statistically significant for the mean speed F(1,24)=6.514, p = .020, ηp2 = .266 and also for the standard deviation of speed kept during the route F(1,24)=6.763, p = .018, η_p^2 = .273 (Figure 4).

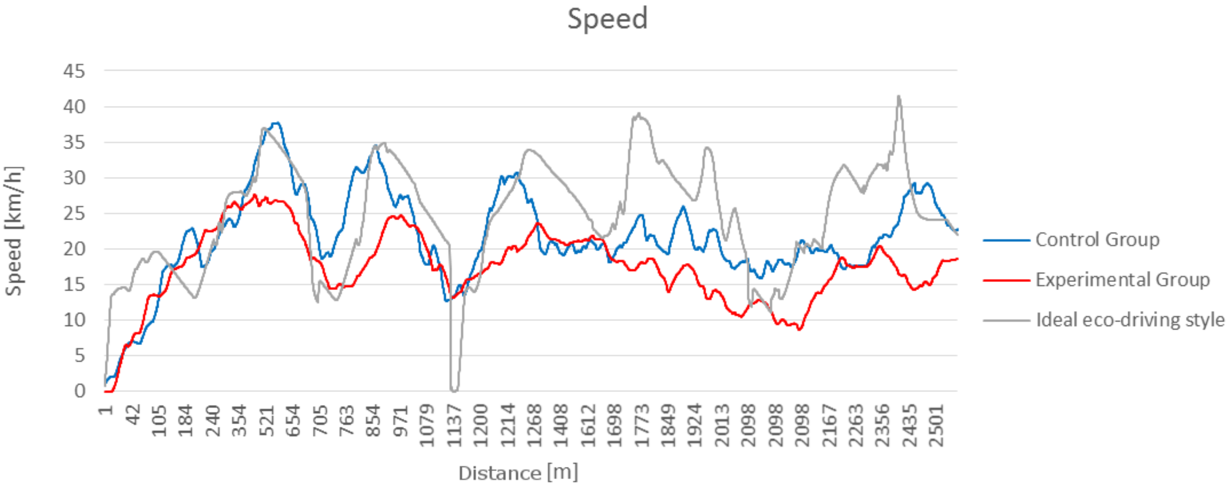

Figure 4. Mean speed of the two groups compared to the ideal eco-driving style.

In addition, compared to the ideal eco-driving style, it was possible to see that there was a difference between the experimental group and the ideal profile during turns, especially at the end of the driving session (e.g. distance1773m, 1924m, 2263). Compared to the speed of the ideal eco-driving style, the lower speed in lateral deviations of the experimental and control group during the turns, forced the drivers to present steeper accelerations after the turns, and thus more fuel consumption. No additional significant differences between the control and experimental groups were found in the number of gear changes $F(1,24)=3.873$, $p = .065$, $\eta_p^2 = .177$, nor in the mean time spent for each of the 5 gears $F(1,24)=.410$, $p = .530$, $\eta_p^2 = .022$, with the second gear as the more used by both groups.

3.2 Fuel Consumption and CO_2 Emissions

The ideal eco-driving style produced for the specific sequence of urban intersections, a final fuel consumption of 0.178 liters of gasoline with a mean of fuel efficiency of 5.14 l/100 km, which corresponds to an equivalent mean emission of 119.36 g of CO_2 per km in the environment. The experimental group and the control group presented values of fuel consumption that were higher than the ideal value. The experimental group presented a mean fuel consumption of 0.217 liters of gasoline, with a mean of fuel efficiency of 20.46

l/100 km, which corresponded to an equivalent mean emission of 474.67 g of CO_2 per km in the environment. The control group had a mean consumption of 0.288 liters of gasoline, with a mean of fuel efficiency of 21.47 l/100 km, which corresponded to an equivalent mean emission of 498.10 g of CO_2 per km in the environment. The difference between the control and experimental groups was significant only for the cumulated consumption at the end of the driving scenario F(1,24)=16.478, p = .001, η_p^2 = .478 (Figure 5), but not for the fuel efficiency and the related CO_2 emissions F(1,24)=.0057, p = .814, η_p^2 = .003 (Figure 6).

