Abstract

Despite both the environmental and financial benefits of eco-driving being well known, the psychological impact of engaging in eco-driving behaviours has received less attention within the literature. It was anticipated that being asked to engage in eco-driving behaviours not only has an impact on vehicle fuel usage, but also on the driver, both in terms of their overall mood and willingness to re-engage with the task at a later time. Results from a simulated driving study suggest that although eco-driving was beneficial in reducing fuel consumption, being asked to eco-drive had a negative effect on overall journey time and mood. Engaging in eco-driving did however have a positive effect on self-esteem, suggesting potential longer term psychological benefits of adopting this behaviour.

Key Words

Fuel Consumption; Eco-Driving; Subjective States

Introduction

Pollution arising from transportation is widely considered a critical issue, which must be addressed (Yin & Lawphongpanich, 2006). Transport emissions, primarily greenhouse gases (GHGs) such as carbon dioxide (CO_2) and Nitrous Oxides (NOx), as a consequence of everyday car use, are currently the leading source of air pollution in the United Kingdom (Department for Environment, Food and Rural Affairs, 2017). It has long been documented that car use contributes to a variety of environmental problems including global warming, acid rain, resource depletion, noise pollution, and congestion (Lowe, 1990). The increasing evidence that GHGs are negatively impacting our environment (Ramanathan & Feng, 2009) has led to a prevailing argument that vehicle use is fundamentally linked to anthropogenic climate change and unstable global weather patterns (Karl & Trenberth, 2003; Chapman, 2007). Kampa and Castanas (2008) explored the impact of air pollution, of which everyday driving is a significant contributor, on human health. They found that air pollution can have a range of universally negative impacts on health, from minor irritation, through chronic conditions to the extreme of premature mortality.

Researchers from a variety of disciplines have proposed interventions to reduce emissions associated with road transportation. Engineering perspectives are typically dominated by the replacement of older vehicles, characterised by inefficient internal combustion engines, with newer, more efficient vehicles. Newer vehicles take advantage of modern drivetrain technologies, typically utilising hybridisation and electrification, leading to considerable improvements in efficiency compared to older vehicles (Yan, Allison, Fleming, Stanton & Lot, 2020). Whilst engineering development has led to significant potential savings both in terms of overall fuel use and emissions (Demirdöven & Deutch, 2004), the initial financial investment required to purchase such a vehicle, alongside other perceived barriers, including concerns relating to the robustness of infrastructure and the social desirability of environmentally friendly vehicles (Kumar & Alok, 2020) means that, for many, the purchase of a newer vehicle for primarily environmental concern is an untenable option. Eco-driving, as a behavioural intervention, in contrast, presents an opportunity for all drivers, to reduce the environmental impact of their own personal transportation as engaging in such behaviours is not reliant on modern drivetrains or specific technology (Sureth, Moll, Nachtwei, & Franke, 2019).

Eco–driving is a driving style typified by behaviours such as gentle acceleration, gentle braking, anticipating traffic flow and driving below the speed limit (Barkenbus, 2010). Eco-driving has been extensively documented to reduce both fuel use and GHG emissions (Barkenbus, 2010). Stillwater & Kurani, (2013) estimate that emissions could be reduced by 5% - 20% should the typical driver engage with eco-diving practices. Recent analysis of naturalistic driving carried out as part of the UDRIVE project has indicated that braking, gear shifting and velocity choice on motorways each have effects on fuel consumption of 10% or more for conventional vehicles (Heijne, Ligterink, & Stelwagen, 2017).

Eco-driving can be largely characterised by the operational decisions which drivers make during their journey (Barkenbus, 2010). Driving behaviours commonly associated with this style include driving below the speed limit, early gear changes, gentle acceleration and minimisation of braking. Whilst the focus of the current article is on direct actions a driver can take relating to driving style, Sivak and Schoettle (2012) extend the view that eco-driving is related to purely actions undertaken during a drive to also includes strategic and tactical decisions. Sivak and Schoettle (2012) argue that strategic decisions relate to vehicle selection and ongoing maintenance, whilst tactical decisions relate to navigational choices and decisions related to current vehicle load. Despite the extra decisions and actions required by driver, use of eco-driving techniques as outlined can mean that fuel savings and emission reductions can be achieved without significantly increasing overall journey time (Barth & Boriboonsomsin, 2009).

Despite proposed benefits, drivers are required to invest a considerable amount of time and effort into eco-driving to see a relatively small fuel saving benefit. Beusen et al., (2009) suggests that a typical driver would achieve an estimated weekly saving of fuel valued at less than £5 (~$7 USD). Several researchers have suggested that the required effort and inherent difficulty of eco-driving is simply not worth this minimal saving (Delhomme, Cristea & Paran, 2013; Dogan, Bolderdijk, & Steg, 2014). Regardless of the proposed fuel and financial savings and environmental benefits offered by eco-driving behaviours, work is needed to encourage user engagement (Allison & Stanton, 2020). By engaging in eco-driving practices, a driver is subject to increased cognitive demands (Pampel, Jamson, Hibberd, & Barnard, 2015). Individuals engaged with such behaviours are required to more actively monitor the ever-changing road environment, their vehicles' state and calculate the perfect moments to take any given action. In addition, stressors related to self-evaluation of driving behaviours and the desire to obtain optimal performance may be greater when considering eco-driving, as performance as actions are compared to personal targets or a perceived social norm. Whilst previous research has explored workload associated with eco-driving (Allison, et al., 2020; Pampel, et al., 2015), work has not considered deeper psychological state changes. This study therefore sets to compare not only participants' fuel usage, when engaging in normal and eco-driving, but also how participants' psychometric state varies as a consequence of being asked to engage in different driving styles.

Despite the proposed financial and environmental benefits of adopting eco-driving strategies, limited research has considered the psychological impact of engaging with such behaviours on the driver, a gap that this paper seeks to begin to offer insight. Based on previous research relating to eco-driving (Barkenbus, 2010) it is hypothesised that asking participants to adopt eco-driving techniques will reduce the amount of fuel consumed within a journey. Based upon Barth and Boriboonsomsin (2009), it is hypothesised that the use of eco-driving will not have a significant impact on journey time. Unlike previous research however, this study will also explore changes in participants subjective and psychological state following normal and eco-driving. It is hypothesised that adopting eco-driving during a simulated journey will impact participants' subjective/ psychological state as participants are required to adjust their behaviour to achieve this goal.

Method

Design

This study used a 2 (Condition) x 2 (Trial Order) mixed design. The independent variables were Condition (Control Drive/ Eco Drive) [Within] and Trial order (Control-Eco/ Eco-Control) [Between]. The dependent variables were fuel usage; travel time; usability, as measured by System Usability Scale (SUS) and subjective driver state metrics as measured by the Dundee Stress State Questionnaire (DSSQ).

Participants

Thirty-Six (36) participants completed this study (18 Males, 18 Female). Participants were aged 19 – 71 years (*M*= 28.92, *SD*= 12.82). All participants possessed a current full driving license (UK or International), had normal or corrected normal vision and were required to successfully complete the Ishihara Colour Blindness Test prior to their participation to demonstrate eligibility. Ethical approval for this study was given by the University of Southampton Research Governance Team (ERGO Number 30746).

