# Mental models of eco-driving: The measurement and activation of drivers' knowledge and skills

**by**

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The candidate confirms that the work submitted is her own, except where work which has formed part of jointly authored publications has been included. The contribution of the candidate and the other authors to this work has been explicitly indicated below. The candidate confirms that appropriate credit has been given within the thesis where reference has been made to the work of others.

Chapter 4: “Study 1: Investigating drivers’ approaches to reducing fuel consumption: An experimental study on mental models of eco-driving” partly based on the publication: 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, Special Issue: “Technologies to support green driving”, http://dx.doi.org/10.1016/j.trc.2015.02.005

The work attributable to the candidate comprises the literature review, planning and conducting experiment, data analysis, writing, creation of graphics.

The contributions of the co-authors consisted of supervision, critique and advice during the whole process, proof-reading and commenting.

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# Abstract

Eco-driving has the potential to reduce fuel consumption and therefore emissions considerably. Previous research suggests that drivers already possess a certain level of eco-driving capability, which they do not practise in their everyday lives. The studies reported in this thesis are based on a mental models approach, which enabled an in-depth exploration of eco-driving knowledge and skills and broadened the understanding of the underlying cognitive mechanisms.

This thesis describes two driving simulator experiments aiming to measure, activate and ultimately interrupt eco-driving mental models in a variety of scenarios, relevant for safe and eco-driving. The studies used simple driving task instructions, text message interventions as well as a workload task. Changes in the participants' behaviour and thoughts were analysed with a combination of quantitative and qualitative methods.

The results suggest that drivers have mental models of eco-driving on several levels, ranging from knowledge and strategies to tactics in specific situations to automated behaviour. However, in the first experiment they did not use them when they were instructed to 'Drive normally'. In the second study text message primes and advice provided over two weeks were not able to replicate the effect of experimental instructions given directly before driving. Behavioural changes following these instructions were abandoned when performing a workload task, and not resumed afterwards.

Future research needs to consider alternative methods to prompt drivers to use their existing eco-driving knowledge and skills. Studies with a larger number of participants, and in real-world settings can then validate findings. It is suggested to expand the mental models approach into other fields such as sustainable transport in general.

# List of abbreviations

| | |
|---|---|
| AI | Artificial Intelligence |
| EDSS | Eco-Driving Support System |
| EID | Ecological Interface Design |
| MPC | Model Predictive Control |
| SDC | Satisficing Decision Theory |
| TH | Time Headway (also $T_h$) |
| TPB | Theory of Planned Behaviour |
| TTC | Time To Collision ($T_C^{-1}$ is the inverted TTC) |
| TQT | Twenty Questions Task |

# Table of Contents

# List of Tables

# List of Figures

# 1 Introduction

In 2012 road transport was responsible for almost a fifth of the total carbon dioxide ($CO_2$) emissions in the EU (European Environment Agency, 2014). It is becoming increasingly difficult to ignore the role of $CO_2$ emissions in climate change (cf. Kollmuss and Agyeman, 2002). Particularly passenger cars are responsible for the major share of the EU carbon emissions (European Commission, 2007). Besides reducing road traffic and developing hybrid and electric vehicles, eco-driving has the potential to further reduce emissions, as it promises to reduce fuel consumption and therefore $CO_2$ emissions by 5 to 10% (Barkenbus, 2010). Eco-driving is defined as a set of behaviours that drivers can practise to save fuel (Mensing et al., 2014). Effective practises include, for example, the maintenance of an efficient speed by avoiding strong acceleration and braking actions (Hof et al., 2012).

In order for eco-driving to contribute to a global reduction in $CO_2$ emissions, the way many people drive needs to be changed. These large-scale behavioural changes, however, are not easy to achieve. It has been shown that the provision of educational material does not address the problem (Delicado, 2012, Martin et al., 2012). In contrast, behavioural changes in several studies indicate that drivers already possess the required knowledge and skills to reduce their fuel consumption (Birrell et al., 2010, van der Voort et al., 2001, Waters and Laker, 1980). To date no study has investigated these existing eco-driving knowledge and skills in detail. Hence, this thesis begins with an in-depth study using a mental models approach in order to explore them from a variety of perspectives. It then investigates the problem of changing drivers' behaviour in a way that makes drivers use their available expertise, thus to activate their eco-driving mental models.

The following paragraphs draw an overview of the contents of the present thesis:

*Chapter One* sets the scene for the current thesis by describing the need to reduce $CO_2$ emissions, and the problem of changing the behaviour of the driving population. It then discusses why mental model research is suitable for exploring what drivers know about eco-driving, and why it is so difficult to encourage them to use their knowledge and skills.

*Chapter Two* begins with a discussion of environmentally friendly behaviour, its importance and impact. It then provides a literature review of behaviour change and the barriers, one of which is central to the second study in the present thesis: habits.

*Chapter Three* provides a background in mental models. It begins with a journey into philosophy, describing how Immanuel Kant and Ludwig Wittgenstein formed the way we think about human cognition. Then it outlines a number of views and approaches before introducing practical applications of the theory, and thereby leading into mental models in the driving domain.

*Chapter Four* describes the first of two studies in this thesis, an in-depth exploration into eco-driving mental models of regular drivers. This experiment used a desktop driving simulator in addition to qualitative interviews and think-aloud protocols. It showed that drivers possess mental models that enable them to reduce their fuel consumption. The problem is that they do not use their knowledge and skills to their full potential during ‘normal’, baseline driving.

*Chapter Five* describes the second study, which attempted to activate eco-driving mental models with regular primes, advice as well as simple instructions by the experimenter. This experiment was conducted with a motion-based driving simulator. Every participant was invited to two sessions, with two weeks in-between, in which the interventions took place. Eventual behaviour changes were then challenged with a workload task in order to interrupt eco-driving mental models, resulting in the drivers reverting to their usual, more familiar habits.

*Chapter Six* summarised the findings of this thesis, addressing the research questions posed at the beginning and emerging from the first study. It highlights the acquired insights into eco-driving mental models, and discusses potentially effective ways to activate them and therefore to change drivers’ behaviour.

## 1.1 Statement of the problem

### 1.1.1 Environmental issues

The share of passenger cars contributes to 12% of the overall $CO_2$ emissions in the EU (European Commission, 2007). Although manufacturers have been decreasing the $CO_2$ emissions of light-duty vehicles since 2005 (USEPA, 2011) their share of the total emissions is still rising. Besides reducing road traffic and developing greener technology, eco-driving is considered a major contributor in generating a substantial impact on $CO_2$ emissions in the transport sector.

### 1.1.2 Behaviour change

In order to achieve a considerable reduction in emissions with eco-driving, the behaviour of a large share of drivers needs to be changed. A number of programmes attempted to educate drivers. For instance, Delicado (2012) described a driving simulator designed to teach eco-driving, but it failed due to the underlying idea that such behaviour change can be achieved by mending an education gap. Martin et al. (2012) asked tested an website called EcoDrivingUSA by asking an experimental group to browse this website. A questionnaire showed that attitudes and self-reported behaviours changed for a subgroup, which was more educated and more concerned about climate change and fuel prices than the average participant. Numerous studies with training programmes provide evidence for their positive impact (e.g. af Wåhlberg, 2007, Beusen et al., 2009, Sullman et al., 2015), and several researchers recommend campaigns in order to raise the necessary awareness (Barkenbus, 2010, Chapman, 2007). In sum, eco-driving education can improve drivers' knowledge, which is a prerequisite for behaviour change, but relevant knowledge alone may not be enough to ensure that drivers use that knowledge. Similarly, addressing motivations to eco-drive can be effective, but this does not solve the problem. Recent research suggests that monetary savings may not be a sufficient motivator for people to take on the effort of practising a new driving style (Stillwater and Kurani, 2013, Tulusan et al., 2012). Some studies suggest to emphasise environmental reasons (Dogan et al., 2014), but drivers tend to rate them even lower than financial gains (Cristea et al., 2012, Harvey et al., 2013). However, the situation is not hopeless and behaviour change has been achieved by several means.

It has been shown that in-vehicle technology has the potential of attaining some behavioural change by providing continuous real-time feedback on parameters such as pedal pressure, gear or miles per gallon (e.g. Kim and Kim, 2012, Nouvelière et al., 2012, van der Voort et al., 2001).

Most studies researching eco-driving test whether an eco-driving intervention results in a reduction of fuel consumption (af Wåhlberg, 2007, Birrell et al., 2014, Boriboonsomsin et al., 2010, Graving et al., 2010, Hellström, 2005, Kamal et al., 2010). Drivers may already have some understanding of eco-driving and therefore need guidance in a different form than currently assumed (Stillwater and Kurani, 2013). Hence, there is still a need to further research drivers' actual knowledge and skills of eco-driving as well as the decision making processes that lead drivers to practise and use eco-driving techniques (Stillwater and Kurani, 2011, Stillwater and Kurani, 2013).

