Article title
Old habits die hard? The fragility of eco-driving mental models and why green driving behaviour is difficult to sustain

Author names and affiliations
Sanna M. Pampel[ab] (+44 115 951 4036, sanna.pampel@nottingham.ac.uk), Samantha L. Jamson[b] (S.L.Jamson@its.leeds.ac.uk), Daryl Hibberd[b] (D.L.hibberd@leeds.ac.uk), Yvonne Barnard[b] (Y.Barnard@leeds.ac.uk)

a Institute for Transport Studies, University of Leeds, University Road 34-40, LS2 9JT Leeds, UK
b Present address: Human Factors Research Group, Faculty of Engineering, University of Nottingham, NG7 2RD, UK, Phone: +44 (0)115 951 4038, E-mail: sanna.pampel@nottingham.ac.uk

Abstract
Tangible incentives, training and feedback systems have been shown to reduce drivers' fuel consumption in several studies. However, the effects of such tools are often short-lived or dependent on continuous cues. Several studies found that many drivers already possess eco-driving mental models, and are able to activate them, for instance when an experimenter asks them to "drive fuel-efficiently". However, it is unclear how sustainable mental models are. The aim of the current study was to investigate the resilience of drivers' eco-driving mental models following engagement with a workload task, implemented as a simplified version of the Twenty Questions Task (TQT). Would drivers revert to 'everyday' driving behaviours following exposure to heightened workload? A driving simulator experiment was conducted whereby 15 participants first performed a baseline drive, and then in a second session were prompted to drive fuel-efficiently. In each drive, the participants drove with and without completing the TQT. The results of two-way ANOVAs and Wilcoxon signed-rank tests support that they drive more slowly and keep a more stable speed when asked to eco-drive. However, it appears that drivers fell back into 'everyday' habits over time, and after the workload task, but these effects cannot be clearly isolated from each other. Driving and the workload task possibly invoked unrelated thoughts, causing eco-driving mental models to be deactivated. Future research is needed to explore ways to activate existing knowledge and skills and to use reminders at regular intervals, so new driver behaviours can be proceduralised and automatised and thus changed sustainably.

Keywords
Mental models; Driving simulator; Eco driving; Workload; Driver behaviour; Automatisation

Highlights

- Driving simulator experiment to test the stability of eco-driving knowledge and skills

- Eco-driving prompt led to lower speed, less acceleration and deceleration

- A mild, cognitive workload task induced slower driving and longer headways

- Over time and after the workload task, drivers fell back into 'everyday' habits

- The effects of time and workload cannot be clearly isolated from each other

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1. Introduction

1.1   Background

A growing body of research suggests that the difficulty of changing drivers' behaviour towards more fuel-efficient driving practices is not simply overcome with organised training sessions (Delicado, 2012, Johansson et al., 1999, Schall et al., 2016) and financial (Harvey et al., 2013, Schall et al., 2016) or environmental motivations (Flynn et al., 2009, Stradling et al., 2008). Continuous feedback and feed-forward systems have the potential to encourage drivers to effectively eco-drive (Barkenbus, 2010, Birrell et al., 2014, Hibberd et al., 2015), but these may be complex and potentially expensive to build. In contrast, simple prompts have been shown to effect reductions in fuel consumption (7 – 8% reduction), albeit to a lesser degree compared to support systems (10 - 16% reduction, van der Voort et al., 2001, Waters and Laker, 1980). Nevertheless, prompts could be a cost-effective way to encourage drivers to utilise their existing knowledge and skills.

Several studies found that many drivers possess at least a certain amount of knowledge and skills to be able to reduce their fuel consumption. Drivers who use eco-driving support systems (EDSS) tend to adhere to the suggestions of support systems, but are also encouraged to apply existing knowledge based on their own understanding (i.e. mental models) of such behaviour. For example, an EDSS tested by Birrell and Young (2011) advised on gear changes and acceleration, but not on speed choice. Nevertheless, participants applied 'typical' eco-driving behaviours such as decreasing speed and the time spent speeding. Similar phenomena have been found with EDSS in the ecoDriver project (Saint Pierre et al., 2016). In a study by Tarkiainen et al. (2014) 39% of the participants reported that the presence of a support system alone led them to drive more safely and economically. Interestingly, drivers can apparently eco-drive without EDSS. Waters and Laker (1980) asked a convenience sample to drive normally and then eco-friendly around a specified course. The eco-driving session improved the average fuel efficiency by around 8%. This was achieved with slower speeds and higher gears. Pampel et al. (2015) explored eco-driving mental models further, and found that that drivers were able to effectively eco-drive, simply after being asked by an experimenter to 'drive fuel-efficiently'. Comparable effects were observed by Birrell et al. (2010) and van der Voort et al. (2001). An activation of eco-driving mental models could cause larger headways in order to prevent harsh braking (Boer et al., 2005), and lower speeds (Birrell et al., 2010). Drivers may keep longer headways during car-following (Birrell et al., 2014, Boer et al., 2005), but be temporarily tolerant when the headway becomes very short (Mensing et al., 2013), e.g. when a front car is reducing its speed, to avoid stepping on the brake pedal. Hence, delivering prompts and reminders to eco-drive may have a similar function, effecting eco-driving mental models to be activated and applied.