Apparatus

The Southampton University Driving Simulator (SUDS) was used as a base vehicle and to display the road environment to participants. This facility is equipped with a fixed base, right-hand drive Land Rover Discovery Sport, with automatic transmission. The forward projected road scene was displayed across three screens positioned in front of the vehicle, offering a 135-degree field of view. A rear-view image was projected behind the vehicle, meaning that rear information was visible in the vehicle's rear-view. Figure 1 provides a view of the SUDS laboratory.

Figure 1. The SUDS Laboratory.

STISIM M500W wide-field-of-view simulation software was used to display the road environment. The road environment used within this work was 21 kilometres long and based upon the surrounding local road network near the University of Southampton. During the simulated drive, participants were faced with a variety of different road types, including urban roads, rural roads and a section of motorway (highway). All three primary road types sections were of equal length; however, the urban element of the route was interspersed, appearing at both the start and the end of the journey. The route took approximately 25 minutes to drive. The simulated route was designed to accurately replicate the real world and had been validated in regards to immersion and presence within a previous study (Allison, Parnell, Brown & Stanton, 2017). Figure 2 presents an image of part of the STISIM simulation environment used within this study. A map of the route that participants were asked to drive within the simulation is presented within Figure 3.

Figure 2. A screen-shot of part of the environment participants drove, created within STISIM.

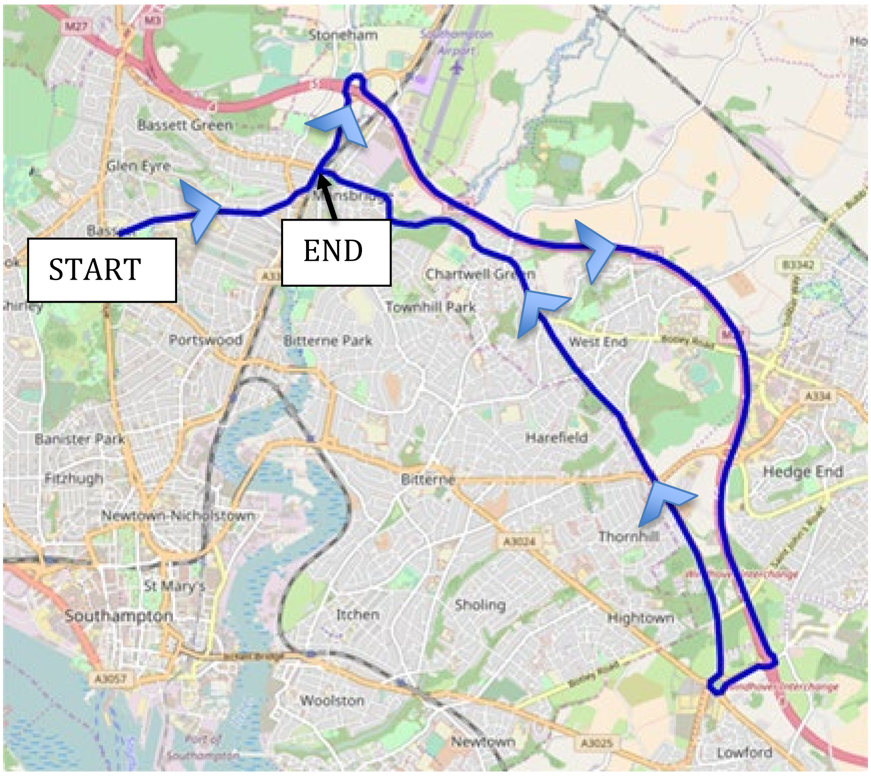

Figure 3. The route that participants were asked to drive within the simulation.

A Microsoft Surface Pro tablet was affixed directly over the vehicle's non-functioning dashboard. The tablet presented a digital speedometer and RPM display to participants. The speedometer and RPM display were developed in C# using Windows Forms as a graphical library. The size and position of both the speedometer and RPM display on the tablet matched the relative size and position of these displays on the original dashboard to limit any disruption to immersion caused by the use of the tablet. The values displayed to the participants were based on data taken directly from STISIM and matched their current actions. The tablet was not larger than the peak height of the dashboard and did not obscure participants view of the road or the simulated environment.

Measures

Participants were required to complete two questionnaires during the study, the System Usability Scale (SUS, Brooke, 1996) and the Dundee Stress State Questionnaire (DSSQ, Matthews, et al., 1999, 2002).

The SUS (Brooke, 1996) is a non-proprietary usability questionnaire containing ten Likert scale questions. Participants are presented with a generic usability question and answered between 1 (Strongly Disagree) to 5 (Strongly Agree). Scores are converted to produce a usability score ranging between 0 (Exceptionally Poor Usability) to 100 (Exceptionally High Usability). The SUS is a common tool for fast usability analysis (Bangor, Kortum & Miller, 2008). It has become widely accepted that any product that scores higher than 68 has achieved a good usability rating. Although participants were not directly assessing the usability of a physical object within the current study, they were required to assess the usability of different driving styles, and thus this metric can be considered as an indication of participants' willingness to engage with different driving styles.

The DSSQ (Matthews, et al., 1999, 2002) is a multifactorial psychometric stress measure, designed to measure state changes induced following a task and accompanying environmental stressors. The DSSQ has been utilised in a variety of fields, including use of surgical instruments (Klein et al., 2012), driving related stress (Heikoop, de Winter, van Arem & Stanton, 2017) and vehicle automation use (Funke, Matthews, Warm & Emo, 2007). The DSSQ is comprised of 12 correlated first-order dimensions linked to three broader second order factors of Task Engagement, Distress and Worry.

The first order dimensions of "Energetic Arousal", "Intrinsic Motivation", "Success Motivation" and "Concentration" are linked to the factor of Task

Engagement. Energetic arousal is synonymous with wakefulness, with low scores being associated with feeling sleepy, and higher scores associated with feelings of wakefulness (Thayer, 1990). Intrinsic motivation refers to participants' interest with the current task (Matthews, et al., 1999), with high scores equating to higher level of task interest. Success motivation refers to participants' desire to excel in task performance (Matthews, Campbell & Falconer, 2001), higher scores indicating a higher desire to succeed. Concentration refers to participants' attention to their current task and their ability to resist distraction (Matthews, 1999), this is also positively scored so that higher levels of concentration equate to a higher ability to resist distraction.

The first order dimensions "Tense Arousal", "Hedonic Tone", "Confidence Control" and "Anger/ Frustration" are linked to the factor of Distress. Low tense arousal scores are indicative of feeling calm whereas high scores are linked to feelings of nervousness (Matthews, Jones & Chamberlain, 1990). Hedonic tone is indicative of overall mood, with high scores being associated with positive mood and low scores indicating negative mood. Confidence Control relates to a participants' perceived ability to control the outcome of their endeavours and their ability to succeed at the given task (Matthews et al., 1999). Extending the concept of participant affect, Anger/Frustration is a measure of participants' mood, with high levels of Anger/Frustration being associated with low mood.