## 1.2 Mental models as a novel approach to study eco-driving

In this research the concept of mental models was utilised for studying eco-driving. Mental models are defined as representations of reality in people’s minds (Johnson-Laird, 1988). These representations make decisions about actions and perceptions (Schank and Abelson, 1977). They are organised on different cognitive levels and therefore range from strategic and easily accessible knowledge to rules guiding highly automated action sequences (Anderson, 1982, Rasmussen, 1983). In the present thesis it is assumed that humans possess a library of mental models in their long-term memory (cf. Johnson-Laird, 1983) and retrieve them for their use in the working memory, which is limited (Miller, 1956, Simon, 1969). The mental model approach offers a research paradigm that is different to the common quantitative and model-driven approach in driving simulator studies. Hence, it does not include standard questionnaires measuring factors that predict behaviour such as motivations to eco-drive (e.g. Dogan et al., 2014, Harvey et al., 2013), people’s awareness of environmental issues (e.g. Christie and Jarvis, 2001) and the locus of control (Hines et al., 1987). Successful approaches for behaviour change include socials norms (cf. Ajzen, 1991) and cognitive dissonance (Thøgersen, 2004). These approaches use people’s need to conform to others’ expectations as well as consistency with their self-image and can cause discomfort with regards to unsustainable behaviours. These concepts are defined and explained in the literature review in section 2.3.1, although they did not inform the design of the studies presented here. This research focusses on individual drivers, and their existing knowledge and skills, and then attempts a novel approach to induce eco-driving behaviours using primes. At the same time, studying driver distraction by using abstract tasks during driving (e.g. Chiang et al., 2001, Chisholm et al., 2007, Dingus et al., 1989, Tijerina et al., 1998), is not part of this work. Instead, in chapter 5 it was attempted to challenge the strength of activated eco-driving mental models with a workload task that was designed to be simple and natural, using findings from distraction studies to hypothesise its effects. Numerous concepts of mental models are introduced in chapter 3. Some of them are formulated in an abstract manner, similar to programming languages (e.g. Charniak, 1972, Simmons, 1972, Winograd, 1972), or created for complex problem solving (e.g. Halasz and Moran, 1983, Johnson-Laird, 1983) rather than driver behaviour. Others are visual-spatially oriented and used to understand the comprehension of texts, for example (e.g. Bower and Morrow, 1990, Graesser et al., 1994). Several studies, particularly in the health sector (e.g. de Bruin et al., 2007, Vogt and Schaefer, 2012), compare patients' with experts' mental models to identify knowledge gaps. A similar approach was utilised in the studies presented here, in which drivers were asked about their eco-driving knowledge. The replies were then compared with results from research investigating effective eco-driving techniques.

Several mental model paradigms were deemed suitable for the studying actual behaviour using a driving simulator. These include Rasmussen's skills, rules and knowledge (SRK) taxonomy (Rasmussen, 1983). The SRK taxonomy has been used to study behaviour on different cognitive levels, which drivers are able to control to differing degrees. This taxonomy is related to ecological interface design (Rasmussen and Vicente, 1989) which has been utilised in the design of eco-driving support systems (EDSS, McIlroy and Stanton, 2014, McIlroy et al., 2013). EDSS are introduced in section 2.3.4 as an example of effective means to change driving behaviour, but such systems, for example their acceptance, are not the focus of the work, besides a small number of design recommendations made at the end in chapter 6. In order to further explore instant decision-making on the rule-level during driving, a method to  measure and represent mental model boundaries was applied with 'normal' and eco-driving in chapter 4. The present thesis is the first work known to the author to explore a variety of existing mental models of eco-driving in an in-depth manner. Therefore, this research incorporates a substantial amount of quantitative and qualitative approaches.

# 2 Environmentally friendly behaviours and eco-driving

## 2.1 Introduction

Climate change is becoming an increasingly pressing problem and greenhouse gases such as carbon dioxide ($CO_2$) emissions play a major role in it (Wuebbles and Jain, 2001). In 2012 road transport accounted for 19% of the total $CO_2$ emissions in the European Union (EU, European Environment Agency, 2014). Governments have been able to tackle some of these emissions with restrictions via a plethora of means such as taxation, incentives and the provision of infrastructure for sustainable transport.

Reviewing several eco-driving studies, Barkenbus (2010) estimated that about a third of US drivers are potentially able to save 5% with an initial training and 10% with support systems. Accordingly, in order to achieve a considerable reduction in transport emissions, the behaviour of a large number of drivers needs to be actually changed. Semenza et al. (2008) argue that individual environmentally-friendly actions have the potential for substantial impact. There is a variety of behaviours individuals can practise, not only related to personal transport, but also to home energy use, consumption and waste generation.

The decrease in fuel consumption due to eco-driving is proportional to a reduction in $CO_2$ emissions, and is crucial in optimising the efficiency of electric vehicles (Knowles et al., 2012). With money-savings accruing in the long-term as well as a relaxed and safe driving style (Young et al., 2011), drivers can benefit from eco-driving. Despite the environmental and financial benefits, it is a challenge to achieve wide-ranging and long-lasting behavioural changes among the population.

This chapter begins with an overview of environmentally friendly behaviours in general and eco-driving in particular. The subsequent section is dedicated to behaviour change. One important barrier is the disconnection between attitudes towards environmentally friendly behaviour on the one hand and effective actions on the other. Another issue is the difficulty of changing ingrained habits. The chapter ends with some successful ways to change people's behaviour towards environmentally friendly behaviours and eco-driving, and possible explanations for these changes.

## 2.2 Environmentally friendly behaviours

### 2.2.1 Environmentally friendly behaviours and their impact

It is undisputed that governments and the industry have the capacity to implement actions that reduce $CO_2$ emissions substantially (Jackson, 2005). However, private individuals have the option to practise a number of behaviours that may achieve considerable reductions as well.

Widespread sustainable household behaviours include limiting energy consumption by switching off lights and appliances as well as the avoidance and recycling of waste (Semenza et al., 2008). Although many people are not convinced of the impact of their individual actions (Blake, 1999), it has been shown that private households are well capable to achieve energy savings that are substantial, even with significant effects in relation to a country's entire emissions. Dietz et al. (2009) estimated that with reasonable changes US households are able to reduce their emissions by more than 13% within 5 years. Using efficient shower heads, water heaters and other technology can make a difference without compromising living habits.

Transport-related behaviours are particularly crucial, because transport is the only sector that witnessed a rise in greenhouse gas emissions in the EU from 1990 to 2012 (European Environment Agency, 2015). Aviation, which is predicted to grow by 4.1% yearly until 2034 (International Air Transport Association, 2014), is particularly disconcerting (Chapman, 2007). Hence, changes in travel behaviours by individual households can have a large impact on emissions. Car-sharing and the use of alternative transport means have a strong potential (Dietz et al., 2009). Eco-driving is the behaviour examined in the current thesis, due to its potentially immediate effect using the current vehicle fleet. For example, in 2012 passenger cars emitted around 450 million tonnes $CO_2$ globally (Olivier et al., 2013). This means that if only 10% of the driving activity is conducted with eco-driving, and achieves a 10% reduction, a total of 4.5 million tonnes of $CO_2$ can hypothetically be avoided.

### 2.2.2 Eco-driving practises

Eco-driving is a set of behaviours that drivers can practise to save fuel and reduce emissions (Mensing et al., 2014). The first studies in eco-driving known to the author emerged during the energy crisis in 1979, when the US Department of Energy launched the Driver Energy Conservation Awareness

Training (cited in Barkenbus, 2010, DECAT, US Department of Energy (USDOE), 1980). At that time driving techniques to reduce fuel consumption were first explored (e.g. Evans, 1979, Waters and Laker, 1980). The five Golden Rules of eco-driving (Austrian Energy Agency, 2013) comprise the following practices:

- anticipation of traffic flow
- maintenance of a steady speed with a low RPM
- early gear shifts
- frequent tyre pressure checks
- additional energy requirements, for example due to air conditioning or excess vehicle load

Hof et al. (2012) provided an overview of measures that are at present considered effective. In their wider scope, they include regular vehicle maintenance, tyre pressure checks and an optimal route choice. When the vehicle and route are given, eco-driving involves maintaining a constant speed, avoiding unnecessary braking and accelerating where possible by anticipating traffic situations, using higher gears and optimal acceleration.

Mensing et al. (2014) discussed whether the prefix ‘eco’ stands for economic or ecologic driving. They found that swift accelerations to efficient speeds can be fuel-efficient, thus economic. At the same time, the high torque causes a rise in the emission of carbon monoxide and hydrocarbons. Hence, they stated that ecologic driving involves lower acceleration rates. In order to have a clear definition of ‘eco-driving’, which can be succinctly communicated to experimental participants, it was decided to place the emphasis on the aim to reduce fuel consumption during driving.