One problem is that eco-driving is less familiar to many drivers compared to their usual driving style, and therefore less automated and habitual. Hence, behavioural changes may not be easy to sustain. In a related example, Allcott and Rogers (2014) demonstrated that the upkeep of household energy saving practices depended on a continuous provision of the prompt. The apparent fragility of sustaining new behaviours raises the question of what causes eco-driving mental models to be abandoned. In driving simulator studies with support systems, participants either worsened their eco-driving behaviours after the system was discontinued (Hiraoka et al., 2011), or they did not show

improvements over repeated support system use (Jamson et al., 2015). Such studies show that eco-driving mental models may be deactivated over time, for example over the course of a journey, suggesting a lack of learning and internalisation. The deactivation may thus be occurring gradually over time. An additional cause may be that drivers encounter a variety of situations during their journeys, which may subject them to interruptions and elevated workload. Such interruptions are studied extensively as a cause for errors in aviation (Dismukes and Nowinski, 2007), due to the well-defined set of tasks in the field, but are applicable in the driving domain as well. In a driving simulator study with a simple display showing the amount of fuel left in the tank, Dogan et al. (2011) found that time- as well as safety-critical situations led to eco-driving behaviours being abandoned. Jamson et al. (2015) tested two EDSS advising on the gas pedal position. Despite the continuous signal, drivers largely prioritised safety in dense traffic conditions. In summary, it would appear that safety tends to be prioritised above eco-driving – as it should be – and, without constant reminders, previous driving behaviour may be resumed.

It could therefore be argued that mental workload is one of the causes for the abandonment of eco-driving. A possible explanation is that eco-driving on its own, when not supported by EDSS, can occupy mental resources (Birrell et al., 2010) and require more conscious effort. Hence, it is not an easy and intuitive task to accomplish over long periods of time. When other mental demands arise (such as safety-critical events or interventions), it may be necessary for drivers to attend to them temporarily. Once the event or intervention has passed, drivers may then revert to more familiar, and thus easier to adopt, driving styles. The current study is concerned with the stability of eco-driving mental models in the face of elevated workload and interruptions. The paper uses a workload task designed to challenge the strength of activated eco-driving models and to interrupt them.

1.2 Mental models

The theoretical underpinning for understanding drivers' eco-driving knowledge and skills in this research was based on mental models. Johnson-Laird referred to a mental model as a schema, "*a single representative sample*" (1983, p. 264) of a real entity. The idea that humans store representative schemas of the world is a central concept in the present study. In essence, it is assumed that humans possess a library of mental models, which comprise many aspects of the world, including objects, situations and events, but also sequences of events and actions (Garnham, 1997, Johnson-Laird, 1983, Rumelhart, 1980). As people perceive information, a matching mental model is retrieved and fed with the variables of the current situation. It then guides the person's perceptions and actions (Johnson-Laird, 1983).

Mental model theory is based on the understanding that the desired mental models need to be activated, and remain activated. In this example, eco-driving mental models need to take precedence over 'everyday' driving mental models. Rasmussen (1983) arranged mental models into hierarchical levels, knowledge, rules and skills. When humans learn how to drive and practise it regularly, the tasks are proceduralised, moving from the more conscious higher levels down to the automated levels (cf. Anderson, 1982, Rasmussen, 1983). Experienced drivers have had more opportunity, through increased exposure, to extract and refine underlying situational rules that define their schema. Therefore, they are able to process and coordinate their knowledge and skill representations in a more

efficient manner (cf. Michon, 1985). Hence, it is expected that 'everyday' driving habits are usually automated, while eco-driving is still placed on more conscious and therefore effortful levels for many drivers. Nevertheless, the activation of eco-driving mental models can be achieved by various means such as prompts. Once activated, it is crucial that the desired mental models then remain activated, and, over time, ideally replace 'default' mental models.

1.3   The deactivation of mental models

One particular challenge regarding eco-driving mental models is that once activated, they need to remain in this state in the face of long timeframes and potentially, during periods of elevated workload or interruptions. The problem is that, when unfamiliar mental models are activated, it is expected that certain conditions can cause a person to revert to more well-learned mental models (Rasmussen, 1979) such as 'everyday' driving. Rasmussen stated that subconscious actions are especially vulnerable to interruptions, and even more so when the unfamiliar actions are very similar to the usually applied mental model. For example, if the investigation of an infrequent type of error in a process plant is disrupted, and the disruption reminds the operator of familiar situations, the operator could settle for an activation of more automated mental models and ignore conflicting information. It has been shown that drivers who are very familiar with a route are more likely to miss new cues in the environment such as a new speed limit or changed priorities at junctions (Martens, 2011, Martens and Fox, 2007, van Elslande and Faucher-Alberton, 1997). This familiarity could explain the heightened occurrence of accidents on roads close to drivers' homes (Burdett et al., 2017).

This raises the question of whether activated eco-driving mental models are robust enough to sustain over time as well as withstand conditions such as unrelated thoughts or mild stress, which can occur frequently in everyday driving. Although a large proportion of drivers are motivated to eco-drive and report that they regularly practise it (Delhomme et al., 2013), eco-driving is usually not the default driving behaviour (Harvey et al., 2013). It is not as familiar and automated as 'everyday' driving, and not as convenient. One reason is that eco-driving can require more effort, especially when unsupported (Birrell et al., 2010, Birrell et al., 2013). It is expected that once drivers have activated their eco-driving mental models, they abandon the fuel-saving goal when competing demands for their attention arise (cf. Dogan et al., 2011).

1.4   The current study and hypotheses

The objective of the current study was to test whether eco-driving mental models weaken over time and are deactivated in the face of a cognitive task that can elevate workload and interrupt eco-driving, and whether eco-driving was resumed after the task was completed.