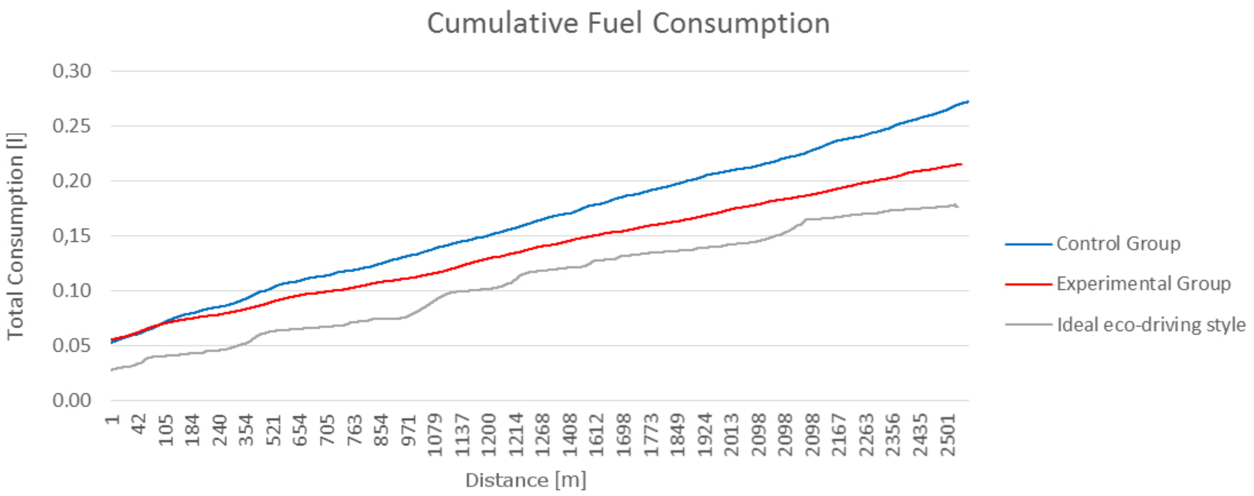

Figure 5: Cumulative fuel consumption in the urban route tested, for the ideal driving-style (bottom gray line), and for the mean consumption of the experimental group (middle red line) and the control group (top blue line).

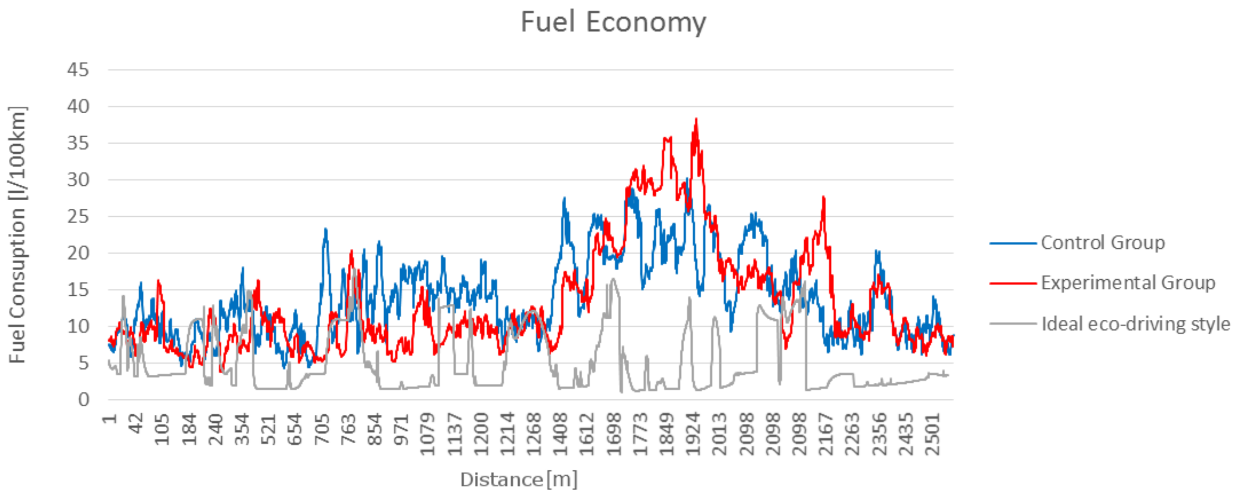

Figure 6. Average fuel efficiency expressed as liters of gasoline per 100 kilometers (L/100 km) for the two groups and the ideal eco-driving style.