The remaining first order dimensions "Self-Focused Attention" "Self Esteem", "Task-related Interference" and "Task-irrelevant Interference" are linked to the second order factor of Worry. Self-focused attention is defined as *"an awareness of self-referent, internally generated information"* (p156) (Ingham, 1990), and is positively correlated with levels of stress and self-occupied thoughts (Matthews, et al., 1999). Self-esteem reflects an individual's overall subjective emotional evaluation of his or her own worth (Coopersmith, 1967; Smith & Mackie, 2007). Task-related interference is a measure of distracting thoughts participants experienced regarding the task they were completing as they were completing it (Sarason et al., 1986). Task-irrelevant interference is a measure of non-task related distracting thoughts participants experienced as they were completing the task (Sarason et al., 1986).

To compare pre- and post- test scores using the DSSQ, one may compute a z-score in each dimension for each participant (Matthews, et al., 1999, 2002)

$$z = \frac{y_{post} - y_{pre}}{\sigma_{pre}}$$

where 'y' denotes the pre- and post- test scores from the DSSQ and 'σ_{pre}' the standard deviation of the pre-test scores. This procedure has the advantage of standardising the scores observed for each of the different dimensions, as these have differing ranges. The null hypothesis that this z-score is equal to zero can then be investigated using standard one-sample variants of a t-test or Wilcoxon test. This enables exploration of whether a factor was affected by a condition. Z-scores for different test conditions may also be compared. If there are two scores, y_1 and y_2, representing outputs from different conditions, and one subtracts the corresponding z-scores, this yields

$$z_2 - z_1 = \frac{y_2 - y_{pre}}{\sigma_{pre}} - \frac{y_1 - y_{pre}}{\sigma_{pre}} = \frac{y_2 - y_1}{\sigma_{pre}}$$

which may again be investigated using a one-sample test, as the null hypothesis that this is zero corresponds to no difference between the two conditions. This allows for exploration of whether the different conditions influence participants in consistent or inconstant ways.

Procedure

Upon entering the laboratory, participants were presented with an information sheet, outlining the aims of the research and participants' ethical rights, as well as a consent form which participants were required to complete before the study could begin. To ensure the participant was fully aware of the procedure and what they would be asked to do, the researcher also outlined the study and the participants' ethical rights verbally, offering participants the opportunity to ask any questions. Following participants consent, they completed the Ishihara Colour Blindness Test and provided evidence of their driving license to confirm eligibility for the study. Participants were asked to record their gender and age, and complete the pre-trial component of the DSSQ prior to entering the simulator. Once in the simulator, the driving position was adjusted to suit the participants' needs and to ensure the participant was in a natural and comfortable driving position. Prior to starting the main study and driving the main route, participants completed two practice drives within the simulator. For both practice drives, participants were asked to drive within a basic urban environment, containing minimal traffic and two turns. These drives were separate from the main route described previously. Participants were informed that data would not collected from these drives, and that the practice drives should be used to become accustomed and acclimatised to the simulator. Participants were not informed about eco-driving before either practice drive and were not asked to practice eco-driving. Each practice drive lasted approximately 5 minutes, depending on participants' rate of acceleration and speed. Once participants had completed both practice drives, they were asked whether they were willing to proceed to the main study.

For each main study drive, participants were required to drive the previously described route surrounding Southampton. Participants completed two main study trial drives as part of this study, a normal drive where participants were asked to drive as they normally would within the real world (Control) and a drive whereby they were asked to drive as fuel efficiently as possible (Eco). Prior to starting the Eco condition, participants were presented a series of 8 eco-driving tips and recommendations to help them drive as fuel efficiently as possible. Tips were presented on a piece of A4 paper, which the researcher verbally reiterated. The researcher answered any questions which the participants had regarding the tips before leaving the laboratory with the piece of paper containing the tips. Tips included gentle acceleration, gentle braking and minimization of harsh actions. Participants were required to complete both Control and Eco trials as part of the research study, however the order that these were completed was fully counterbalanced between participants.

Following each main study drive, participants were required to exit the simulator and complete both the SUS and the DSSQ. Once participants had completed these questionnaires, they returned to the simulator in preparation for the remaining trial. Once participants had completed both test trials, and accompanying questionnaires, they were debriefed. During the debriefing session, the researcher explained the aim of the study and presented participants with a debriefing form. Participants were free to ask any questions regarding the study before leaving. Following completion of the study, participants were compensated £10 for their time.

Data Analysis

STISIM software recorded a variety of participant related measurements based on participants' actions within the simulation. Participants' velocity, acceleration, throttle input and braking input were sampled at a rate of 10Hz. Fuel usage was calculated from these statistics following the study using Simulink, using a detailed simulation model of the vehicle powertrain to calculate the associated fuel usage for each trial. This included a realistic engine map of fuel usage based on engine torque and RPM generated from 1 dimensional fluid dynamics simulations in Ricardo wave, and incorporates efficiency losses in the transmission, aerodynamic losses due to vehicle drag, and losses due to rolling resistance.

Results

An alpha level of .05 was set for all statistical comparisons reported within the current study. For tests involving direct simulator performance and the SUS, a 2 Condition (Control/ Eco) x 2 Trial order (Control-Eco/ Eco-Control) mixed ANOVA was used. For all tests involving metrics collected from the DSSQ, the Z-score calculation as explained previously was used, with a 1 sample Wilcoxon non-parametric hypothesis test being used.

Fuel Consumption

Figure 4 presents participants' fuel usage for both control and eco drives. As can be seen from this figure, participants recorded greater fuel consumption within the control condition compared to the eco-drive.

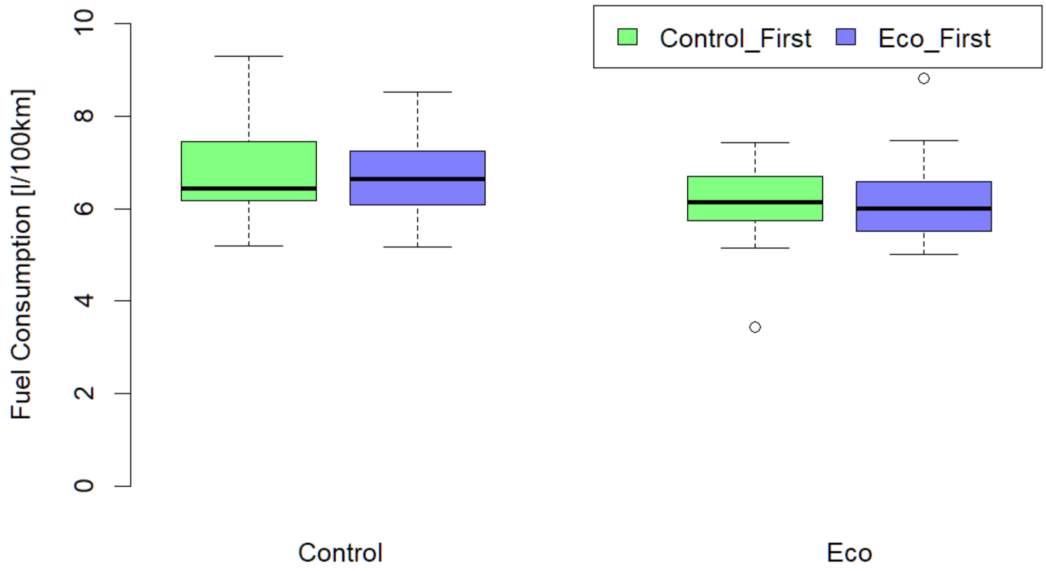

Figure 4. Participants' recorded mean fuel consumption for control and eco drives.