Firstly, eco-driving mental models were activated by verbal prompts, and their activation confirmed based on drivers' behaviour when negotiating a varied road layout and a non-emergency braking scenario that enabled typical fuel-efficient behaviours such as mild deceleration and coasting. It was expected that, when drivers are asked to drive fuel-efficiently, they will increase such eco-driving behaviours and reduce fuel consumption as a result. They may also use more travel time, drive more slowly and worsen car-following, compared to driving after receiving no specific instructions.

The stability of participants' eco-driving mental models was subsequently investigated by inducing elevated cognitive workload. It was hypothesised that a secondary workload task during a car-following scenario will worsen car-following performance, compared to performing car-following without a secondary workload task. In previous research it has been found that elevated workload can cause drivers to react more slowly to the front vehicle's speed fluctuations (Ward et al., 2003). Higher safety margins are also possible, as drivers compensate for the change in workload (Haigney et al., 2000), measurable in lower speeds and longer headways (Kircher et al., 2004). Specific to this study, it was also expected that effects caused by the eco-driving instructions would diminish while performing the workload task and not be resumed after the workload task has been completed.

2. Methodology

2.1 Participants

Participants were recruited utilising the participant databases of the Leeds University Driving Simulator as well as the Institute for Psychological Sciences. The sample consisted of 15 drivers (Mean = 33.9 years, SD = 11.6 years), 9 of them male and 6 of them female. Every participant drove at least 4000 miles per year (Mean = 11,125 miles, SD = 6,840 miles), and had held a full EU license for at least 3 years (Mean = 14.8 years, SD = 10.7 years). As a gesture of appreciation all participants were given £20.

2.2 Apparatus

This research employed the motion-based University of Leeds Driving Simulator (University of Leeds, 2013). It is based on a 2005 Jaguar S-type vehicle with fully operational controls, including a steering wheel (with force feedback) and pedals, as well as rear view and side mirrors. The vehicle cab is placed inside a dome, shown in Figure 1, which provides the projection area for the screen, onto which the road environment is projected at 266°. An immersive speaker system mimics engine sound and other road noise. The dome is attached to a hexapod motion platform with eight degrees-of-freedom to simulate forces caused by braking and cornering. The vehicle's software assumes an engine model from a 2002 Jaguar X-type and braking data from a Ford Mondeo.

Figure 1: The University of Leeds Driving Simulator (University of Leeds, 2013)

A voice recorder was placed into the vehicle to record the responses to the workload task to ensure the participants' engagement with the task.

2.3 Workload task

The Twenty Questions Test (TQT, Kafer and Hunter, 1997, Mosher and Hornsby, 1966) was selected as a workload task to ensure that the drivers were engaged in typical, natural activities and thoughts such as conversations with passengers, in contrast to the arithmetic and logical reasoning tasks commonly used in driver behaviour studies (e.g. Haigney et al., 2000, Kircher et al., 2004, Patten et al., 2004). The TQT is based on a common children's game and requires cognitive resources for problem solving, planning and working memory (Horrey et al., 2009). In a study by Horrey et al. (2009) the TQT resulted in driving performance decrements, as measured by brake response time, speed accuracy and lane keeping. Merat et al. (2012) found that this task led to lower speeds and fewer lane changes in a driving simulator.

The original version of the TQT tends to trigger competitive behaviours, as the participants are expected to find as many correct answers as possible (Kafer and Hunter, 1997, Mosher and Hornsby, 1966). Accordingly, the TQT can be demanding, frustrating and pressurising as a secondary task for drivers (Horrey et al., 2009, Venables and Fairclough, 2009). Therefore in order to create a more moderate, non-competitive version of the TQT, the roles of the experimenter and participant were reversed. Before the experimental drives, the participants were given one of nine small cards with four words written on it. These answers constituted a fruit, vegetable or animal and were selected from a list created by Horrey et al. (2009), which was partly anglicised for the British audience by Merat et al. (2012). With 15 pre-formulated questions the experimenter narrowed down to the solution using the constraint seeking strategy. This strategy aims to eliminate half of the remaining alternatives with each question (cf. Kafer and Hunter, 1997, Mosher and Hornsby, 1966). The participants were instructed to reply to each question with either 'yes', 'no' or 'I don't know'. Feedback on the answers was not provided to avoid influencing the participants' motivation and effort (cf. Venables and Fairclough, 2009).

2.4 Design

A 2x2 within-subjects design was employed whereby participants completed two drives (Everyday-drive and Eco-drive); within each they encountered two workload conditions (no TQT and TQT). The order of the drives was not counterbalanced to prevent the participants from knowing the study's purpose during the Everyday-drive and possibly influencing their driving behaviour accordingly. The participants completed two car-following tasks in each drive, and performed the TQT during the second occurrence. A braking scenario involving red traffic lights was placed after each car-following scenario. This braking scenario was designed to test eco-driving, particularly deceleration behaviours, before the TQT, and afterwards, once the TQT was completed.
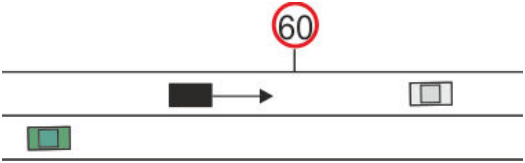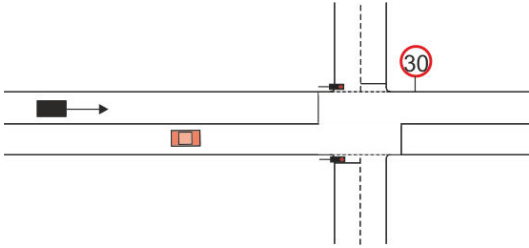
2.5 Driving scenarios

The experimental road totalled about 18 km and required approximately 30 minutes of driving. The road contained one lane in each direction, leading the participant through urban and rural sections. In the entire drive, there was no traffic in the participant's lane, except for the car-following scenario.