3.2 Driver's acceptance and attitudes toward eco-driving

Considering the independent variable manipulated, the experimental group reported higher levels of perceived fatigue while trying to keep an eco-driving style compared to the control group F(1,24) = 9.815, p = .006, η_p^2 = .353. On a 1-7 Likert scale, participant that drove following the eco-driving style feedbacks reported a mean fatigue level of 4.9 (SD = 1.2) while the control group reported a mean level of 3.2 (SD = 1.2). The two groups perceived the driving task in a similar way in terms of perceived pleasantness F(1,20) = 2.565, p = .127, η_p^2 = .125, irritation F(1,24) = 1.800, p = .196, η_p^2 = .091, frustration F(1,24) = 1.758, p = .201, η_p^2 = .089 and difficulty F(1,24) =.456, p = .508, η_p^2 = .025. On a 1-7 Likert scale, the participants reported an overall medium-high value of being aware of CO_2 emissions, without significant difference between the experimental groups. More precisely, participants of both groups declared to be equally respectful towards the environment (*M* = 5.5, *SD* = 1.1), F(1,24) = 2.909, p = .105, η_p^2 = .139; to be both moderately available to spend more money for products that are respectful of the environment (*M* = 4.8, *SD* = 1.4), F(1,24) =.000, p = 1.000, η_p^2 = .000; to consider the impact of the driving style on carbon emissions (*M* = 3.9, *SD* = 1.9), F(1,24) = .013, p = .910, η_p^2 = .001, and declared to be prone to not use the car when green alternatives like bikes and public transportations are available (*M* = 2.8, *SD* = 1.5), F(1,24) = .545, p = .470, η_p^2 = .029. After the test, the participants of both groups declared a mean value of 4.5 of being willing to keep an eco-driving style in the future (*M* = 5.5, *SD* = 1.8), without significant difference between the groups F(1,24) = .390, p = .540, η_p^2 = .021.

3.4 Driver's Workload

The experimental group at the first measurement time at the beginning of driving (T1) presented an increase of Mean Heart Rate compared to baseline of 10.1 (*SD* = 6.7), with a tendency to decrease at 5.3 (*SD* = 6.8) during the second measurement time at the end of driving (T2), while the control group reported more constant values of 7.6 (*SD* = 9.8) at T1 and 7.8 (*SD* = 7.4) at T2. However, the differences of Heart Rate values represent only a tendency as no statistically significant differences were found neither for the main effect F(1,24) = .001, *p* = .975, η_p^2 = .001, or for Time effect F(1,24) = 1.254, *p* = .277, η_p^2 = .065. The High Frequency (HF) component of heart rate presented a tendency to increase for the eco-driving group from 8.4 (*SD* = 13) at T1 to a 18.2 (*SD* = 14) at T2, while the control group presented a tendency to decrese from 10.1 (*SD* = 18) at T1, to 6.8 (*SD* = 18) at T2. The differences in HF alone were not statistically significant for the main effect F(1,24) = .589, *p* = .453, η_p^2 = .032, and for Time F(1,24) = .817, *p* = .378, η_p^2 = .043. Similarly, BVP amplitude presented a tendency to increase for the control group from -1.8 (*SD* = 2.0) at T1 to a 0.4 (*SD* = 3.4) at T2, while the eco-driving group presented a more constant tendency from -2.4 (*SD* = 3.3) at T1, to -2.4 (*SD* = 2.0) at Time 2. The differences in BVP amplitude alone were not significant neither for main effect F(1,24) = 2.692, *p* = .118, η_p^2 = .130, and Time F(1,24) = 2.805, *p* = .111, η_p^2 = .135.

However, considering the Cardiac Autonomic Balance index, the combined parasympathetic and sympathetic tendencies became statistically significant. The interaction effect reported significant difference between groups during the driving session, from T1 to T2 F(1,24) = 6.757, *p* = .018, η_p^2 = .273. The cardiac autonomic balance component presented a significant increase for the eco-driving group from 1.3 (*SD* = 1.5) at T1 to a value of 1.8 (*SD* = 1.3) at T2, while the control group presented a sigificant decrese from 1.2 (*SD* = 1.5) at T1, to 0.3 (*SD* = 1.2) at the T2 (Figure 7). For all the physiological measures, the values recorded during the final resting baseline went back to the initial resting baseline values.