A focus on economic driving does not fully clarify what constitutes optimal acceleration. In some studies it has been found that lower acceleration rates can result in fuel reductions (Ericsson, 2001, Waters and Laker, 1980). Others suggest swift acceleration rates to an efficient speed, which is then held constant (Mensing et al., 2014, Mensing et al., 2013). In a recent study Mensing et al. (2013) modelled ‘normal’ and eco-driving on a computer. Compared to the former, they achieved a 34% reduction of fuel consumption with fast accelerations to optimal speeds, which were then maintained as much as possible. Such speed maintenance, during free-flow traffic conditions, is known as cruising. Avoiding very strong accelerations can be beneficial for fuel savings, for example by pushing the throttle not more than 50% (Johansson et al., 1999). Indeed, there is some certainty that pushing the accelerator pedal excessively is inefficient (Birrell et al., 2014, El-Shawarby et al., 2005, Ericsson, 2001, Johansson et al., 1999). Hence, it can be concluded that eco-driving involves swift, but not aggressive, accelerations to efficient speeds. Eventually, the exact effects on the fuel consumption strongly depend on the vehicle model (USEPA, 2011). Depending on the road situation as well as the available gears, choosing an optimal speed can further improve fuel savings. Samaras and Ntziachristos (1998) conducted detailed real-world measurements and concluded that efficient speeds range from 60 to 80 km/h, which would allow staying at around an urban speed limit of 40 mph (64 km/h), but suggest driving below the motorway speed limit of 70 mph (113 km/h).

It has been found that lower variations in speed can affect fuel savings positively (Mensing et al., 2014, Mensing et al., 2013). These can, amongst other means, be achieved with smooth decelerations using coasting by releasing the throttle without stepping on the brake pedal and staying in gear. Coasting is commonly used as one attempts to avoid stopping in situations such as crossings with red traffic lights (Johansson et al., 2003), and therefore a subsequent acceleration. This example signifies that anticipation is crucial to maintain a constant speed. It involves monitoring the road situation in order to prevent strong speed fluctuations. By predicting the behaviour of other road users and changes of traffic lights drivers are able to act early on. When hazards are expected, anticipatory behaviours can include accelerating at lower rates, coasting early on and generally keeping higher safety margins (Andrieu and Pierre, 2012, Delhomme et al., 2013, Johansson et al., 1999). A real-world study with electric vehicles found that eco-driving was especially effective in an urban setting, compared to rural roads and motorways. Higher fuel savings were possible due to more occasions for braking and accelerating (Knowles et al., 2012), and therefore more potential for anticipatory driving behaviours.

In most situations eco-driving can increase driving safety. Besides opting for lighter vehicles or alternative transport means, lower speeds and anticipation are beneficial practises for both safe and eco-driving (Haworth and Symmons, 2001). In trade-off situations drivers tend to prioritise safety. Dogan et al. (2011) asked drivers to eco-drive, but the participants abandoned the eco-driving goal, when the driving situation became complex. However, eco-driving can have negative implications for safety in some occasions, for example where safety margins are in conflict with the aim of maintaining a constant speed (Young et al., 2011). For instance, when traffic lights switch to amber when a driver is close to them, but it is still safe to stop, eco-driving could lead to a crossing of the junction. Similarly, during busy motorway traffic one could avoid stepping on the brake pedal by accepting shorter headways. Driving safety can be compromised by support systems as well. In a driving simulator study drivers gazed at eco-driving feedback, even in demanding conditions (Jamson et al., 2015b).

## 2.3 Behavioural change

### 2.3.1 Inducing behavioural change

Changing drivers' behaviours can have a substantial impact on $CO_2$ emissions. However, when drivers do not eco-drive, it may not be correct to assume that the underlying reason is a gap in their knowledge and skills that simply needs to be mended with education and training. Delicado (2012) exemplified this by showing how a driving simulator designed to teach eco-driving missed this goal. Different user groups driving the simulator at an exhibition misunderstood its purpose. Several people were using it as a computer game, attempting to race rather than to reduce their fuel consumption. In addition, the assumption that being sufficiently motivated to eco-drive is sufficient to attain eco-driving behaviours is obsolete. Both, reducing one's impact on the environment as well as monetary incentives are ascribed potential to change behaviour in several studies (e.g. Man et al., 2010, Syme et al., 1987). However, Harvey et al. (2013) organised focus groups and conducted a questionnaire survey in the UK and the Czech Republic, and found that only 20% of the respondents would be motivated by environmental considerations. In addition, fuel savings of an estimated £5 per week did not justify behaviour change. Hence, getting drivers to eco-drive poses a challenge for institutions, researchers and vehicle manufacturers.

A lot of research has been conducted in the field of environmentally friendly actions. Past studies based on the Theory of Planned Behaviour (TPB), discussed in section 3.2.1, used questionnaires to identify strong factors that are meant to predict such behaviours. Firstly, it is important that people are generally knowledgeable and aware of environmental issues (Hines et al., 1987, Kollmuss and Agyeman, 2002). At the same time, one needs to possess relevant knowledge and skills to take action (Abrahamse et al., 2005). It can be expected that abilities to act environmentally friendly vary in the population, but also that even a minimum level of knowledge, for example that switching off water taps and lights when they are not needed can save energy, can make an impact when it is applied (Dietz et al., 2009). Hence, motivations and capabilities are prerequisites for acting environmentally friendly, but these alone do not cause behaviour change. It is important that people have a sense of control over the outcomes of their actions. People who are convinced that, due to high levels of pollution caused by the industry as well as emerging countries, their actions do not have an impact, are less likely to act environmentally friendly (Bamberg and Möser, 2007). The belief that one is able to influence outcomes was termed internal locus of control (Hines et al., 1987). In addition, a sense of personal responsibility, positive attitudes towards the behaviours, and situational factors play a role (Hines et al., 1987). Kollmuss and Agyeman (2002) stated that personal motivation is crucial. Stern et al. (1993) suggested that the motivation for ecological action first of all stems from one's egoistic orientations such as money savings. However, the motivation may also be socially and environmentally oriented. Social factors include altruism, or 'actively caring' for the community, and are assumed to have an influence on acting selflessly (Schwartz, 1977) or ecologically (Borden and Francis, 1978).

Educational campaigns can inform, persuade and motivate people to change their behaviour (Rice and Atkin, 2002). Barkenbus (2010) as well as Cristea et al. (2012) particularly recommended the use of social norms, related to environmental impacts. Social norms define the behaviours that are acceptable in societies or groups. They are well suited for campaigns, for example by stating that other people conduct and expect certain behaviours (cf. Ajzen, 1991). Such a campaign could communicate that people similar to the addressee value the environment and regularly eco-drive. Social norms have also been successful in programmes such as promoting eco-driving within organisations. Siero et al. (1989) studied the effects of such a programme in a mail delivery organisation and concluded that the collective nature of the intervention was one reason of its success. Similarly, campaigns can challenge the self-identity of drivers (Whitmarsh and O'Neill, 2010). People tend to see themselves as being concerned with the environment (Johansson-Stenman and Martinsson, 2006). When inconsistent behaviour is pointed out, cognitive dissonance, defined as conflicting thoughts, beliefs or attitudes, can arise (Thøgersen, 2004). This cognitive dissonance can then be decreased by actually behaving more environmentally friendly. For example, someone who is buying organic food could make attempts to eco-drive.

Hendrickx and Uiterkamp (2006) discuss the effects of technology on behaviour in the choice of passenger transport. The model of relative importance of car characteristics for car type choice by Van Oijen (as cited in Hendrickx and Uiterkamp, 2006, 1996) indicates how innovations in vehicles can boost or reduce sales. Lightweight materials and alternative fuel vehicles can reduce perceived safety and lead to a decrease in sales. A reduction of cost on the other hand, can attract buyers and support innovative technologies. Tertoolen et al. (1998) argue that mode choice is influenced by similar determinants. Cars are desired, because they are convenient, fast and comfortable. They suggest that these determinants need to be increased in more sustainable transport modes, and decreased in cars, in order to change behaviour.

When it comes to eco-driving, a number of concepts have been tested, and some of these have shown some success in changing behaviour. In a questionnaire drivers rated monetary incentives higher than environmental considerations (Cristea et al., 2012). A survey among US truck drivers found a similar result, that drivers expect to be sufficiently motivated by money (Schweitzer et al., 2008). During a focus group in Australia drivers stated that financial savings would  motivate them too (Boriboonsomsin et al., 2010). However, during actual driving, eco-driving yields small savings. In addition, fleet drivers are not motivated by financial savings. Instead, environmental feedback tends to have more meaning and therefore stronger effects (Dogan et al., 2014, Harvey et al., 2013).

Feedback such as information on personal energy consumption has been shown to induce behavioural change. Seligman et al. (1981) explained the effectiveness with the teaching, rewarding and motivating functions of feedback. For example, the simple provision of fuel consumption information (af Wåhlberg, 2007) or regular meetings with collective feedback (Siero et al., 1989) can encourage drivers to eco-drive. Fuel saving advice and feedback are especially effective when provided repetitively, possibly in real-time (Hibberd et al., 2013, Stillwater and Kurani, 2013). Because learning effects can decrease over time, it might be beneficial to personalise feedback and ideally adapt it to the drivers' skills, as they become more proficient in eco-driving (Hiraoka et al., 2011, Stillwater and Kurani, 2013). Different types of eco-driving feedback are further discussed in section 2.3.4.

Once a continuous practise is maintained, new behaviours can become automated (Rasmussen, 1983). This leads to increased entropy, which can be observed and measured in more systematic, consistent and predictable actions (Boer and Goodrich, 2005).