The posted speed limits were 30 mph (48 km/h) and 60 mph (97 km/h). The 30 mph speed limit is commonly applied in residential areas in the UK, and 60 mph on single carriageways (UK Government, 2015).

Overall effects of the eco-driving instructions, such as changes in fuel consumption, mean speed, travel time and speed fluctuations, were investigated. Two scenarios were particularly relevant for the controlled testing of eco-driving mental models as well as the effects of the workload task. These scenarios, described in Table 1, occurred twice in each drive and were applicable to study behaviours such as accelerating, cruising and decelerating, as well as headway. For the first scenario, participants were told to follow a lead car. This car-following scenario was designed to evaluate how well the driver matches speed fluctuations of the front car. It has been used by a number of researchers to study driving safety. The car-following task was developed and first described by Brookhuis et al. (1994), and then improved for the driving simulator environment by Ward et al. (2003). In this study, the car-following scenario was presented with and without a workload task. The braking scenario was added after each car-following scenario. Hence, the first braking scenario was placed before the TQT, and the second one occurred when the workload task was completed. It was included to measure behaviour following the workload task, which can be behaviours caused by the absence of resuming eco-driving after a possible interruption. The scenario is particularly suitable for measuring eco-driving-relevant behaviours such as milder deceleration and coasting.

Table 1 Scenarios

Road layout	Scenario description
Car-following 	In this scenario the host followed a lead car that varied its speed between 50 and 60 mph in an approximate sinusoidal cycle with a frequency of about 0.03 Hz (this means that the lead car reached its minimum/maximum speed of 50/60 mph every 33.3 seconds and oscillates between them). Usually, drivers are instructed to follow the front car at a constant distance and then perform a secondary distractor task. In order to investigate effects of eco-driving on headways, participants in this study were not asked to maintain a certain distance. The scenario was 3 km long, lasted around 100 seconds and ended with the lead car turning into a side road. It was relevant for measuring car following performance, speed, and lateral variation, with and without a workload task.

Road layout	Scenario description
Braking	The braking scenario involved a junction, where the drivers could to bring the vehicle to a stop. The traffic lights were red from the point where the participant was 350m before them. Hence, deceleration behaviours could be measured, including the smoothness and the time spent in the scenario.

There were two identical occasions of both scenarios in each drive. The car-following scenario was placed at the beginning and towards the end. The braking scenario was located in the middle and at the very end of the drives, to present a natural end point following the car-following scenario.

2.6 Procedure

During recruitment, the participants were told that the study was about 'driving styles', without mentioning the eco-driving focus, to prevent them from preparing for the study. At the beginning of the first session, the participants were briefed and asked to sign a consent form. Together with the experimenter, the participants performed a practice drive to become familiar with the driving simulator. The scenarios involving traffic lights and other vehicles in the participant's trajectory were not included in the practice drive. For the first experimental drive, Everyday-drive, each participant was asked to drive through a combined urban and rural section normally, as they would every day, without driving style instructions. Subsequently, the participants were given questionnaires enquiring about their demographic information.

After a period of two weeks, the participants were scheduled for a second session in the driving simulator. This provided the benefit of lessening the familiarity of the participants with the scenarios. This second session involved a drive that was designed with the same road layout as Everyday-drive but the participants were asked to drive fuel-efficiently. No further explanation regarding what 'fuel-efficient' meant was provided with the instructions, so the participants needed to apply their own understanding of eco-driving. These instructions were considered sufficient for behaviour change, following the results of an earlier study (Pampel et al., 2015). At the end of the session, a debriefing took place and the participants had the opportunity to ask questions about the study.

2.7 Measures and data analysis

The data recorded in this study consisted of objective, behavioural measures collected by the driving simulator at 60 Hz. For overall eco-driving performance, fuel consumption, speed variations and the occurrence of coasting were measured. Increased travel time and reduced speed reflect typical understandings of eco-driving. In the car-following scenario, the measures furthermore included coherence (the correlation between the speed of the lead and the participant car), phase shift (the delay of reactions to the speed fluctuations of the lead car), and modulus. The modulus is an amplification factor, which is 1 in the case of perfectly identical amplitudes, larger than 1, if the

participant overreacts by a tendency to exceed the lead car's maximum speed and decelerate to speeds lower than its minimum speed. A modulus smaller than 1 signals underreacting. Good following behaviour is usually expressed as high coherence, a low phase delay and a modulus of around 1. The measures for the car-following scenario also included headway and the variation of lateral acceleration. For the braking scenario, fuel consumption, mean speed, mean and standard deviation of deceleration were analysed.

The raw data collected by the driving simulator were processed in Matlab to extract the dependent variables, overall and separately for each scenario. For modelling realistic effects of driving behaviour on fuel consumption, the Passenger car and Heavy-duty Emission Model PHEM (Rexeis et al., 2005) was employed. PHEM was developed using extensive emission measurements of different types of engines, and was able to predict realistic fuel consumption figures using speed and location data generated by the driving simulator.