The overall NASA-TLX score was also significantly different between the two groups F(1,24) = 5.080, p = .036, η_p^2 = .291, with the experimental group accordingly reporting higher levels of workload compared to the control group. In addition, the experimental group reported a significant direct correlation between the weighted NASA-TLX overall scores and the perceived difficulty of the driving task and at the same time an indirect correlation with the perceived utility of the device (Table 2). The control group did not report any significant correlation with the NASA-TLX values (Table 3). No further significant differences were found for the workload sub-scales for mental F(1,24) =.001, p = .976, η_p^2 = .000, physical F(1,24) = .561, p = .464, η_p^2 = .030, temporal F(1,24) = .138, p = .715, η_p^2 = .008, performance F(1,24) = 1.119, p = .304, η_p^2 = .059, effort F(1,24) = 1.188, p = .290, η_p^2 = .062 nor frustration F(1,24) = .538, p = .473, η_p^2 = .029 workload.

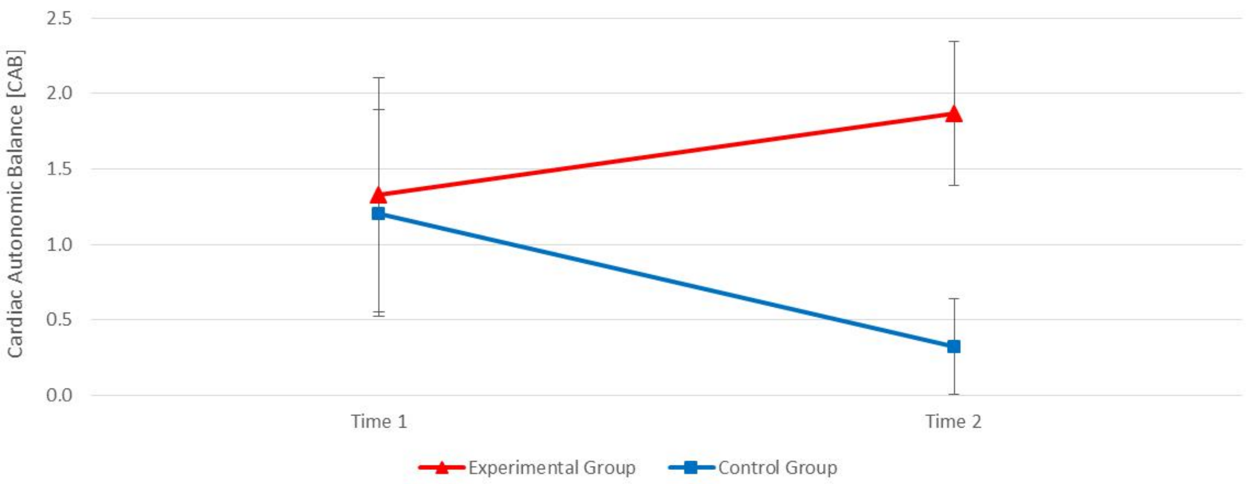

Figure 7. Cardiac Autonomic Balance changes across time for the experimental vs. control group. At time 2 the experimental group reported statistically significant increase in workload indexes.

Table 2. Perceived Workload correlations for the Eco-driving style group (N=12)

		Perceived Pleasantness	Perceived Fatigue	Perceived Irritation	Perceived Frustration	**Perceived Difficulty**	**Perceived Utility**
NASA-TLX Score	Pearson Correlation	-.152	.478	.464	.275	**.761***	**-.712***
	Sig. (2-tailed)	.675	.163	.177	.441	**.011**	**.021**

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3. Perceived Workload correlations for the Control Group (N=12)

		Perceived Pleasantness	Perceived Fatigue	Perceived Irritation	Perceived Frustration	Perceived Difficulty	Perceived Utility
NASA-TLX Score	Pearson Correlation	-.300	.389	.305	.005	.342	.267
	Sig. (2-tailed)	.400	.267	.392	.990	.334	.456

*. Correlation is significant at the 0.05 level (2-tailed).