### 2.3.2 Barriers to behavioural change

One prerequisite for environmentally friendly behaviour is the awareness of environmental issues. For many people such awareness is limited by indirect and delayed experiences of environmental destruction (Kollmuss and Agyeman, 2002). Reports based on questionnaires claim that a large proportion of the UK population carries a positive attitude towards environmentally friendly behaviours (Christie and Jarvis, 2001). However, a large-scale attitude survey found that these attitudes are not reflected in self-reported behaviour to the same extend (Christie and Jarvis, 2001). This mismatch was termed the value-action gap by Blake (1999). Kollmuss and Agyeman (2002) argued that a part of this gap can be explained with research-methodological problems. When attitudes and behaviours are measured in surveys, but the predicted behaviours are not verified later, a mismatch is likely. However, there are numerous personal barriers that prevent people from acting environmentally friendly. Kollmuss and Agyeman (2002) emphasised that such behaviours are influenced normatively by the society, by demographic, economic, and also internal and psychological factors.

Paul Stern (2000) distinguished intend- and impact-oriented behaviour, explaining that good intention alone does not necessarily lead to the most effective actions. Only a small proportion of people are actually performing actions with a substantial impact in mitigating climate change (Whitmarsh, 2009). The actions taken are often the actions that are convenient, such as recycling, or cost saving. Sustainable travel behaviours, which are considered impact-oriented actions (Chapman, 2007), are often difficult to incorporate into daily lives. Many people tend to overestimate one's actions towards mitigating climate change, while underestimating negative impacts through car use, for example (Whitmarsh, 2009). Eco-driving is one feasible means to act environmentally friendly, because of its cost-saving potential, without drastically compromising on travel time or safety. The downside is that drivers might have the impression they strongly contribute to the mitigation of climate change and therefore either drive more or neglect other impact-oriented actions (Vlek and Steg, 2007).

An external locus of control, the sense that one's actions do not have an impact in the grand scheme of things, is another common barrier (Blake, 1999). Hence, it is understandable that comparing one's potential fuel savings within the global vehicle fleet can demotivate. Flynn et al. (2009) added a perceived lack of agency and responsibility of others. Even when the right attitudes and knowledge are present, Flynn et al. (2009) stated that situational factors, a reluctance for change and ingrained lifestyles, related to one's energy use behaviour, are major culprits in behaviour change.

Behavioural changes towards environmentally friendly actions are particularly difficult when it comes to personal car-use. Cars are linked to one's status (Johansson-Stenman and Martinsson, 2006), and changes in travel habits can signify particular efforts and sacrifices (Stradling et al., 2008). Apart from changing transport modes and driving less, getting people to eco-drive is a challenge. The horsepower of cars has increased since the early 1980s (Alson et al., 2014). Barkenbus (2010) argued that cars are often marketed communicating powerful engines and their ability to accelerate quickly and achieve high speeds, which contrasts the principles of eco-driving. The fun and comfort of travelling fast on motorways adds to the problem. A study by Harvey et al. (2013) involving focus groups and questionnaires revealed that the perceived costs of eco-driving can outweigh the rather small monetary benefits. One of these 'costs' is the threat of increased travel time. There are further studies showing that people expect eco-driving techniques to make them drive more slowly and to lose time (Dogan et al., 2011, van der Voort et al., 2001, Waters and Laker, 1980). However, in experiments where participants were guided by feedback devices time losses were either low or not present at all (Birrell et al., 2010, van der Voort et al., 2001). Such results exemplify how gaps in the knowledge and skills can present a barrier to eco-driving.

### 2.3.3 Long-term behavioural change

Changing behaviour in the long-term poses a particular challenge, especially with regards to habitual behaviour. Habits are practised repeatedly without deliberation (Goldenbeld et al., 2000) and are therefore relatively automated (Rasmussen, 1983). Although people can have access to information, and possess the knowledge enabling them to perform desired actions, automated habits can cause them to ignore information that is in conflict with ingrained behaviours (Nisbett and Ross, 1980). For example, the diminishing effects following an eco-driving course indicate their failure over time. A reversion to ‘normal’ driving has been shown with fuel consumption data (af Wåhlberg, 2007) as well as acceleration rates and idling time (Beusen et al., 2009). Drivers, who use a support system and then discontinue it, tend to return to old behaviours soon (van der Voort et al., 2001). It is possible that such systems need to be tested over a long time period before achieving learning or behavioural change effects (Jamson et al., 2015b). However, social norms and expectations, particularly when an individual is motivated to comply, can create enough pressure to break old habits (Ajzen, 1991).

Approaches to change behaviour need to be sustainable. This means they are ideally both cost-efficient and effective in the long-term. Detailed and continuous feedback can change behaviour sustainably, because they form new behaviours with reinforcement, as studies with household energy consumption have shown (e.g. Seligman et al., 1981). Similar studies have found that positively phrased messages can be particularly effective (Fischer, 2008). However, it might not be ideal to continue providing the same kind of feedback for a long time. Van der Voort et al. (2001) suggested giving more detailed advice to novice drivers while reducing the amount of information presented to experienced drivers. They reasoned that experienced drivers would become annoyed by unhelpful information. Conversely, a system developed by Wada et al. (2011) increases the difficulty level when drivers' eco-driving skills improve. The ecoDriver project (Hibberd et al., 2013) involved a study with prolonged exposures, of about 12 minutes for each condition, to visual and haptic EDSS in a driving simulator. The study found that haptic pedals were superior over visual systems in subjective criteria such as workload, usefulness and satisfaction.

Successful behaviour change over time can result in altered habits. Paul Fitts (1964) described the formation of new habits in three stages. John Anderson (1982) summarised them as a declarative stage, where new information challenges old patterns, followed by a knowledge compilation stage, where a new set of behaviours is practised for the first time. Lastly the new habit is automated in the procedural stage. Hence, habits become stronger with the frequency of their practise and therefore the frequency, relevance and strength of their reinforcement. However, there is a risk that behaviours are too strongly reinforced, which can result in people justifying unsustainable actions instead. Instead of changing behaviours, they adjust their goals, which can even lead to giving up on environmentally friendly actions altogether.

### 2.3.4 The effects of eco-driving campaigns and support systems

In order to encourage drivers to eco-drive, a number of different approaches have been successful. It is known that education, altered road design as well as in-vehicle messages can change habitual driving behaviour (Hof, 2008). Barkenbus (2010), for example, advocates public campaigns, because they have the potential to create awareness. This awareness can affect well-planned, conscious decisions such as the purchase of a new car (Chapman, 2007). When campaigns use social norms, they are even able to overcome habits, and convince drivers of eco-driving (Cristea et al., 2012). Public education campaigns increase awareness and can partly change behaviour. Martin et al. (2012) show how the EcoDrivingUSA website helped to change self-reported driving habits of a subset of their experimental group. The sub-group is on average more educated and wealthy, as well as more concerned about climate change and fuel prices. It seems that these people already have a raw or a hidden eco-driving mental model in place, which can be completed, enhanced or brought into use with education. Simply asking people can be effective in the short-term. In an experiment by Waters and Laker (1980) a convenience sample was asked 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. This result indicates that drivers have mental models of eco-driving that could be brought to use by prompting them.

Hof et al. (2012) reviewed the latest developments in eco-driving support systems (EDSS). Several car manufacturers have created their own technologies. In the same time navigation systems were extended and applications for other nomadic devices were programmed. On the market one can find among others pre-trip route planning systems, which optimise driving conditions with regards to road types and traffic. During driving in-vehicle systems provide visual, audio and haptic feedback. For example, Birrell et al. (2010) developed a haptic eco-driving pedal, which vibrates when the throttle is pressed beyond 50%. Post-trip systems inform about past eco-driving performance. The system of the Trafisafe project provided safety and eco-driving scores and compared the drivers' performance with their peers (Tarkiainen et al., 2014). A considerable amount of literature has been published on user acceptance across these technologies. With a large-scale survey across Europe Trommer et al. (2012) investigated the perceived usefulness (Davis, 1989), the perceived impact on fuel consumption and the environment, and the willingness to pay for different categories of EDSS. All categories, pre-, in- and post-trip systems, were rated as useful. However, the personal benefits of trip-planning systems were not rated as high. This lower rating can be explained with longer travel times and general distrust in its recommendations, which were given without explanation. In addition, drivers tend to prefer systems that benefit them individually over systems that optimise the broader traffic situation (Risto and Martens, 2013).