For the combined analysis of the effects of Drive, TQT and Drive*TQT interactions, two-way repeated-measures ANOVAs were performed for the car-following and braking scenarios. If the workload task disrupts eco-driving mental models, a significant Drive*TQT interactions should be found. The factor TQT has 2 levels (no TQT and TQT) as does Drive (Everyday-drive and Eco-drive). For measures that violated the assumptions of parametric tests in a minimum of two of the four conditions, the Wilcoxon signed-rank test was used for the comparisons. The effect size was computed by dividing the Z-test statistic by the square root of the number of participants and may thus be positive or negative, depending of the direction of the effect. Interaction effects for non-normally distributed measures were not tested. Where a significant effect was found, post-hoc tests were performed to compare the experimental conditions with each other. Because the analysis of the entire routes resulted in a lack of effects of the eco-driving instructions, it was decided to eliminate the effects of the workload task, which occurred after the first half. Hence, the analysis of overall fuel consumption, travel time and measures indicative of eco-driving were performed in isolation for the first half of the drives (from the start to the end of the first braking scenario). The comparisons were performed with one-tailed t-tests, as the direction of the effects had been hypothesised. Statistical significance was accepted at $p < 0.05$.

3. Results

3.1 Overall effects for the first halves of the drives

Fuel consumption was significantly reduced by 2.2% from Everyday- to Eco-drive. Travel time increased by 3.2%, while mean speed was lowered slightly, but significantly, by 1 mph. However, participants did not coast more in the Eco-drive. Nevertheless, the drivers reduced speed fluctuations. Mean acceleration decreased by 13%, mean deceleration by the same percentage and the standard deviation of acceleration, a measure for the smoothness of acceleration, by 18%. A list of these measures is provided in Table 2.

Table 2: Fuel consumption and travel time effects for the first half of the drives (SE in brackets, * indicates significance)

Variable	Everyday-drive	Eco-drive	Test results for factor Drive
Fuel consumption total (g/s)*	.411 (.004)	.402 (.003)	t(14) = 2.033, p = .031, r = .477
Time total (min:sec)*	20:02 (9.50 sec)	20:41 (9.08 sec)	t(14) = -2.851, p = .007, r = .606
Mean speed (mph)*	36.3 (.277)	35.3 (.212)	t(14) = 2.895, p = .006, r = .612
Time coasting (s)	49.3 (15.8)	51.8 (16.2)	Z(14) = -.126, p = .450, r = -.033
Mean acceleration (m/s²)*	.174 (.007)	.151 (.007)	t(14) = 2.774, p = .008, r = .596
Mean deceleration (m/s²)*	-.225 (.013)	-.196 (.011)	t(14) = -2.348, p = .017, r = .532
Sd. of acceleration (m/s²)*	.222 (.016)	.183 (.012)	t(14) = 2.110, p = .027, r = .491

3.2   Car-following scenario

The measures used to investigate car-following behaviour were the coherence, phase shift and modulus, as well as measures related to headway, speed and lateral acceleration. No significant Drive*TQT interaction was found for any of these variables. In addition, no significant main effects of Drive and TQT were found for coherence, phase shift and modulus. Drive did not affect mean speed, speed variability and standard deviation of lateral acceleration. However, an effect for Drive revealed a change in mean time headway from Everyday-drive to Eco-drive, which increased by an average of 1 second in the car-following scenario without the workload task.

TQT produced a number of significant effect however. The participants drove slower when the workload task was performed, especially during the Eco-drive, with 3.2 mph difference. In addition, the speed variability decreased with TQT and mean time headway increased by 0.5 seconds in the Everyday- and by 4.5 seconds in the Eco-drive. The workload task also effected reduced lateral variation. There were no significant main or interaction effects on fuel consumption. A summary of the results for the car-following scenario are displayed in Table 3.

Table 3: Measures analysed in the car-following scenario (SE in brackets, * indicates significance)

Variable	Everyday-drive no TQT	Everyday-drive TQT	Eco-drive no TQT	Eco-drive TQT	Significant differences (in bold)	Test results
Fuel cons. (g/s)	.433 (.009)	.437 (.009)	.438 (.007)	.467 (.015)	Drive TQT Drive*TQT	Z = 1.347, p = .178, r = .348 Z = 1.800, p =.072, r = .465 not tested
Coherence	.327 (.073)	.189 (.038)	.198 (.050)	.191 (.050)	Drive TQT Drive*TQT	$F(1, 14) = 2.000$, p =.179, $\eta^2 = .125$ $F(1, 14) = 2.443$, p =.140, $\eta^2 = .149$ $F(1, 14) = 1.169$, p =.298, $\eta^2 = .077$
Phase shift	6.66 (1.06)	6.60 (1.08)	6.67 (1.20)	6.67 (1.17)	Drive TQT Drive*TQT	Z = .592, p =.554, r = .153 Z = -.557, p =.577, r = -.144 not tested
Modulus	.896 (.094)	.728 (.106)	.793 (.100)	.661 (.079)	Drive TQT Drive*TQT	$F(1, 14) = 2.103$, p =.169, $\eta^2 = .131$ $F(1, 14) = 3.683$, p =.076, $\eta^2 = .208$ $F(1, 14) = 0.052$, p =.823, $\eta^2 = .004$
Mean speed (mph)*	56.1 (.465)	55.5 (.452)	56.4 (.396)	53.2 (1.54)	Drive **TQT** Drive*TQT	Z = -0.751, p =.453, r = -.194 Z = -2.088, p = .037, r = -.381 not tested
Sd. of speed (mph)*	3.69 (.318)	2.91 (.443)	3.58 (.434)	3.18 (.405)	Drive **TQT** Drive*TQT	$F(1, 14) = 0.060$, p =.810, $\eta^2 = .004$ $F(1, 14) = 4.724$, p = .047, $\eta^2 = .252$ $F(1, 14) = 0.279$, p =.606, $\eta^2 = .020$
Mean headway (s)*	5.70 (.914)	6.19 (.934)	6.70 (.797)	11.19 (2.76)	**Drive** **TQT** Drive*TQT	Z = 2.191, p = .028, r = .400 Z = 2.047, p = .041, r = .374 not tested
Stand. dev. of lateral acc. (m/s²)*	.810 (.015)	.793 (.016)	.825 (.019)	.744 (.040)	Drive **TQT** Drive*TQT	Z = -0.607, p =.544, r = -.157 Z = -2.211, p = .027, r = -.404 not tested

3.3 Braking scenario

The first braking scenario was placed exactly half-way along the road layout. The second braking scenario occurred at the end of the route directly after the second car-following scenario. It was therefore encountered by the drivers directly after the TQT was completed. In this part of the analysis, all four braking scenarios were compared with each other.