4. DISCUSSION

The effect of first time use of eco-driving assistance device (EDAS) was analyzed according to Theory of Planned Behavior adapted to measure the primacy effect (Todd, Provost & Cooper, G. 2011) on the user of the introduction of advanced driver assistance systems. The global impact of following the EDAS training and feedbacks for eco-driving for the first time, were tested measuring input, output and cost / benefits analysis. Performance measure, acceptance, and direct/indirect measure of workload were analyzed in a group of male drivers trained to follow for the first time an eco-driving style, compared to a control group.

Results show that being exposed to an assisting device for the first time produces some negative impact on drivers. The changes in the driving style produced initial effects achieved by an incorrect management of the assisting technology advices. Drivers were not able to immediately input the eco-driving feedbacks into a correct eco-driving behavior, but rather the eco-driving training generated an unspecific reduction of speed (Hao, et al., 2016) and perceived fatigue and effort as output of the transition. The experimental group presented poor overall fuel efficiency levels, almost similar to the levels of the control group. At the same time, the experimental group showed a clear tendency to increase in fatigue to maintain an eco-driving style over time. This appears significant when considering the activity of Autonomic Nervous System, which modulates the Cardiac Autonomic Balance interplay (Berntson, Norman, Hawkley & Cacioppo, 2008) of both sympathetic and parasympathetic nervous system indexes. Following the eco-driving feedbacks produced a tendency to increase parasympathetic inhibition, with a reciprocally coupled increase in sympathetic activity, which all together generated a significant interaction over time of Cardiac Autonomic Balance (Lenneman & Backs, 2009). This type of modulation of autonomic control is usually related to increase in workload (Ruscio, Bos, Ciceri, 2017), and that highlights the presence of higher cognitive load while driving with eco-driving style, compared to spontaneous drivers that presented no particular workload activity over time, nor any signal of dual-task interference while driving.

The pattern of autonomic control over time was also coherent with the self-reported levels of fatigue and the weighted NASA-TLX workload scores, measured between the two groups.

The assisted experience of eco-driving produced higher levels of perceived fatigue, and that perceived workload correlated directly with lower scores of “perceived utility” of the assisting device, suggesting potential negative “primacy effects” based on the first-time experience with the device. Driving in a spontaneous way did not produce any variation in the perceived levels of fatigue, nor in levels of workload or in perceived difficulty and perceived utility to keep an eco-driving style in future. These subjective difficulties show that eco-driving cannot simply be learned just introducing assisting device that have as learning goal the cognitive knowledge of the golden rules of eco-driving.

What emerge from the result is that learning a psychomotor skill following prescriptive information (Bloom et al. 1956) provided by the EDAS may be not be enough to immediately apply the best possible driving style to save fuel efficiency, because of psycho-physiological costs modify the existing different driving style. These difficulties can be amplified in young drivers, where the attentional and cognitive resources required to manage dual-tasks driving are not as ready as in experienced drivers (Ciceri & Ruscio, 2014). Even when the motivation to change the driving style, is already present, experiencing a problematic first time use, could generate negative primacy effect (Di Girolamo and Hintzman, 1997). Primacy effect are able to persistently influence the future experience with the device, preventing future differentiation in subsequent experiences (Todd, Provost & Cooper, G. 2011) and impacting the product evaluation beyond the design features (Becker, van Rompay, Schifferstein & Galetzka, 2011). These potential criticalities can become even more relevant, since previous research has already shown that prosaically and environmental behaviors dropouts (Steg & Vlek, 2009; Lavergne, & Pelletier, 2015) can occur when the costs of adopting the prosaically behavior are perceived greater than the potential benefits of maintaining a new behavior (Jenkins, et al. 2009).

Follow an eco-driving style seems a complex process that cannot be learned simply following prescriptive real-time indications, especially if the process increases the workload level, affecting the perceived ease of use and the perceived usefulness of the device (Donald, Cooper & Conchie, 2014). That is why the design of assistance device that aims to change the driving style, could consider the precise measure of user’s workload: to preventively adapt and modify the working features in order to minimize the negative side-effects in the initial steps of adoptions; and avoid “primacy effects” that could undermine or bias the acceptance of assisting technology and the intention of adopting a pro-environmental behavior in the future (Nordlund, & Garvill, 2002).