Regarding feedback systems, drivers tend to prefer clear, visual interfaces (Fors et al., 2015), and systems that communicate the rate of the required change (Jamson et al., 2015a). Studies about haptic pedals yielded mixed results, regarding their acceptance (Fors et al., 2015, Hibberd et al., 2015), efficiency and clarity (Jamson et al., 2015b, Päätalo et al., 2001). One study investigated a force feedback system assisting accelerations by communicating the ideal position with an abrupt increase in the force applied against the accelerator pedal. It showed that such a pedal system is both effective and easily understood (Jamson et al., 2015a). Drivers tend to prefer suggestive feedback over invasive interventions. One type of invasive system was tested by Nozaki et al. (2012). It controlled the fuel injection, changed the reaction of the gas pedal and stopped the engine when the vehicle was not moving. Their indirect system communicated real-time feedback with the purpose of changing the driver’s behaviour. Both EDSS significantly improved fuel consumption, while the participants reported that they would rather engage with and conform to suggestions. During the study the feedback system was superior, as the drivers invested active effort and improved their proficiency. It allowed them to practice by trial and error, so they became conscious and active drivers. EDSS that communicate with the driver instead of manipulating the vehicle encourage the driver to participate, expend more effort and ultimately improve their skills.

Adapting to the driver’s eco-driving proficiency (Jamson et al., 2015b, Wada et al., 2011) or making it obvious where the driver is standing in relation to their goal (Stillwater and Kurani, 2013) can further improve fuel savings, acceptance of the technology and interest in eco-driving. Nouvelière et al. (2012) created eco-driving algorithms for a visual EDSS. The algorithms optimise speed and gear, while taking safety limits into account. A simulation clearly showed improvements in economical and safety terms. An EDSS prototype was then tested in an experiment with a Renault Clio Eco2 on a test track, with and without preceding vehicles. With the EDSS the drivers managed to improve safety and to increase fuel efficiency between 1.6%

and 12.9%, compared to driving with eco-driving instructions only. Kim and Kim (2012) as well as Jamson et al. (2015a) found that auditory feedback can aid a visual device even more in achieving a fuel-efficient driving style.

Feedback systems have limitations. For instance, it is not always clear to drivers which actions are most effective in improving their eco-driving scores (Man et al., 2010). A miles per gallon measure alone can be misleading, because it does not take kinetic energy into account and therefore encourages suboptimal acceleration and deceleration (Stillwater, 2011). In addition, a feedback system can annoy and distract drivers, for instance with auditory signals or too much information (Fors et al., 2015, Jamson et al., 2015b). Distraction may however lessen with practise (Rouzikhah et al., 2013). Lee et al. (2011) demonstrate how drivers' satisfaction with an in-car eco-drive system changes over time. At the beginning, the satisfaction is high due to high expectations, but soon users developed some frustration with the system's constant suggestions. Later they get used to the way the system works and the satisfaction levels improve. Competitive gaming systems such as post-trip comparisons can be problematic, especially when rankings with other drivers are involved. By definition this approach allows a subgroup of drivers to 'win'. Those who find themselves in the mid- and lower ranks could be discouraged from exerting further effort (Venables and Fairclough, 2009).

In several studies it remained unclear which behavioural changes are due to the system's communication and which are due to the driver's eco-driving proficiency triggered by the system or experimental situation (Birrell et al., 2014, Tarkiainen et al., 2014). A control condition in which participants are asked to eco-drive without any feedback has been effective in accounting for these unwanted effects (van der Voort et al., 2001).

Tulusan et al. (2012) show that corporate drivers using an eco-drive application for mobile phones reduce their fuel consumption by 3.23%, even though they do not receive any tangible incentives. Generally, there is little agreement about the effectiveness of money savings as a motivator to drive fuel-efficiently. In a large-scale survey Man et al. (2010) found that information about money savings are the biggest motivator for drivers to change their behaviour, followed by information about fuel consumption and at least information about the impact on the environment. In contrast, with a qualitative study using feedback devices in hybrid cars Stillwater and Kurani (2013) suggest that these savings are not motivating actual behaviour changes. Participants in their study found cost related feedback simply informative and a few were surprised how cheap a trip with a hybrid vehicle was in fact. Information about miles per gallons coupled with personalised goals had a much stronger effect on eco-driving. It seems that money is initially a high motivator and is mentioned in people's intentions and plans (cf. Boriboonsomsin et al., 2010). However, when it comes to driving with feedback devices the goal to simply decrease fuel usage in order to achieve better scores and emit less greenhouse gases seem to be a stronger actual motivators for behavioural change.

## 2.4 Summary and conclusions

In summary, eco-driving is one means to behave in an environmentally friendly manner, and to contribute towards the mitigation of climate change, with a minimum of lifestyle changes and the potential for accruing considerable cost savings over time. In order to achieve substantial reductions in greenhouse gas emissions, the behaviour of a large proportion of the driving population needs to be changed. The behaviour change is neither a simple matter of providing education nor relying on monetary incentives. Neither does the prospect of behaving in an environmentally friendly way encourage people enough to practise eco-driving. On the other hand, feedback has been shown to be able to change behaviour, at least for the duration it is provided. These conflicting findings suggest that there is a need for more knowledge about drivers' cognition. Mental models are a way to gain further insights into drivers' knowledge and skills regarding eco-driving and may shed more light into the reasons eco-driving is not practised, and into possible ways to overcome the barriers.

# 3 Mental models

## 3.1 Introduction

In a case study by Delicado (2012) a driving simulator was designed for teaching eco-driving. The underlying assumption was that drivers do not know how to eco-drive, which needs to be mended. The success of the educational simulator was limited. Firstly, it has been shown that the 'right' knowledge and attitudes do not result in the according action (Flynn et al., 2009). In fact, there is evidence that motorists know more about reducing fuel consumption than they are given credit for (Delicado, 2012). The current research aspired to explore drivers' actual understanding and practise of eco-driving by employing a mental models approach. It was designed to measure and later activate existing eco-driving mental models, without focussing on goals and motivations. By regarding eco-driving mental models in detail, the research extended beyond the stimulus-response paradigm, which views the human as a 'black box'. Mental models are defined as representations of reality (Johnson-Laird, 1988), which are stored in people's minds. They are retrieved in every-day life, as they are needed, to direct people's perceptions and actions (Schank and Abelson, 1977). Mental models have been used in the fields of education (Anderson, 1982), logical reasoning and robotic (Johnson-Laird, 1988) as well as user-friendly design (Norman, 1983).

The research reported here is not intended to supplement the mental model literature with new theory. Instead, mental model theory is used as a tool to study drivers' cognition and behaviour. The purpose of this chapter is the provision of an overview of mental model research and a discussion of its suitability for studying eco-driving. Section 3.2.1 begins with its history, as philosophers began to form ideas of mental models in the 18$^{th}$ century. Then mental models are defined, with reference to different approaches, and scoped for the current research. Subsequently it is explained how mental models function, and then how they are constructed and refined. The background section concludes with an overview of how mental models have been utilised in research, education and communication, as well as in engineering. Section 3.5.4 concentrates on examples of how mental models have been researched in the driving domain to demonstrate that they can be a usable tool in understanding eco-driving. In order to create a complete picture, the varied perspectives and approaches in the literature were reviewed to select the approaches that are suitable for the present thesis. People do not have physical mental models stored in their brains, and neither are the neurological mechanisms parts of this work. Hence, in this work the concept of mental models does not claim to be the true way the human brain works. Rather, mental models are understood as a construct that is useful for researching and understanding human behaviour and thoughts.

## 3.2 What are mental models?

### 3.2.1 History and philosophy

Until the 18th century there had been a long-standing argument between two sides of philosophers about the way human beings gain knowledge. The rationalists on the one hand included notable names such as René Descartes, Gottfried Wilhelm Leibniz and Baruch Spinoza. They explained knowledge via deduction, which is the generation of conclusions based on premises. For them, reason is the sole source of knowledge. The empiricists on the other hand, including John Locke and David Hume, assumed that human beings experience reality unfiltered, as it is. They were thought to update their knowledge directly with the information available to them. At the end of the 18th century the philosopher Immanuel Kant combined these ideas in his major work ‘Critique of Pure Reason’ (Kant and Erdmann, 1884), and introduced the concept of schemata (p. 177/142). According to Kant humans neither purely deduct their knowledge nor do they completely rely on reality (p.26/45). Instead, schemata serve as the link between stored concepts and reality (p. 185/147). They guide and filter perceptions. This means that people do not directly perceive the world around them. The idea that schemata are placed between reality and the conscious mind became the predecessor of the concept of mental models (Johnson-Laird, 1983, p. 189f.).

Ludwig Wittgenstein (1953) further elaborated on the philosophy of human minds, showing how human beings need to create sample representations in their minds in order to understand the world. He exemplified his arguments by attempting to create an exact definition of the term ‘game’ (p. 31ff.) He began by asserting that games are competitive, but he soon found examples of non-competitive, playful games, such as a child bouncing a ball against a wall. Then he stated that games are generally rule-bound, but then discovered that some games evolve around improvisation. Arriving at a universal definition was deemed impossible. Instead Wittgenstein argued that it is more natural for a person to think in examples of typical games. Wittgenstein's thoughts about colour further clarify this idea (p. 28). For most people it is easy to imagine and even to agree with each other on a typical shade of red. However, setting firm boundaries defining the colour red is much more difficult and individual.