Exploring this data in more detail revealed a significant main effect of condition ($F(1, 34) = 41.49$, $p<.01$, $\eta p^2 = .55$), confirming that participants used a significantly greater amount of fuel within the control drive ($M= 7.02$, $S.D.= 0.53$) compared to the eco drive ($M= 6.40$, $S.D.= 0.43$). No effect of trial order ($F<1$, *ns*) was observed and no interaction between condition and trial order ($F(1, 34) = 2.33$, $p<.14$, *ns*), was seen however, indicating that trial order did not impact performance. Overall this suggests that that participants were able to directly improve their fuel efficiency within the eco drive by adapting their driving style.

Travel Time

Participants' travel time for both control and eco drives are presented in Figure 5. As can be seen from this figure, participants recorded noticeably greater travel time within the eco, compared to the control drive.

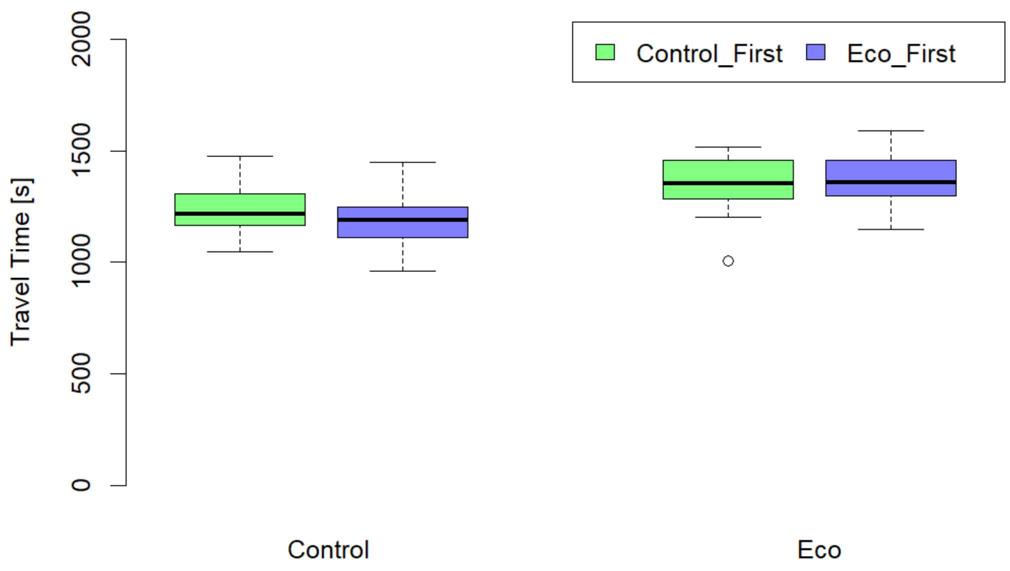

Figure 5. Participants' recorded mean travel time for Control and Eco Drives.

Exploring travel time in more detail revealed a significant main effect of condition ($F(1, 34) = 73.91$, $p<.01$, $\eta p^2 = .68$), confirming that participants did take a significantly greater amount of time to drive the route when within the eco drive (M= 1365.50, SD= 124.97) compared to the control drive (M= 1215.11, SD= 116.66). No effect of trial order was identified ($F<1$, *ns*), and no interaction was observed between condition and trial order ($F(1, 34) = 3.69$, $p = .06$, *ns*), suggesting that trial order did not affect participants' travel time.

Combined with the previous finding relating to fuel consumption, this supports the view that participants actively changed their driving style within the eco drive, raising the question of whether cognitive state changes as a consequence of the change in behaviour.

System Usability Scale

Figure 6. presents participants' recorded mean SUS scores for both test trials. From this figure it appears that participants more consistently rated the control drive as having greater usability than the eco-drive.

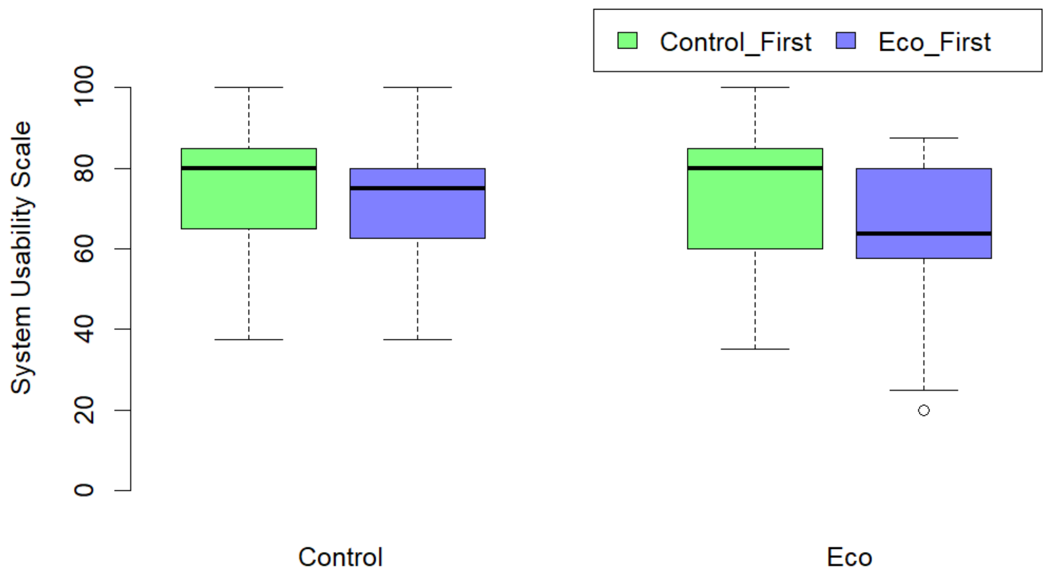

Figure 6. Participants' mean SUS scores for both control and eco-drive conditions.

A significant effect of condition was identified, $F(1, 34) = 7.73$, $p<.05$, $\eta p^2 = .19$. This suggests that condition influenced participants' usability ratings. No significant effect of trial order was observed, *(F<1, ns*), and no interaction between condition and trial order was observed, $F(1, 34) = 1.77$, *ns,* suggesting trial order did not influence usability ratings. By examining recorded means, it was clear that participants rated the control drive (M= 73.40, SD= 16.41) as more usable, and thus more desirable to engage with than the eco-drive condition (M= 68.33, SD= 19.04).

DSSQ

Table 1 explores the differences between control and pre-test DSSQ results. Considering the impact of the control drive compared to pre-test statistics, limited differences were identified. It was observed however that participants recorded greater Intrinsic Motivation pre-test, demonstrating that their interest within the task declined as a consequence of completing the trial. A significant effect was also observed for Self-Focused Attention, demonstrating that this was reduced following the task, indicating a decline of stress.