No Drive*TQT interaction effects were found for fuel consumption, travel time, mean speed and standard deviation of deceleration. Mean deceleration was the only measure that resulted in a

Drive*TQT interaction. The TQT had a stronger effect in the Eco-drive. Hence, as a consequence of being asked to drive fuel-efficiently, the participants reduced their mean deceleration initially from -0.43 to -0.38 m/s^2. Following the workload task, the deceleration increased to a level similar to the second braking scenario in the first drive (-0.46 in Everyday-drive and -0.48 in Eco-drive). These subtle differences in deceleration behaviours are visible in the speed profiles in Figure 2.
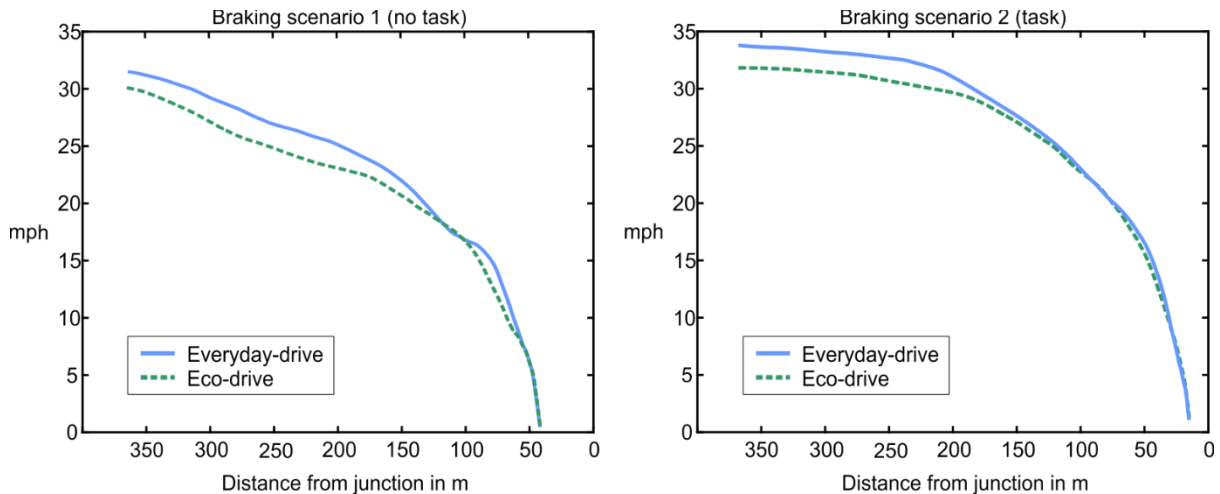

Figure 2: Speed profiles for the braking scenarios

No effects for Drive were found for fuel consumption, mean speed and deceleration measures. However, the time spent in the braking scenario increased from Everyday- to Eco-drive, by 4.9 seconds, where no workload task was performed.

A significant effect for TQT points to an increase in fuel consumption following the workload task. It rose from the no TQT to the TQT condition by 13%. The time spent in the braking scenario produced a significant effect for TQT as well. When the workload task was performed, the time decreased. Analysing the mean speed identified a significant effect for TQT. The mean speed was 15% lower when the task was not performed. Mean deceleration across the braking scenario became stronger with TQT. The variation of deceleration increased by 16% from the no TQT to the TQT condition, supported by a significant effect. The measures are listed separately for each braking scenario in Table 4.

Table 4: Everyday-drive to Eco-drive changes for the braking scenario (SE in brackets, * indicates significance)

Variable	Everyday-drive no task	Everyday-drive task	Eco-drive no task	Eco-drive task	Significant differences (in bold)	Test results
Fuel cons. (g/s)*	.239 (.008)	267 (.005)	.226 (.008)	.257 (.008)	Drive **TQT** Drive*TQT	$F(1, 14) = 3.556$, $p = .080$, $\eta^2 = .203$ $F(1, 14) = 41.700$, $p < .001$, $\eta^2 = .749$ $F(1, 14) = 0.067$, $p = .799$, $\eta^2 = .005$
Time (sec)*	44.7 (1.81)	39.8 (1.03)	49.6 (2.68)	40.8 (1.26)	**Drive** **TQT** Drive*TQT	$F(1, 14) = 6.694$, $p = .022$, $\eta^2 = .323$ $F(1, 14) = 17.945$, $p = .001$, $\eta^2 = .562$ $F(1, 14) = 2.917$, $p = .110$, $\eta^2 = .172$
Mean speed (mph)*	18.3 (.761)	20.3 (.508)	16.8 (.848)	19.9 (.660)	Drive **TQT** Drive*TQT	$F(1, 14) = 4.265$, $p = .058$, $\eta^2 = .233$ $F(1, 14) = 25.398$, $p < .001$, $\eta^2 = .645$ $F(1, 14) = 1.827$, $p = .198$, $\eta^2 = .115$
Mean decel. (m/s²)*	-.432 (.026)	-.463 (.022)	-.384 (.028)	-.481 (.029)	Drive **TQT** **Drive*TQT**	$F(1, 14) = 0.399$, $p = .538$, $\eta^2 = .028$ $F(1, 14) = 14.270$, $p = .002$, $\eta^2 = .505$ $F(1, 14) = 7.389$, $p = .017$, $\eta^2 = .345$
Sd. of decel. (m/s²)*	.347 (.034)	.402 (.036)	.337 (.036)	.389 (.034)	Drive **TQT** Drive*TQT	$Z = -0.689$, $p = .491$, $r = -.178$ $Z = 3.260$, $p = .001$, $r = .595$ not tested