Mental models, originating from philosophy, entered the field of psychology later with the psychologist Philip N. Johnson-Laird. Before the 19$^{th}$ century, psychology was part of philosophy and considered a domain of the church (Brett, 1921, Robinson, 1995). Especially in medieval times, psychology was closely linked to theology and was concerned with the soul. Research was based on philosophical reflections of individuals rather than empirical and quantitative research (Brett, 1921). In 1879 Wilhelm Wundt founded a laboratory for psychological research in Leipzig (Smith, 1982) and psychology was first considered an independent field of study suitable for both introspection and experimental research. With the latter, Watson (1963) argued, Brett provided a quantitative dimension to Kant's schemata. Johnson-Laird based his notion of mental models strongly on Kant's work (Johnson-Laird, 1983, p. 189f.), and, accordingly, defined them as internal representations of reality (1988). Since then, mental models have been applied in different fields of psychology such as psychiatry and psychoanalytics (e.g. Lombardi, 2003, Stern et al., 1998) and experimental psychology (e.g. Anderson et al., 2004, de Boer and Badke-Schaub, 2013, Georgeon et al., 2007).

Mental models have been used to understand human cognition. In the field of artificial intelligence (AI) it was also attempted to replicate its processes. AI is defined as "the science and engineering of making intelligent machines" (McCarthy, 2007), and is a way to make mental models explicit in programming language. In the 1970s computer-simulated functions such as the understanding of language (Charniak, 1972, Simmons, 1972, Winograd, 1972) were based on mental models. Today there is a renewed interest in AI, for example in computer vision, expert systems and classification in domains such as fraud detection (McCarthy, 2007). Mental models have also been studied from the perspective of users. Mental models represent their knowledge of a technology, system or process (Norman, 1983, Rasmussen, 1983), and the degree of learning (Boer and Goodrich, 2005).

It is important to distinguish mental models from other common psychological paradigms such as the Theory of Planned Behaviour (TPB, Ajzen, 1991) and theories derived from it. The TPB predicts behaviour, in particular the intention to perform this behaviour, with beliefs, attitudes and perceived control over it. Accordingly, behavioural change is initiated by changing the predicting factors. It is then expected that the change occurs at the next opportunity (Ajzen, 2002). In contrast, mental models allow a more subtle approach. For example, section 3.4.3 illustrates how behaviour can be altered by activating mental models with simple experimental instructions.

The current mental model theory extends into diverse fields and is accompanied by a variety of understandings and definitions. The following section gives an overview of definitions, from history until today, and conceptualises the mental model approach used in this study.

### 3.2.2 Definitions

Kant, Wittgenstein and Johnson-Laird set the groundwork for mental model research. Ludwig Wittgenstein (1953) created the idea that the human mind incorporates a storage of sample representations of the world. Johnson-Laird, the originator of the mental model theory as it is presently understood, based his notion of mental models strongly on Kant's work (Johnson-Laird, 1983, p. 189f.). Following up on his and on Wittgenstein's ideas, he referred to a schema as "a *single representative sample*" (1983, p. 264) of a real entity. The idea that humans store representative schemas of the world, which guide their perceptions and actions, is central to the understanding in the current research.

Human beings store mental models of many aspects of the world, including objects, situations and events, but also sequences of events and actions (Garnham, 1997, Johnson-Laird, 1983, Rumelhart, 1980). According to Merrill (2000) mental models are also referred to as 'schema', 'frame' (Minsky, 1974), 'production' (Anderson, 1982, Newell, 1973) and 'script' (Schank and Abelson, 1977). These terms do not always mean exactly the same, nor are they applied in the same domain, and many authors do not even agree on the definition of one single term.

It is assumed that the representations that people create, store and communicate are first and foremost practical. Hence, mental models are stereotypical and not necessarily exact (Putnam, 1975). Johnson-Laird (1983, p. 264) clarified that mental models can be typical examples of situations. Humans tend to apply well-known mental models to new, but similar situations (Moray, 1987). Mental models vary in their degree of correctness and abstraction. In fact, mental models are usually not very elaborate and often naïve (Johnson-Laird, 1988). For example, Norman (1983) found that many people carry naïve mental models of calculators, which result in the performance of unnecessary actions such as clearing the calculator’s memory several times. Even mature mental models do not necessary match reality closely. Instead, in line with Kant’s philosophy, mental models are understood as a compromise (Johnson-Laird, 1983, Johnson-Laird and Byrne, 1991). Therefore they are not meant to fully represent reality, but to provide a link between assertions about the world and the world itself (Johnson-Laird, 1983, p. 437). Brunswik (1934) agreed on the assertion that humans do not perceive the world as it is. His understanding of mental models was less logical and mechanical, but more visual-spatial and descriptive. His examples employ landscape sceneries and cities. He stated that humans build their mental models based on probabilistic cues. For examples, a mental model of a city can include a probability for the city to have a football team in the national league (Brunswik, 1956).

Johnson-Laird (1983) used mental models in the domain of logical problem solving. He defined a mental model as an internal representation that is consistent with the problem’s assertions. He provided an example, expressing such assertions as “All scientists are sceptics” and “There may be sceptics who are not scientists”. Johnson-Laird stated that persons and objects represented in the mental model should "occur in the real world with the same properties and the same relations holding between them" (Johnson-Laird, 1983, p. 441). Minsky (1974), who referred to mental models as frames, described them as remembered frameworks, which match reality to a certain degree. However, they may only be receptive to certain types of values and create their own default values, if necessary, for example based on similar experiences from the past.

Dijk and Kintsch (1983) established the concept of situation models in the field of text and language comprehension. They viewed situation models as mental models of a specific situation, whereas mental models were considered more generic. In more abstract terms, Zwaan and Radvansky (1998) defined situation models as "integrated mental representations of a described state of affairs". A situation model is the representation of events, persons, actions and situations within a text. It extends beyond syntax, semantics and single sentences. Like mental models, they are neither guaranteed to be successful nor unique and can potentially be disconfirmed at a later point in time. A situation model is based on both, the current text and existing knowledge (Graesser et al., 1994). The model is aligned with the reader's goal, and aims to be coherent in local text chunks as well as the global level of the text. However, as the reader is searching for meaning, they often use more or less naive theories about the story’s plot. They create inferences, which are conclusions resulting from several premises by the process of reasoning (Collins English Dictionary, 2015). Common inferences are related to superordinate goals of the characters, causal antecedents that state why certain actions, events and states are mentioned in the text and global thematic inferences that convey a major message of the text, for example.

Mental models can also represent visual geometrical aspects of the world, such as a lake, including attributes such as its beauty, or its surrounding area, for example depicted as a 2-dimensional image (Brunswik, 1934) with objects positioned adjacent to each other (Johnson-Laird, 1988). Bower and Morrow (1990), referring to mental models of texts, asserted that a spatial mental model can contain characters and objects as well as their location in the scene as well as non-geometric aspects such as goals, actions and events, and is therefore more than a simple image. Hence, besides spatial relations such a mental model includes connections between elements of the text, the real and imaginary worlds, and existing knowledge such as expertise in related areas.

Rumelhart (1980) elaborated on mental models of action sequences as he researched what humans understand while reading a text. Schank and Abelson (1977) introduced the concept of scripts, which are similar to mental models, but with a different structure of the memory (Garnham, 1997). This is to say, scripts are an episodic series of actions related to a situational context. Schank and Abelson (1977) described an example with a person walking into a restaurant, ordering, eating and paying. This is a simple, stereotyped sequence of actions. The following sequence, a person walking in the street, thinking about cabbage and then picking up a shoe horn, does not make sense to most people, because they do not have a suitable script stored in their memory. Such an example of an action sequence is displayed in Figure 1. Walking into a restaurant, ordering a meal, eating, paying and leaving is a typical action sequence. Each time this sequence is gone through in a person’s every-day life, the mental model is recognised, retrieved and its variables are filled, for example with the location of the actual restaurant and the menu currently on display. In a narrative, for example, parts of such an action sequence can be automatically assumed. If such a story involves a couple walking into a restaurant and later leaving it, it may not be necessary to mention that they pay for their meals before leaving. Radvansky and Zacks (1997) distinguished between mental models representing static situations, also termed the state-of-affairs model, as well as mental models of dynamic, evolving situations, a course-of-event model.

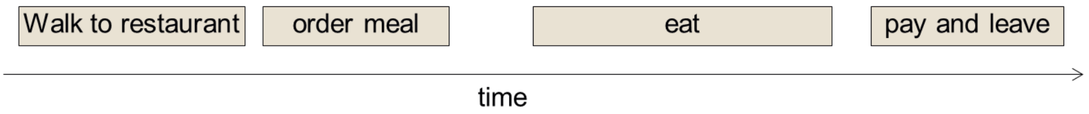


**Figure 1: Time line with action sequence, adapted from Schank and Abelson (1977)[1]**

Besides understanding action sequences in texts, mental models of ‘doing’ actions have been represented by Takahashi and Kuroda (1996) as production rules with IF-THEN clauses. The IF-conditions represent the boundaries of the resulting behaviours. As an example, a driver of a car can have the rule ‘IF current gear = 5 and speed < 40 kmh THEN I change to 4$^{th}$ gear’. Driving at a higher speed in 5$^{th}$ gear, the boundary that marks a change to the 4$^{th}$ gear is 40 kmh. Such boundaries of mental models are further elaborated on in section 3.5.5. The ACT-R theory of John Anderson (2004) is based on mental models with a similar production concept also formulated with IF-THEN rules. He (1982) developed a framework for skill acquisition that includes 2 major stages in the development of a cognitive skill, a declarative and a procedural stage. In the declarative stage facts about the skill domain are interpreted on a conscious level and in the procedural stage the domain knowledge is automated and embodied in procedures for performing the skill.