Table 1 – Difference in medians and test statistics – Control vs Pre-test

	Diff med	**Z**	***p* (adj)**	***r***
Energetic Arousal	0.000	-0.539	1.000	-0.064
Tense Arousal	0.000	-0.764	1.000	-0.090
Hedonic Tone	-0.297	-1.065	0.861	-0.126
Anger/Frustration	0.000	-0.463	1.000	-0.055
Success Motivation	-0.113	-0.835	1.000	-0.098
Intrinsic Motivation	-0.473	-2.765	0.017*	-0.326
Self-Focused Attention	-0.811	-4.722	0.001***	-0.556
Self Esteem	0.176	-2.293	0.066	-0.270
Concentration	0.000	-0.245	1.000	-0.029
Confidence Control	0.200	-1.814	0.209	-0.214
Task Interference	-0.083	-0.467	1.000	-0.055
Task Irrelevant Interference	-0.423	-2.341	0.058	-0.276

* $p < .05$, ** $p < .005$, *** $p < .001$

A greater number of significant effects were observed between pre-test data and following the eco-drive regarding the DSSQ data, as presented within Table 2. Consistent with the control drive, it was seen that Intrinsic Motivation and Self-Focused Attention decreased, demonstrating that participants interest with the task declined after the task, and that stress was also decreased. Unlike the differences seen between the control and pre-simulation data set however, Energetic Arousal decreased following the eco-drive trial, demonstrating that participants experienced greater feelings of lethargy. It was also identified that Hedonic tone decreased following the eco drive, this is indicative that overall mood was decreased. Similarly, participants reported increased Anger/Frustration following the eco-trial. These findings indicate that following the eco drive trial, participants experienced largely negative psychological effects. One finding in contrast to these negative psychological effects however was that Self-Esteem increased, suggesting that Self-Esteem was improved by completing this task.

Table 2 – Difference in medians and test statistics – Eco driving vs Pre-test

	Diff med	**Z**	***p* (adj)**	***r***
Energetic Arousal	-0.562	-2.864	0.013*	-0.338
Tense Arousal	0.237	-1.529	0.378	-0.180
Hedonic Tone	-0.743	-3.196	0.004**	-0.377
Anger/Frustration	0.000	-2.468	0.041*	-0.291
Success Motivation	-0.226	-0.069	1.000	-0.008
Intrinsic Motivation	-0.709	-3.609	0.001***	-0.425
Self-Focused Attention	-0.516	-3.981	0.001***	-0.469
Self Esteem	0.353	-3.160	0.005**	-0.372
Concentration	-0.204	-1.064	0.862	-0.125
Confidence Control	0.100	-0.845	1.000	-0.100
Task Interference	0.333	-1.321	0.560	-0.156
Task Irrelevant Interference	-0.423	-1.266	0.617	-0.149

* $p < .05$, ** $p < .005$, *** $p < .001$

To consider differences between control and eco-driving conditions, the Z-scores for these were also compared and presented in Table 3. Significant differences were observed between the eco-driving and control conditions in regards to Energetic Arousal, with energetic arousal seen following eco-drive trial being significantly lower than the control drive. In addition, significant differences were seen within Hedonic Tone, with Hedonic Tone following the eco-drive being significantly lower than Hedonic tone recorded following the control drive. These results suggest that whilst the driving task itself does not increase lethargy and negatively affect mood, engaging with eco-driving techniques do.

Table 3 – Difference in medians and test statistics – Eco driving vs Control

	Diff med	**Z**	***p* (adj)**	***r***
Energetic Arousal	-0.562	-2.847	0.013*	-0.336
Tense Arousal	0.237	-1.938	0.158	-0.228
Hedonic Tone	-0.446	-2.557	0.032*	-0.301
Anger/Frustration	0.000	-1.667	0.286	-0.196
Success Motivation	-0.113	-0.984	0.975	-0.116
Intrinsic Motivation	-0.236	-1.529	0.379	-0.180
Self-Focused Attention	0.295	-1.470	0.425	-0.173
Self Esteem	0.176	-0.547	1.000	-0.064
Concentration	-0.204	-1.050	0.881	-0.124
Confidence Control	-0.100	-0.618	1.000	-0.073
Task Interference	0.416	-1.852	0.192	-0.218
Task Irrelevant Interference	0.000	-0.771	1.000	-0.091

* $p < .05$, ** $p < .005$, *** $p < .001$

Table 4 presents a descriptive summary of the identified findings. This table highlights the mixed findings identified within this study, and the typical negative psychological effects of being asked to eco-drive.

Table 4. Descriptive Summary of DSSQ Results

Second Order Factor	First Order Dimension	Control	Eco Drive
Task Engagement	Energetic Arousal	-	Lowered
	Intrinsic Motivation	Lowered	Lowered
	Success Motivation	-	-
	Concentration	-	-
Distress	Tense Arousal	-	-
	Hedonic Tone	-	Lowered
	Confidence Control	-	-
	Anger/ Frustration	-	Increased
Worry	Self-Focused Attention	Lowered	Lowered
	Self Esteem	-	Increased
	Task-Related Interference	-	-
	Task-Irrelevant Interference	-	-

Discussion

This paper sought to examine the psychological effects of engaging in eco-driving behaviours compared to regular driving practices. It was clear that although eco-driving was associated with reduced fuel usage, supporting hypothesis 1, this benefit did have implications both on the nature of the drive as demonstrated by increased travel time, counter to that predicted by hypothesis 2. Furthermore, being asked to eco-drive did have a psychological impact, demonstrated by a decreased level of energetic arousal, and decreased hedonic tone, compared to normal driving, supporting hypothesis 3. The psychological impact of eco-driving was not all negative however, as engaging in eco-driving had a positive effect on participants' self-esteem scores, indicating that although participants' overall mood was reduced, engaging in eco-driving behaviours fostered feelings of self-worth.

Consistent with previous literature (Barkenbus, 2010; Pampel Jamson, Hibberd & Barnard, 2015), this study demonstrated that individuals were able to dramatically reduce their fuel consumption after being asked to eco-drive and being provided with tips regarding how this can be achieved. Participants recorded a significant reduction in their fuel consumption for the Eco-drive trial following the presentation of simple eco-driving tips and guidance prior to their drive. This finding demonstrates that individuals were able to rapidly adjust their driving style, with minimal guidance, supporting previous research (McIlroy & Stanton, 2017). Participants did however record significantly reduced usability ratings for the eco-drive, suggesting that the eco-drive was not an engaging driving style, and that participants would be unlikely to continue to engage in eco-driving actions outside of the laboratory environment.