4. Discussion

The majority of eco-driving efforts focus on teaching drivers how to eco-drive, or on motivating them to practise it. This research, however, was based on the understanding that fulfilling these factors does not completely solve the problem. Instead, it focussed on people's existing knowledge and skills that constitute their eco-driving mental models. Many drivers possess eco-driving mental models, but these tend to be less familiar, less automatised and less utilised, than the usual driving mental models. In previous studies, eco-driving mental models have been activated with prompts, or the presence of support systems, but this raises the question of whether this activation would be stable over time and in the face of everyday driving conditions such as unrelated thoughts or stress. Hence, it was attempted to challenge the strength of activated eco-driving mental models with a workload task. Driving behaviour was measured overall in the first halves of the experimental routes and separately

in two scenarios, a car-following and a braking scenario. These scenarios were experienced by the participants four times, using a motion-based driving simulator.

For the first simulator drive, the participants did not receive specific instructions on their driving style, and for the second drive, they were asked to drive fuel-efficiently in order to allow them to apply their own understanding of eco-driving. A comparison of the first halves of the routes shows that the drivers lowered their fuel consumption by 2.2% in the Eco-drive, which is a small reduction compared to previous studies with similar instructions (Pampel et al., 2015, van der Voort et al., 2001, Waters and Laker, 1980). The participants drove more slowly and thus lengthened their travel time, reduced speed fluctuations and accelerated more smoothly, but did not coast more. Had the statistical tests been two-tailed, the differences in travel time, mean speed, acceleration and deceleration would still have been significant. In summary, the participants applied some typical eco-driving behaviours. Lower speeds can be beneficial for eco-driving (Haworth and Symmons, 2001, Waters and Laker, 1980), although drivers tend to believe that they need to drive slower than necessary (Eriksson and Svenson, 2012), especially within urban speed limits (Samaras and Ntziachristos, 1998). Lower acceleration rates can help save fuel (Ericsson, 2001, Waters and Laker, 1980), but several studies suggest a swift, but not aggressive acceleration up to an efficient speed is also fuel-efficient (Mensing et al., 2014, Mensing et al., 2013). Maintaining steady speeds is an effective way to save fuel (Mensing et al., 2014, Mensing et al., 2013), and can be achieved with anticipation (Johansson et al., 2003). However, coasting in order to smoothen speed changes at junctions (cf. Beusen et al., 2009, Knowles et al., 2012) was not increased in the Eco-drive. Nevertheless, the increased time in the braking scenario signifies more time used for decelerating to a stop. A larger headway, however, is another means to ensure a steadier speed, and was applied in the car-following scenario. Using larger headways, eco-driving also has positive implications for driving safety. In summary, it appears that the drivers were applying their own eco-driving knowledge and skills when they were asked to eco-drive, i.e. they activated their eco-driving mental models, but conclusions cannot be drawn as clearly as in previous studies. It is also possible that these mental models are not necessarily effective, and less useful than drivers may think. Hence, support systems or training may be necessary to achieve significant environmental benefits.

Detailed comparisons of the car-following and the braking scenarios did not demonstrate consistent effects of the eco-driving instructions on most measures, including fuel consumption. Coherence, phase shift and modulus were not affected, but an increase in time headway was found. One possible explanation is that, in this study, the drivers were not asked to follow the lead car at a constant distance, as had been done in past studies (Brookhuis et al., 1994, Ward et al., 2003). These instructions were omitted to allow the drivers to apply their eco-driving mental models without modifying them. Hence, it may be possible that the car-following scenario is not suitable for studying and evaluating eco-driving. Similarly, in the braking scenario, mean speed and deceleration variation were not affected. This may mean that eco-driving mental models were not fully activated in the present study, reflected in the lack of general effects such as fuel savings. It could also be expected that, without repeated reminders, eco-driving mental models deactivate over time (Hiraoka et al., 2011, Jamson et al., 2015). Because the first braking scenario was placed half-way along the route, eco-driving behaviours may have lessened by the time the participants reached it. Hence, eco-driving

mental models may not have been stable enough to persist until the braking and car-following scenarios.

The rationale of the study was that, as the drivers activated their eco-driving mental models, the stability of this activation was challenged with a workload task. The TQT was performed in each drive, during the second car-following scenario towards the end of the road layout. A braking scenario was placed after the car-following scenario, which meant that this scenario was encountered by the participants after the TQT was completed in order to measure whether eco-driving was resumed or not. If a workload task disrupts eco-driving mental models, Drive*TQT interactions should occur. However, the results created a different picture.