Rasmussen (1983) created a taxonomy of mental models, grouping them into a hierarchy of three levels, which are knowledge-, rule- and skill-based. The knowledge-based level is the most conscious level, where humans

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reason and plan their actions according to their goals. On the rule-based level action sequences are carried out, similar to steps set out in a cooking book. These routines are based on explicit know-how and can be consciously controlled. Because humans are able to adjust their behaviour, mental models on the rule-based level are not equivalent to rules. Well-learned, automated behaviour is attributed to the skill-based level, where individual actions cannot be consciously controlled. Figure 3 depicts Rasmussen’s hierarchy, and the mechanisms are further explained in section 3.3.1.

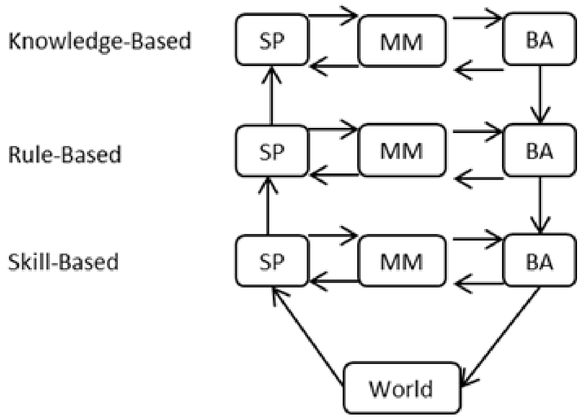


**Figure 2: Communication and Control with a Society of Mental Model Agents. SP = Sensor Perception, MM = Mental Model, BA = Behaviour Actuation © 1998 IEEE (Goodrich and Boer, 1998)**

Some scientists view mental models as social rather than individual constructs (Hutchins, 1995, Lynam et al., 2012, Pianelli et al., 2007). This concept is known as social representations, and was first described by Serge Moscovici (1961) and then extended by Jean-Claude Abric (1987). In contrast to mental models social representations encompass groups and communities and thus exist beyond the mind of an individual. Social representations serve two functions, providing a societal order and enabling communication and behaviour in groups. Looking into human behaviour in collaboration with each other and with artefacts in the environment Hutchins (1995) investigated internal representations in the field of navigation. He did not support the idea that humans have internal representations of a large part of the environment they are working with. Especially when humans intensively interact with it they simply do not need them, as is the case in navigation. However, experienced navigators make fewer errors than novices. A reason could be that experienced navigators have more knowledge about processing and coordinating different representations. Because the focus of the research reported here is put on the understanding the minds of individuals, mental models are seen as individual. This view is underpinned by the individual nature of the driving task and the diversity of the participants in the experiments.

Mental models are applied in the health sector, where it can be beneficial to identify discrepancies between expert and patient mental models. Vogt and Schaefer (2012) represented mental models of medication using complex diagrams. These grouped conditions into categories such as benefits, typical side effects and severe health risks. This method has the inherent assumption that expert mental models are the correct mental models and differences to the patients' mental models signify knowledge gaps in the latter. This normative approach can be problematic, because the experts' models, as seen in public health advice (Shai et al., 2008), can be incorrect and incomplete.

In sum, there is a variety of definitions of mental models, and the most relevant of them are compiled into a workable definition for this research. Mental models are defined as representations of reality (Johnson-Laird, 1988), which are stored in people's long-term memory. These representations do not have to be correct, and can be stereotypical, simple and inexact. Michon and Rasmussen provided the bases for a hierarchy of mental models (Michon, 1985, Rasmussen, 1983), describing how mental models represent goals, strategies and knowledge on the highest levels, and make decisions on the tactical or rule-based level in order to activate behaviours. Mental models by Goodrich and Boer (2003), based on Rasmussen's taxonomy, show how drivers activate and deactivate a skill. For this work it is not discussed whether and where mental models physically exist in the human brain. Instead, they are a concept, used to approach driver behaviour, and especially eco-driving in the studies in the current research. Mental models are different from psychological paradigms such as the stimulus-response mechanism, regarding humans as black box. Mental model theory can be linked to an economic view of human beings aiming at maximising their utility functions, or, as understood in SDT, to find an acceptable combination of positive and negative utilities. Some researchers state that mental models can be linked to emotions (Heijs, 2006), such as anxiety acquired during frightening experiences, which can then further influence behaviour. However, in this work emotions are not regarded. The focus is limited to the cognitive aspect of an individual's knowledge and skills.

## 3.3 Cognitive processes

### 3.3.1 Operation and functions

It is understood that mental models function in certain ways and a lot of literature refers to the ideas of Johnson-Laird (1983). In essence, it is assumed that humans possess a library of mental models. As people perceive information, a matching mental model is retrieved and fed with the variables of the current situation. If no matching mental model is found, a new one needs to be built. The creation of a new mental model is described further in section 3.4.1. If the new information is matching an existing mental model, the latter is retrieved from the memory and instantiated. An instantiation is defined as the creation of a concrete example of an abstract, general or universal entity (Collins English Dictionary, 2015). For example, when a dog is encountered, a mental model for 'dog' can be instantiated with some of the particular dog's features, such as its bread, height and temperament. Some researchers assume that mental models are created, or in programming terms 'compiled', for any new situation (e.g. Greeno, 1989, Lynam et al., 2012, Smith and Semin, 2004). However, due to the limited processing capacity of the human mind, it is understood that mental models are sufficiently abstract to be re-used. Therefore the idea of compilations for any new situation is not adopted for the present thesis. Instead, it is assumed that the mental models are stored as readily compiled versions that are somewhat generic for the type of situation. When a matching situation is encountered, the relevant mental is retrieved and instantiated with the current situational variables before use (cf. Anderson et al., 2004, Johnson-Laird, 1988).

An instantiated mental model then guides further perceptions, for instance, to gauge a dog's conduct. It guides which features are evaluated and interpreted (Brunswik, 1956) and then determines actions accordingly (Schank and Abelson, 1977), e.g. whether to stroke the dog or not. These actions are typically oriented towards higher-level mental models, including goals, which are located on the knowledge-level in Rasmussen's hierarchy (1983). The reasons behind these goals can be experiences from previous actions, their causes and restrictions in the physical environment. This means that humans select their goals and subsequently adjust their actions according to these goals. Goals control actions in unfamiliar environments and provide some orientation in more familiar settings. In this way mental models help humans to cope with complexity, and some mental models can take the form of rules. Nevertheless, humans are expected to be able to override knowledge- and rule-based mental models. The more mental models are available to the human, the more efficient the coping with different situations will be, and, for example in the case of text comprehension, the better the understanding across different scenes and episodes (Zwaan and Radvansky, 1998).

Kieras and Bovair (1984) have shown that people who have a more exact mental model of a control device perform better in its operation. Correct mental models also allow the transfer of one's skills from one system to another (Gentner and Schumacher, 1986). Halasz and Moran (1983) tested two groups of people with tasks involving a calculator. One of these groups was taught the way the calculator works, its internal mechanics. Then both groups practised routine problems. Afterwards, the participants were asked to solve routine and complex problems. Both groups were able to solve the routine tasks equally well using skilled methods, corresponding to lower-level mental models. The group that had learned the underlying model of the calculator was better able to solve novel problems. Interestingly, some members of the naïve group used a simple, but effective algorithm. They entered the commands into the calculator, as they appeared in the problem. However, the participants with the calculator's mental model did not use this algorithm. They were able to benefit from the stack algorithm of the calculators, especially for the most complex problems. These results show that correct mental models can be useful in operating a device such as a calculator, but also that naïve users may develop effective strategies as well.

Johnson-Laird (1988) stated that mental models are naïve and stereotypical in order to be employable for the working memory. Baddeley (1992) defined the working memory as a "system that temporarily stores information as part of the performance of complex cognitive tasks". It stores the information from the long-term memory and perceived information that is needed to complete the current task. The problem is that its capacity is limited (Miller, 1956, Simon, 1969). Hence, it is unable to host overly complex mental models. As an example of a serviceable mental model, a spatial diagram of the Common Room in the Institute for Transport Studies (ITS) was drawn by the author from memory without having another look at this room, as displayed in Figure 3. The room was used by the author on most workdays for several months. However, as the comparison to a photo shows, the drawing does not match reality well. Instead of the large table in the drawing there are two small tables in the room and details about the coffee corner as well as the recycle bins were hardly remembered. This mental model appeared to be sufficient for the author’s use of the room, and the omitted details were either unnecessary or very ingrained in her mental model.