The results found in the present research apply only for young and novice male drivers that have never been exposed to EDAS or eco-driving training before. More generalizable conclusions could be achieved by increasing sample size and setting up longitudinal studies that measure changes in eco-driving style after repeated use of the device. However, this type of experiment highlights the importance to consider a complexity of measures to assess the first-time impact of the interaction with advanced assisting technologies, to prevent unsafe or inefficient development of “not completely compelling” devices or user interfaces. An integrated and interdisciplinary approach could support the production of intelligent devices that could make this change more immediate and easy to understand (McIlroy & Stanton, 2015). Supporting a sustainable use of assisting technologies and a more effective user-vehicle-environment interaction to increase safety while reducing CO_2 emissions.

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References

Af Wåhlberg, A. E. (2006). Short-term effects of training in economical driving: Passenger comfort and driver acceleration behavior. International Journal of Industrial Ergonomics, 36(2), 151–163. http://doi.org/10.1016/j.ergon.2005.10.001

Ahlstrom, C., & Kircher, K. (2017). Changes in glance behaviour when using a visual eco-driving system? A field study. Applied Ergonomics, 58, 414–423. http://doi.org/10.1016/j.apergo.2016.08.001

Andrieu, C., & Saint Pierre, G. (2012). Comparing Effects of Eco-driving Training and Simple Advices on Driving Behavior. *Procedia - Social and Behavioral Sciences, 54*(2011), pp. 211–220. doi:http://doi.org/10.1016/j.sbspro.2012.09.740

Ajzen I. (1991) The theory of planned behavior Organ. Behav. Hum. Decis. Process., 50, pp. 179–211

Backs, R. W., Rohdy, J., & Barnard, J. (2005). Cardiac control during dual-task performance of visual or auditory monitoring with visual-manual tracking. *Psychologia: An International Journal of Psychology in the Orient, 48*, pp. 66-83.

Barkenbus, J. N. (2010). Eco-driving: An overlooked climate change initiative. *Energy Policy, 32*(2), p. 762–769. doi:http://doi.org/10.1016/j.enpol.2009.10.021

Beggiato, M., Krems, J.F., 2013. The evolution of mental model, trust and acceptance of adaptive cruise control in relation to initial information. Transport. Res. Part F 18, 47–57.

Berntson, G. G., Norman, G. J., Hawkley, L. C., & Cacioppo, J. T. (2008). Cardiac autonomic balance versus cardiac regulatory capacity. *Psychophysiology, 45*(4), pp. 643-652.

Biassoni, F., Ruscio, D., & Ciceri, M. R. (2016). Limitations and automation. The role of information about device-specific features in ADAS acceptability. *Safety Science, 85*, pp. 179–186. doi:http://doi.org/10.1016/j.ssci.2016.01.017

Bloom BS, Englehart MD, Furst EJ, Hill WH, Krathwohl DR (1956) Taxonomy of educational objectives: the classification of educational goals, Handbook 1: The cognitive domain, Long- man, New York

Boztepe, S., 2007. User value: competing theories and models. International Journal of Design 1 (2), 55e63.

Ciceri, M. R., & Ruscio, D. (2014). Does driving experience in video games count? Hazard anticipation and visual exploration of male gamers as function of driving experience. *Transportation research part F: traffic psychology and behaviour, 22*, pp. 76-85. doi:http://dx.doi.org/10.1016/j.trf.2013.11.001

Delbeke, J., & Vis, P. (Eds.). (2015). *EU climate policy explained.* Routledge.

Donald, I. J., Cooper, S. R., & Conchie, S. M. (2014). An extended theory of planned behaviour model of the psychological factors affecting commuters' transport mode use. *Journal of Environmental Psychology, 40*, p. 39–48. doi: ISSN 0272-4944, http://dx.doi.org/10.1016/j.jenvp.2014.03.003.

Drijvers, Paul; Trouche, L. (2008). From artifacts to instruments: A theoretical framework behind the orchestra metaphor. Research on Technology and the Teaching and Learning of Mathematics, Cases and Perspectives., 2, 363–391.

Fishbein, M., Ajzen, I., 1975. Belief, Attitude, Intention and Behavior: An Introduction to Theory and Research. Addison-Weasley, Reading, MA.