Mean deceleration in the braking scenario was the only measure that resulted in a Drive*TQT interaction. After being asked to drive fuel-efficiently, the participants reduced their mean deceleration initially. Following the workload task, the deceleration was similar to the level in the corresponding braking scenario in the first route. Although milder deceleration can be indicative of eco-driving, the stronger braking at the end of the second drive can have other causes. More abrupt deceleration behaviours could point to an increased reaction time, as was found in studies using distraction tasks (Horberry et al., 2006, Kircher et al., 2004, Laberge et al., 2004). As the TQT was not performed in this scenario, effects due to answering the questions were unlikely. It is possible that the braking scenario at the end of the study led drivers to brake harsher in anticipation of finishing the drive, which also led to lower time spent in this scenario. Increased fuel consumption and mean speed add to the explanation.

The findings do not fully support the hypothesis that drivers abandoned eco-driving mental models following an interruption in the form of a workload task. However, the data indicate that eco-driving was practised to a limited degree in the first half of the drive, which lasted about 15 minutes. It is possible that the effects of the single prompt ('drive fuel-efficiently') waned over time. Hence, the length of time and the varied road layout may have led to the regression to familiar habits (cf. Rasmussen, 1979). The distinct behaviour changes in previous studies (van der Voort et al., 2001, Waters and Laker, 1980) as well as in the current experiment support the hypothesis that eco-driving is not the default driving behaviour for drivers. Without a support system, it appears to require effort and elevates workload (cf. Birrell et al., 2010). With passing time and different road situations, comparable to a short car journey, participants abandoned behavioural changes (cf. Weick, 1990). 'Prospective memories' provide an alternative explanation for the lack of eco-driving in specific scenarios. Trawley et al. (2017) describe prospective memories as the process of remembering a task that is to be performed in the future, when certain cues are presented. For example, a person could remember to buy milk at the supermarket while driving home. The goal to eco-drive can be considered such a memory, as eco-driving behaviours should be performed at the next suitable junction, for example. Trawley et al. (2017) demonstrated that such memories can increase cognitive load and thus worsen driving performance. Additionally, demanding driving situations may impair the success of prospective memories, and thus cause eco-driving behaviours to be forgotten. In summary, the participants seemingly deactivated eco-driving mental models at some point during the route and reverted back to old, automated habits.

It was apparent that the workload task had a measurable effect on driving behaviour in the car-following scenario, although not on coherence, phase shift and modulus. Nevertheless, the mean speed was 3.2% lower with TQT compared to the same scenario without task. In addition, the variation of speed was lower when the participants were completing the TQT. This more stable speed could have been related to an increase in the time headway in the TQT condition. At the same time, the lateral variation was reduced when the task was performed. These results are in line with research using distraction tasks, which can reduce speed (Hatfield and Chamberlain, 2005, Salvucci et al., 2007, Funkhouser and Chrysler, 2007, White et al., 2006) and increase headways (Kircher et al., 2004). Drivers tend to establish these larger safety margins in order to compensate for distraction (Haigney et al., 2000). Lower lateral variations have been demonstrated in previous research as well, particularly when the distraction was predominantly cognitive in nature (Engström et al., 2005, Kircher et al., 2004). Considering these effects, the reduced lateral variation when undertaking the TQT can be considered a common response to a cognitive workload task. The larger safety margins furthermore suggest that the TQT allowed some compensations and did not affect driving as strongly as tasks involving visual and manual elements.

The present research has several limitations, the first being the length of the drive. It is possible that eco-driving behaviours were either not fully activated or abandoned simply due to time and varying road situations, before the drivers encountered the TQT. The design does not allow to distinguish whether eco-driving lessened over time or due to the TQT. A future study could include an eco-driving condition without a workload task, to contrast the effects of time and demanding situations on eco-driving. A major limitation of the present study is the low sample size, reflected in the variation in the measures, large effect sizes, and low significance levels. Especially the lack of the predicted interaction effects could be an artefact of it. Nevertheless, the TQT itself had a measurable effect on car-following behaviour. It was designed as a conversational task (Horrey et al., 2009) and proved to be very effective; but it can still be argued whether it required too much concentration from the drivers and appeared unnatural, possibly more than a simple conversation with a passenger. Therefore, future studies could involve even more moderate and natural tasks such as simple conversations and the experimenter as passenger. Although the driving simulator environment was designed to display a high degree of realism and capture subtle behavioural changes (cf. Jamson et al., 2010), on-road studies offer a more naturalistic context, with realistic risk estimates and time constraints, for example (Boyle and Lee, 2010), allowing a more typical driving mind set.

5. Conclusions

Encouraging drivers to consistently practise fuel-efficient driving styles has been challenging. Previous research found that many drivers possess eco-driving mental models, and activate them following experimenter instructions or the presence of support systems. The current study investigated the strength of eco-driving mental models over time and attempted to interrupt them with a workload task involving simple questions. The findings suggest that, when drivers utilise their own, existing eco-driving knowledge and skills, this effect can be easily interrupted during car journeys with a duration

of more than 15 minutes and a variety of driving situations. Future research is needed to explore practical ways to increase the activation of existing knowledge and skills. For instance, prompts and reminders could be provided in regular intervals by support systems. However, it could be more relevant to reinstate such messages after the drivers' workload has been raised, although this direct relationship between workload and the deactivation of eco-driving mental models still needs to be established in future research. Modern technology allows measuring workload in unobtrusive ways via steering movements (de Groot et al., 2011, Nakayama et al., 1999), changes in speed (de Waard, 1996, Engström et al., 2005) and eye movements (Bartels and Marshall, 2012). The development of comprehensive workload managers (Teh et al., 2014) can further aid identifying situations, depending on factors inside and outside the vehicle, that can cause drivers to divert from the fuel-saving goal. Simple messages could then mean that driver behaviour can be changed sustainably and in a cost-effective manner.

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