Participants' significant increase in travel time during the eco-drive trial compared to the control condition adds weight to the suggestion that many participants would be unlikely to engage in eco-driving outside of laboratory conditions. Gardner and Abraham (2007) found, following a grounded theory analysis of driver discourse, that shorter journey times was one of the prime motivators for use of private cars over alternative means of transport. They found that many participants view journey time as wasted time, time which could be better spent engaged in other activities for example with families. It should be noted that the finding that eco-driving significantly increased journey time is not consistent with previous research (Barth & Boriboonsomsin, 2009). However, it should be noted that Barth and Boriboonsomsin's (2009) research was based largely on optimal conditions and computer simulation models. The use of human-in-the-loop trials here suggests that the participants were not able to engage in optimal eco-driving strategies and use of techniques such as gentle acceleration and traveling below the speed limit did induce a time cost greater than previous work identified. It is likely that many drivers, especially those initially adapting to eco-driving, will experience a time penalty from the use of these techniques, which must be accounted for in driver training and in interfaces designed to encourage fuel efficient driving.

Considering findings based on the DSSQ (Matthews, et al., 1999, 2002), it was found that, regardless of condition, participants experienced a decrease in Intrinsic Motivation and Self-Focused Attention. These findings are related to interest with the task itself and levels of stress. Participants became less motivated with the tasks following their completion, and reported lowered feelings of stress. As this was consistent with both drives, it is not possible within the current study to identify whether this was a consequence of the fundamental driving task, or as a consequence of driving within the simulator. Due to the graphical limitations of the simulation, which were not equal to those available within commercial video games, it is possible that participants become less engaged with the study than they would have been in a real vehicle.

Of central interest within the current study is the four metrics which were impacted by eco-driving, decreased Energetic Arousal, decreased Hedonic Tone, increased Anger/ Frustration and increased Self-Esteem, each which will be considered in turn. The finding that eco-driving lowered energetic arousal suggests that either, drivers are required to work more to eco-drive, resulting in increased fatigue or that eco-driving is less engaging than normal driving, leading to greater boredom, and as a consequence, drivers experience feelings of lethargy. Although the current results are unable to identify which explanation is more appropriate, Both Pampel, et al., (2015) and Allison, et al. (2020) identified that eco-driving is associated with an increase in workload, suggesting that drivers may be having to work harder to complete the drive and hence may be more susceptible to fatigue. Taking this idea forward, interfaces designed to encourage eco-driving should look to engage the driver in the active task of driving and act to maintain drivers focus and commitment to the goal of eco-driving. This can be achieved using visual or auditory cues, for example reminders of the positive impact that their behaviours have had compared to previously completed journeys.

Participants decreased hedonic tone following the eco-drive trial is analogous to participants experiencing reduced mood. Considering this effect provides potential evidence to explain a fundamental barrier in the wider adoption of eco-driving. As Larsen (2000) argued "… people are motivated to feel good, to create and maintain generally pleasant or positive subjective states" (p. 131). Isen (2000), notes that positive affect, analogous to positive Hedonic Tone, is linked to a variety of positive outcomes including productivity, problem solving and cooperation, important in the maintenance of behaviour. Participants also reported significant increase in their level of Anger/ Frustration following the eco-driving trial. This finding supports the negative effects already identified. Whilst previous research has identified that traditional driving is associated with positive affect (Sheller, 2004), the current study suggests that this is not the case for eco-driving. This finding therefore suggests that designers of eco-driving interfaces should seek ways to encourage positive affect within eco-drivers. Identifying ways to encourage positive affect within in-vehicles displays could therefore be a valuable direction for future research.

One result that does appear to contradict data presented thus far was that eco-driving acted to enhance Self-Esteem. The results of the current study are surprising as Self-Esteem is typically positively correlated with positive affect (Brockner, 1983).

Significant research has explored the impact of self-esteem on mood regulation (Wood, Heimpel & Michela, 2003; Heimpel, Wood, Marshall, & Brown, 2002; Smith & Petty, 1995), and often suggest that self-esteem can have a mediating effect. If an individual has low self-esteem, they often maintain low affect as they do not believe they can change their affect, or may not believe that they can maintain positive affect. In contrast, an individual with high self-esteem is more likely to maintain positive affect as they are empowered to do so. The finding that participants experienced negative affect, as documented by reduced Energetic Arousal and increased Anger/ Frustration, yet a boost to Self-Esteem therefore requires further exploration. It can be argued that the boast to this metric was as a consequence of participants completing what they perceived as a difficult task. Bongers, Dijksterhuis, and Spears (2009) explored the impact of task completion on Self-Esteem and found that successfully attaining goals did positively affect Self-Esteem. It remains to be seen however whether this transient boost to Self-Esteem would be sufficient to overcome the negative affect experienced when eco-driving to encourage the adoption of these behaviours. The fact that Self Esteem improved as a consequence of the eco-drive trial can be harnessed by interface developers as increasing the drivers' awareness of this positive change may be key to ensuring the long term adoption of these behaviours.

In the future it is likely that automation will become increasingly prevalent in vehicles (Louw, & Merat, 2017). Although drivers may not be required to actively drive these vehicles, they will be required to act as passengers to vehicles which may be engaging with a driving style that does not suit their traditional ways of driving. Although it is not possible within the current study to ascertain whether it is the driver having to complete a task or if the style of the completed journey which has caused the identified changes in mood. Further research therefore is needed to consider future development of autonomous vehicles in a human centric way (Sun, Cao & Tang, 2021; Fleming, Yan, & Lot, 2020).

It is worth noting the limitations associated with this study. A key limitation of this study was its reliance on self-report metrics, obtained from the DSSQ, to measure participants' mood state. The use of self-report is common for tasks which explore cognitive load (Paas, Tuovinen, Tabbers, & van Gerven, 2003) and have been shown to have high levels of concurrent validity with physiological measures including both heart rate and skin conductance levels when specifically exploring the driving task (Mehler & Reimer, 2013). That said greater understanding of the physiological effects of engaging with eco-driving practices would support the view that engaging with eco-driving behaviours directly impacts the drivers state. It should be noted however that users' perceptions, as measured by self-report questionnaires, may be more useful when considering the design of future interfaces. Previous research (Clarkson, Hirt, Jia & Alexander, 2010) suggests that task performance was impacted more by perceptions of state than actual physiological state, indicating that designers should consider the perceptions of users. Indeed, François, Osiurak, Fort, Crave, and Navarro (2021) found that in-vehicle displays with user-centred design was highly effective in terms of performance and highly rated by users.

A second key limitation of the research was the nature of the driving environment and reliance on the static simulator for data collection. Previous research has identified that static simulators differed from dynamic, or motion-enabled, simulators in terms of driving behaviours demonstrated, with static simulators being associated with higher acceleration and speeds (Tu, Li, Li, Zhang, & Sun, 2015). Furthermore, the simulator was an automatic vehicle with no requirement to change gear, a factor extensively discussed within eco-driving literature (Mensing, Bideaux, Trigui, Ribet, & Jeanneret, 2014; Sanguinetti, Kurani, & Davies, 2017) potentially influencing participants driving style and success during the eco-drive trial. This is compounded by use of a driving simulator to explore these effects rather than a real car journey. Whilst previous research has frequently identified that data gathered in driving simulators are correlated with performance within the real world, the size of effects is rarely identical (Knapper, Christoph., Hagenzieker, & Brookhuis, 2015). Whilst previous evidence suggests that individuals can successfully eco-drive on the real road (Barić, Zovak, & Periša, 2013), future research should seek to explore the psychological impact on drivers, not only after a single simulated drive but after extensive engagement with such techniques on the real road to explore whether impacts on mood and affect identified within the current paper persist.