Gaspar, J., Fontul, M., Henriques, E., & Silva, A. (2014). User satisfaction modeling framework for automotive audio interfaces. International Journal of Industrial Ergonomics, 44(5), 662–674. http://doi.org/10.1016/j.ergon.2014.07.009

Hart, S. G., & Staveland, L. E. (1988). Development of NASA-TLX (Task Load Index): Results of empirical and theoretical research. *Advances in psychology, 52*, pp. 139-183.

Hao, L., Chen, W., Li, L., Tan, J., Wang, X., Yin, H., Ding, Y., Ge, Y. (2016). Modeling and predicting low-speed vehicle emissions as a function of driving kinematics, Journal of Environmental Sciences, Available online 13 August 2016, ISSN 1001-0742, http://dx.doi.org/10.1016/j.jes.2016.05.037.

Hood, C., & Jones, D. K. (Eds.). (2003). Accident and design: Contemporary debates on risk management. Routledge.

Hof, T., van der Weerdt, C. A., & Wijn, R. (2014). *Ecodriver. D11. 1: A state of the art review and users' expectations.* European Union.

Hunecke, M., Haustein, S., Bohler, S., & Grischkat, S. (2010). Attitude-Based Target Groups to Reduce the Ecological Impact of Daily Mobility Behavior. Environment and Behavior, 42, 3–43. http://doi.org/10.1177/0013916508319587

Jenkins, D. P., Stanton, N. A., Salmon, P. M., & Walker, G. H. (2009). *CognitiveWorkAnalysis: Coping With Complexity.* Farnham: Ashgate.

Kircher, K., Fors, C., & Ahlstrom, C. (2014). Continuous versus intermittent presentation of visual eco-driving advice. *Transportation Research Part F: Traffic Psychology and Behaviour, 24*, pp. 27–38. doi:http://doi.org/10.1016/j.trf.2014.02.007

Lavergne,, K. L., & Pelletier, L. G. (2015). Predicting individual differences in the choice of strategy to compensate for attitude-behaviour inconsistencies in the environmental domain. *Journal of Environmental Psychology, 44*, pp. 135–148. doi:http://dx.doi.org/10.1016/j.jenvp.2015.10.001

Lenneman, J. K., & Backs, R. W. (2009). Cardiac Autonomic Control During Simulated Driving With a Concurrent Verbal Working Memory Task. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 51*(3), pp. 404–418. doi:http://doi.org/10.1177/0018720

McIlroy, R. C., & Stanton, N. A. (2015). A decision ladder analysis of eco-driving: the first step towards fuel-efficient driving behaviour. *Ergonomics, 58*(6), pp. 866–882. doi:http://doi.org/10.1080/00140139.2014.997807

McLoone, H. E., Jacobson, M., Hegg, C., & Johnson, P. W. (2010). User-centered design and evaluation of a next generation fixed-split ergonomic keyboard. Work, 37(4), 445–456. http://doi.org/10.3233/WOR-2010-1109

Nordlund, A. M., & Garvill, J. (2002). Value Structures behind Proenvironmental Behavior. Environment and Behavior, 34(6), 740–756. http://doi.org/10.1177/001391602237244

Ohtomo, S., & Hirose, Y. (2007). The dual-process of reactive and intentional decision-making involved in eco-friendly behavior. *Journal of Environmental Psychology, 27*(2), pp. 117–125. doi:http://dx.doi.org/10.1016/j.jenv

Park, J., & Han, S. H. (2013). Defining user value: A case study of a smartphone. International Journal of Industrial Ergonomics, 43(4), 274–282. http://doi.org/10.1016/j.ergon.2013.04.005

Parmar, D., Bertrand, J., Babu, S. V., Madathil, K., Zelaya, M., Wang, T., Wagner, T., Gramopadhye, A. K., Frady, K. (2016). A comparative evaluation of viewing metaphors on psychophysical skills education in an interactive virtual environment. Virtual Reality, 20(3), 141–157. http://doi.org/10.1007/s10055-016-0287-7

Patton, J. H., & Stanford, M. S. (1995). Factor structure of the Barratt impulsiveness scale. *Journal of clinical psychology, 51*(6), pp. 768-774.