This study has presented initial exploration regarding the psychological impact of eco-driving. Further research is clearly needed to more deeply explore the impact of eco-driving, and it is argued that research must start to focus more on the drivers engaged with such behaviour and not simply remain focused on fuel consumption and emissions, both of which are well established. The insight gained from greater understanding of the psychological benefits and costs of engaging with eco-driving could facilitate the adoption of eco-driving practices to the wider driving community and could be instrumental in developing effective interventions (Ahlstrom & Kircher, 2017) for promoting and supporting this behaviour.

Conclusion

This study explored the impact of asking participants to engage in normal and eco-driving behaviours within a driving simulator. Results indicate that eco-driving, despite being associated with reduced fuel usage, was also associated with a negative impact overall mood and affect, proving insight on why eco-driving behaviours may be difficult to maintain long term. Interestingly however, eco-driving appeared to foster self-esteem, suggesting that such behaviours can promote increased feelings of self-worth. Of immediate interest within the data is the unexpected independence of mood, which was impeded by eco-driving, and self-esteem, which was facilitated by eco-driving. Engaging with eco-driving not only impacts fuel consumption and emissions, but can also impact key elements of psychological well-being.

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References

Ahlstrom, C., & Kircher, K. (2017). Changes in glance behaviour when using a visual eco-driving system–A field study. *Applied Ergonomics*, *58*, 414-423.

Allison, C. K., & Stanton, N. A. (2020). Ideation using the "Design with Intent" toolkit: A case study applying a design toolkit to support creativity in developing vehicle interfaces for fuel-efficient driving. *Applied Ergonomics*, *84*, 103026.

Allison, C. K., Fleming, J. M., Yan, X., Lot, R., & Stanton, N. A. (2021). Adjusting the need for speed: assessment of a visual interface to reduce fuel use. *Ergonomics*, *64*(3), 315-329.

Allison, C. K., Parnell, K. J., Brown, J. W., & Stanton, N. A. (2017, July). Modeling the Real World Using STISIM Drive® Simulation Software: A Study Contrasting High and Low Locality Simulations. In *International Conference on Applied Human Factors and Ergonomics* (pp. 906-915). Springer, Cham.

Bangor, A., Kortum, P. T., & Miller, J. T. (2008) An Empirical Evaluation of the System Usability Scale. International Journal of Human-Computer Interaction 24, 574–594.

Barić, D., Zovak, G., & Periša, M. (2013). Effects of eco-drive education on the reduction of fuel consumption and CO2 emissions. *Promet-Traffic & Transportation*, *25*(3), 265-272.

Barkenbus, J. N. (2010). Eco-driving: An overlooked climate change initiative. *Energy Policy*, *38*(2), 762-769.

Barth, M., & Boriboonsomsin, K. (2009). Energy and emissions impacts of a freeway- based dynamic eco-driving system. *Transportation Research Part D: Transport and Environment*, *14*(6), 400-410.

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*, *14*(7), 514-520.

Bongers, K. C., Dijksterhuis, A., & Spears, R. (2009). Self-esteem regulation after success and failure to attain unconsciously activated goals. *Journal of Experimental Social Psychology*, *45*(3), 468-477.

Brockner, J. (1983). Low self-esteem and behavioral plasticity: Some implications. *Review of personality and social psychology, 4,* 237-271.

Brooke, J. (1996). SUS: a "quick and dirty" usability scale. In P.W.Jordan, B. Thomas, B.A. Weerdmeester, and I.L. McClelland (Eds.) Usability Evaluation in Industry (189-194). London: Taylor and Francis.

Buckeridge, D. L., Glazier, R., Harvey, B. J., Escobar, M., Amrhein, C., & Frank, J. (2002). Effect of motor vehicle emissions on respiratory health in an urban area. *Environmental health perspectives*, *110*(3), 293.

Chan, C. C. (2007). The state of the art of electric, hybrid, and fuel cell vehicles. *Proceedings of the IEEE*, *95*(4), 704-718.

Chapman, L. (2007). Transport and climate change: a review. *Journal of Transport Geography*, *15*(5), 354-367.

Clarkson, J. J., Hirt, E. R., Jia, L., & Alexander, M. B. (2010). When perception is more than reality: the effects of perceived versus actual resource depletion on self-regulatory behavior. *Journal of personality and social psychology*, *98*(1), 29.

Coopersmith, S. (1967). The antecedents of self-esteem San Francisco. *H Freeman and Company*.

Delhomme, P., Cristea, M., & Paran, F. (2013). Self-reported frequency and perceived difficulty of adopting eco-friendly driving behavior according to gender, age, and environmental concern. *Transportation Research Part D: Transport and Environment*, *20*, 55-58.

Demirdöven, N., & Deutch, J. (2004). Hybrid cars now, fuel cell cars later. *Science*, *305*(5686), 974-976.

Dogan, E., Bolderdijk, J. W., & Steg, L. (2014). Making small numbers count: environmental and financial feedback in promoting eco-driving behaviours. *Journal of Consumer Policy*, *37*(3), 413-422.

Fleming, J., Yan, X., & Lot, R. (2020). Incorporating driver preferences into eco-driving assistance systems using optimal control. *IEEE Transactions on Intelligent Transportation Systems*.

François, M., Osiurak, F., Fort, A., Crave, P., & Navarro, J. (2021). Usability and acceptance of truck dashboards designed by drivers: Two participatory design approaches compared to a user-centered design. *International Journal of Industrial Ergonomics*, *81*, 103073.

Funke, G., Matthews, G., Warm, J. S., & Emo, A. K. (2007). Vehicle automation: A remedy for driver stress?. *Ergonomics*, *50*(8), 1302-1323.

Gardner, B., & Abraham, C. (2007). What drives car use? A grounded theory analysis of commuters' reasons for driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*(3), 187-200.

Gardner, B., & Abraham, C. (2007). What drives car use? A grounded theory analysis of commuters' reasons for driving. *Transportation Research Part F: Traffic Psychology and Behaviour*, *10*(3), 187-200.

Heijne, V., Ligterink, N., Stelwagen, U., 2017. Potential of eco-driving. UDRIVE Deliverable D45.1. EU FP7 Project UDRIVE Consortium. https://doi.org/10.26323/ UDRIVE_D45.1.

Heikoop, D. D., de Winter, J. C., van Arem, B., & Stanton, N. A. (2017). Effects of platooning on signal-detection performance, workload, and stress: a driving simulator study. *Applied Ergonomics*, *60*, 116-127.

Heimpel, S. A., Wood, J. V., Marshall, M. A., & Brown, J. D. (2002). Do people with low self-esteem really want to feel better? Self-esteem differences in motivation to repair negative moods. *Journal of personality and social psychology*, *82*(1), 128.

Ingram, R. E. (1990). Self-focused attention in clinical disorders: review and a conceptual model. *Psychological bulletin*, *107*(2), 156.

Isen, A. M. (2000). Some perspectives on positive affect and self-regulation. *Psychological Inquiry*, *11*(3), 184-187.