Peper, E., Harvey, R., Lin, I., Tylova, H., & Moss, D. (2007). Is There More to Blood Volume Pulse Than Heart Rate Variability , Respiratory Sinus Arrhythmia , and Cardiorespiratory Synchrony ? Biofedback, 35(2), 54–61.

Rakotonirainy, A., Haworth, N., & Saint-Pierre, G. (2011). Research issues in Eco-driving. *Queensland University of Technology and French Institute in Science and Technology of Transport*, p. 1–7.

Ruscio, D., Bos, A. J., & Ciceri, M. R. (2017). Optimal levels of autonomic nervous system modulations while driving with an advanced driving assistance system: drivers' workload. *Accident Analysis & Prevention.* Volume 103, June 2017, Pages 105 – 111. https://doi.org/10.1016/j.aap.2017.03.023

Saade, R. G., & Otrakji, C. A. (2007). First impressions last a lifetime : effect of interface type on disorientation and cognitive load. *23*, pp. 525–535. doi:http://doi.org/10.1016/j.chb.2004.10.035

Sivak, M., & Schoettle, B. (2012). Eco-driving: Strategic, tactical, and operational decisions of the driver that influence vehicle fuel economy. *Transport Policy, 22*, 96-99. doi:http://dx.doi.org/10.1016/j.tranpol.2012

Stanford, M. S., Mathias, C. W., Dougherty, D. M., Lake, S. L., Anderson, N. E., & Patton, J. H. (2009). Fifty years of the Barratt Impulsiveness Scale: An update and review. *Personality and Individual Differences, 47*(5), pp. 385–395. doi:http://dx.doi.org/10.1016/j.paid.2009.04.008

Steg, L., & Vlek, C. (2009). Encouraging pro-environmental behaviour: An integrative review and research agenda. *Journal of Environmental Psychology, 29*(3), pp. 309-317. doi:http://dx.doi.org/10.1016/j.jenvp.2008.10

Steg, L., Lindenberg, S., & Keizer, K. (2016). Intrinsic Motivation, Norms and Environmental Behaviour: The Dynamics of Overarching Goals. *International Review of Environmental and Resource Economics,, 9*, pp. 179–207. doi:http://doi.org/10.1561/101.00000077

The Golden Rules of Ecodriving. (2013, January 23). Retrieved from ecodrive.org: http://www.ecodrive.org/en/what_is_ecodriving-/ the_golden_rules_of_ecodriving/

United Nations. (2013). *United Nations Environment Programme: Ecodriving.* Retrieved from http://www.unep.org/ transport/Programmes/Ecodriving/

Utting, M., & Legeard, B. (2007). *Practical model-based testing: a tools approach.* San Francisco, CA, USA: Morgan Kaufmann Publishers Inc.

Vlassenroot, S. Brookhuis, K. Marchau, V. Witlox F. (2010). Towards defining a unified concept for the acceptability of Intelligent Transport Systems (ITS): a conceptual analysis based on the case of

Intelligent Speed Adaptation (ISA) Transport. Res. Part F: Psychol. Behav., 13 (3) (2010), pp. 164–178 http://dx.doi.org/10.1016/j.trf.2010.02.001

Wåhlberg, A. E. (2007). Long-term effects of training in economical driving: Fuel consumption, accidents, driver acceleration behavior and technical feedback. *International Journal of Industrial Ergonomics, 34*(4), pp. 333–343. doi:http://doi.org/10.1016/j.ergo

Whitmarsh, L., & O'Neill, S. (2010). Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *Journal of Environmental Psychology, 30*(3), p. 305–314. doi:http://dx.doi.org/10.1016/j.jenvp.2010.01.003

Young, M. S., Birrell, S. A., & Stanton, N. A. (2011). Safe driving in a green world: A review of driver performance benchmarks and technologies to support "smart" driving. *Applied Ergonomics, 42*(4), pp. 533–539. doi:http://doi.org/10.1016/j.apergo.2010.08.012.

Zhang, J., Ouyang, Z., Miao, H., Wang, X. (2011). Ambient air quality trends and driving factor analysis in Beijing, 1983–2007, Journal of Environmental Sciences, Volume 23, Issue 12, 2011, Pages 2019-2028, ISSN 1001-0742, http://dx.doi.org/10.1016/S1001-0742(10)60667-5.