Kampa, M., & Castanas, E. (2008). Human health effects of air pollution. *Environmental Pollution, 151*(2), 362-367.

Karl, T. R., & Trenberth, K. E. (2003). Modern global climate change. *Science*, *302*(5651), 1719-1723.

Klein, M. I., Warm, J. S., Riley, M. A., Matthews, G., Doarn, C., Donovan, J. F., & Gaitonde, K. (2012). Mental workload and stress perceived by novice operators in the laparoscopic and robotic minimally invasive surgical interfaces. *Journal of Endourology*, *26*(8), 1089-1094.

Knapper, A., Christoph, M., Hagenzieker, M., & Brookhuis, K. (2015). Comparing a driving simulator to the real road regarding distracted driving speed. *European journal of transport and infrastructure research*, *15*(2).

Kumar, R. R., & Alok, K. (2020). Adoption of electric vehicle: A literature review and prospects for sustainability. *Journal of Cleaner Production*, *253*, 119911.

Larsen, R. J. (2000). Toward a science of mood regulation. *Psychological Inquiry*, *11*(3), 129-141.

Lorf, C., Martínez-Botas, R. F., Howey, D. A., Lytton, L., & Cussons, B. (2013). Comparative analysis of the energy consumption and CO2 emissions of 40 electric, plug-in hybrid electric, hybrid electric and internal combustion engine vehicles. *Transportation Research Part D: Transport and Environment*, *23*, 12-19.

Louw, T., & Merat, N. (2017). Are you in the loop? Using gaze dispersion to understand driver visual attention during vehicle automation. *Transportation Research Part C: Emerging Technologies*, *76*, 35-50.

Martin, E., Chan, N., & Shaheen, S. (2012). How public education on ecodriving can reduce both fuel use and greenhouse gas emissions. *Transportation Research Record: Journal of the Transportation Research Board*, (2287), 163-173.

Matthews, G., Campbell, S. E., Falconer, S., Joyner, L. A., Huggins, J., Gilliland, K., ... & Warm, J. S. (2002). Fundamental dimensions of subjective state in performance settings: Task engagement, distress, and worry. *Emotion*, *2*(4), 315.

Matthews, G., Jones, D. M., & Chamberlain, A. G. (1990). Refining the measurement of mood: The UWIST mood adjective checklist. *British journal of psychology*, *81*(1), 17-42.

Matthews, G., Joyner, L., Gilliland, K., Campbell, S., Falconer, S., & Huggins, J. (1999). Validation of a comprehensive stress state questionnaire: Towards a state big three. *Personality psychology in Europe*, *7*, 335-350.

Matthews, G., Szalma, J., Panganiban, A. R., Neubauer, C., & Warm, J. S. (2013). Profiling task stress with the Dundee stress state questionnaire. *Psychology of stress: New research*, 49-90.

McCubbin, D. R., & Delucchi, M. A. (1999). The health costs of motor-vehicle-related air pollution. *Journal of Transport Economics and Policy*, 253-286.

McIlroy, R. C. and Stanton, N. A. (2017b) What do people know about eco-driving? *Ergonomics, 60* (6), 754-769.

McIlroy, R. C., Stanton, N. A., and Harvey, C. (2014). Getting drivers to do the right thing: a review of the potential for safely reducing energy consumption through design. *IET Intelligent Transport Systems. 8* (4), 388–397.

Mehler, B., & Reimer, B. (2013). An initial assessment of the significance of task pacing on self-report and physiological measures of workload while driving.

Mensing, F., Bideaux, E., Trigui, R., Ribet, J., & Jeanneret, B. (2014). Eco-driving: An economic or ecologic driving style?. *Transportation Research Part C: Emerging Technologies*, *38*, 110-121.

Paas, F., Tuovinen, J. E., Tabbers, H., & Van Gerven, P. W. (2003). Cognitive load measurement as a means to advance cognitive load theory. *Educational psychologist*, *38*(1), 63-71.

Pampel, S. M., Jamson, S. L., Hibberd, D. L., & Barnard, Y. (2015). How I reduce fuel consumption: An experimental study on mental models of eco-driving. *Transportation Research Part C: Emerging Technologies*, *58*, 669-680.

Ramanathan, V., & Feng, Y. (2009). Air pollution, greenhouse gases and climate change: Global and regional perspectives. *Atmospheric environment*, *43*(1), 37-50.

Sanguinetti, A., Kurani, K., & Davies, J. (2017). The many reasons your mileage may vary: Toward a unifying typology of eco-driving behaviors. *Transportation Research Part D: Transport and Environment*, *52*, 73-84.

Sarason, I. G., Sarason, B. R., & Shearin, E. N. (1986). Social support as an individual difference variable: Its stability, origins, and relational aspects. *Journal of Personality and Social psychology*, *50*(4), 845.

Sheller, M. (2004). Automotive emotions: Feeling the car. *Theory, culture & society,* 21(4-5), 221-242.

Smith, E. R., & Mackie, D. M. (2007). *Social Psychology.* New York: Psychology Press.

Smith, S. M., & Petty, R. E. (1995). Personality moderators of mood congruency effects on cognition: The role of self-esteem and negative mood regulation. *Journal of Personality and social Psychology*, *68*(6), 1092.

Stillwater, T., & Kurani, K. S. (2013). Drivers discuss ecodriving feedback: Goal setting, framing, and anchoring motivate new behaviors. *Transportation Research Part F: Traffic Psychology and Behaviour*, *19*, 85-96.

Sun, X., Cao, S., & Tang, P. (2021). Shaping driver-vehicle interaction in autonomous vehicles: How the new in-vehicle systems match the human needs. *Applied Ergonomics*, *90*, 103238.

Sureth, A., Moll, V., Nachtwei, J., & Franke, T. (2019). The golden rules of ecodriving? The effect of providing hybrid electric vehicle (HEV) drivers with a newly developed set of ecodriving-tips. Transportation Research Part F: Traffic Psychology and Behaviour, 64, 565-581.

Thayer, R. E. (1990). *The biopsychology of mood and arousal*. Oxford University Press.

Tu, H., Li, Z., Li, H., Zhang, K., & Sun, L. (2015). Driving simulator fidelity and emergency driving behavior. *Transportation Research Record*, *2518*(1), 113-121.

Windecker, A., & Ruder, A. (2013). Fuel economy, cost, and greenhouse gas results for alternative fuel vehicles in 2011. *Transportation Research Part D: Transport and Environment, 23,* 34-40.

Wood, J. V., Heimpel, S. A., & Michela, J. L. (2003). Savoring versus dampening: self-esteem differences in regulating positive affect. *Journal of personality and social psychology*, *85*(3), 566.

Yan, X., Allison, C. K., Fleming, J. M., Stanton, N. S., & Lot, R. (2021) The benefit of assisted and unassisted eco-driving for electrified powertrains. *IEEE Transactions on Human-Machine Systems*.

Yin, Y., & Lawphongpanich, S. (2006). Internalizing emission externality on road networks. *Transportation Research Part D: Transport and Environment*, *11*(4), 292-301.