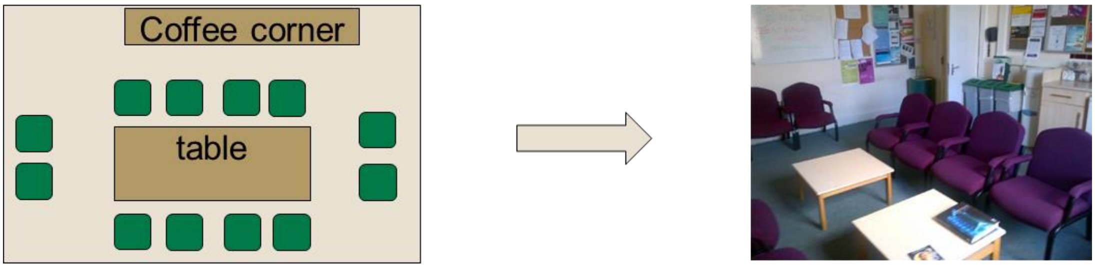


**Figure 3: Mental Model of the ITS Common Room**

The exercise of drawing the ITS Common Room was conducted twice with a group of fellow postgraduate research students, 6 at the first and 5 at the second session, with a few weeks in-between. At the beginning of a session the participants were handed empty sheets of paper and pens. Then they were simply asked to draw the aforementioned room, on their own, within a few minutes. They were also instructed to avoid talking, to prevent the students from influencing each other. One participant brought his young son to the first session. During the exercise the boy asked which room was meant and subsequently exclaimed “It is the room with the books!”

The resulting drawings provide varying degrees of detail. A simpler one was drawn from a bird’s eye view with labelled boxes, see Figure 4. A more complex drawing depicts the room from the point of view of a human who just stepped into the room, with a skilfully crafted interior, and appears to peer through a window at a tree. Two of the 6 images created during the first session include a charity book box on one of the tables, and 2 explicitly include a bookshelf at the wall. None of the drawings from the second session includes the charity book box, and only one clearly shows the bookshelf.


**Figure 4: Two drawings of the ITS Common Room**

In sum, the exercises indicate that visual-spatial mental models of the same room can vary strongly across different people, particularly in their degree of detail, abstraction and correctness. The boy’s mention of ‘books’ appeared to have activated some detail within the room’s mental models, although 2 students remembered a book box and 2 others a book shelf.

The relationship between mental models and actual behaviour is not coherent in the literature. Bellet and Tattegrain-Veste (1999) conceptualised mental models as a framework of knowledge that is communicating with a different part of the brain that is actuating behaviour. Other theories view mental models as directly controlling behaviour including fine-tuned and automated actions (Anderson et al., 2004, Rasmussen, 1983). The assumption for the research presented here is in line with the latter. Mental models determine both the higher level and also the very detailed, automated, behaviours. Therefore mental models make all the behavioural decisions of human beings. In the driving domain a lot of the mental models research relies on the hierarchy of behaviours by Rasmussen (1983) and Michon (1985). Michon divided the driving task into the three hierarchical levels as depicted in Figure 5, which roughly correspond to the knowledge, rule and skill levels by Rasmussen. These are the strategic, tactical level and the operational level. The strategic level is dedicated to well-thought through actions and planning, the tactical level is concerned with the manoeuvring of the car and the operational level ensures its control. Control tasks can then be performed while the driver has sufficient cognitive resources for thinking and planning the next actions on the strategic level, for example. These levels are not strictly divided. For instance, driving beginners perform their actions on a higher level, with conscious cognitive effort, which results in a slower performance.

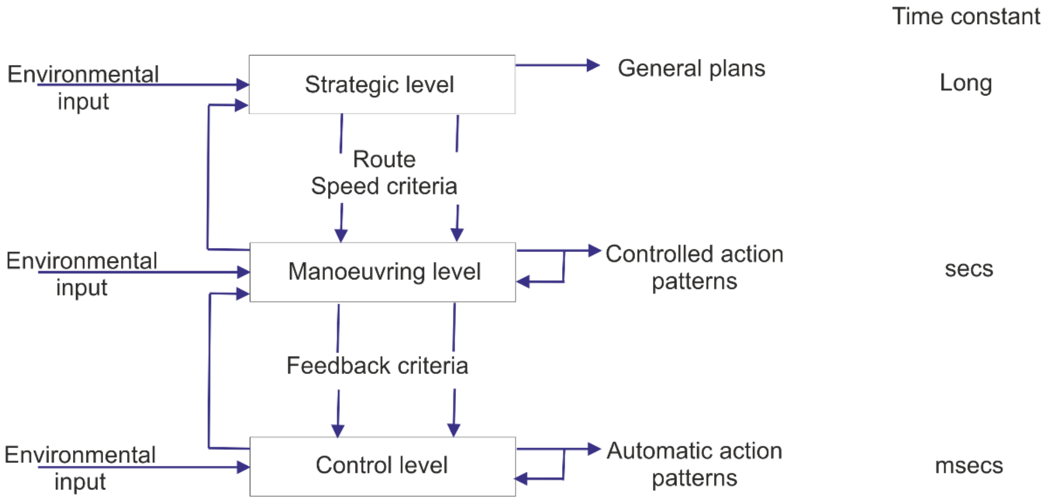


**Figure 5: Hierarchical model of the driving task (1985)**

Bellet et al. (2007) created a computational simulation of mental models. They are situated on the tactical level in their COSMODRIVE model, a cognitive simulation model of the driving task (Bellet and Tattegrain-Veste, 1999). COSMODRIVE was developed to model the driver's cognition and to explain why they behave in the way they do. Mental models are instantiated on the Current Representation BlackBoard, a temporary storage space. They then produce anticipations, coordinate the road exploration as well as information processing, arrange decisions and choose driving actions. Errors in them can cause errors in decision making and therefore possibly accidents.

The hierarchy of mental models by Boer et al. (1998) illustrates how mental models are organised and how they interact with each other. Figure 6 displays the three hierarchical levels, a strategic, a tactical and an operational level (cf. Michon, 1985). In this model, each level contains mental models and decision makers. According to Boer et al. (1998), the 'needs' mental model provides evaluations of the current and potential routes and task sets according to the driver's needs. The resulting strategy is the basis for the selection of tactical mental models, which then provide the 'tactical decision maker' with predictive information and assessments of situations and current tasks. The 'tactical decision maker' schedules tasks and allocates attentional resources to the operational level, which interacts with reality. In this model it is understood that mental models exist on the lower, operational level. However, humans are not able to consciously access and influence behaviour on these levels. Car-following and lane-changing are well-learned skills that are potentially the same in ‘normal’ and eco-driving, although the decision to activate and deactivate them might differ in these driving styles. Hence, in the present thesis the view that mental models exist on such a lower, operational, level is nor adopted. What can be attributed to this level, though, is the collection of perceptive information and its upward direction. The operational decision makers are the task handlers executing the chosen actions.

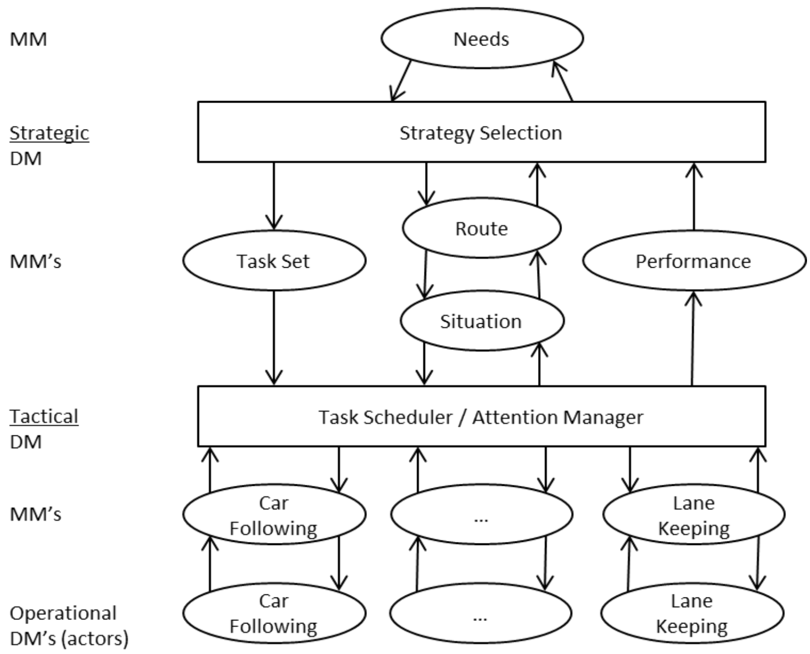


**Figure 6: Hierarchical Driver Model (Boer et al., 1998)**

The hierarchy was rearranged by Goodrich and Boer (1998) into a society of mental model agents and consists of three levels which are knowledge-based, rule-based and skill-based, respectively. This hierarchy is based on the hierarchy of human performance as defined by Rasmussen (1983). The skills are actuated from and monitored on higher levels. Humans perceive on the skill level, and the information is then transferred to the rule and knowledge levels. There the mental models receive this information and allocate resources to the levels below them

There has been a debate about mental models from a psychological point of view, particularly about the idea of a set of specified schemas in the memory. Some researchers view mental models as loose structures that are compiled into usable models when the human being needs them (Lynam et al., 2012). Oaksford and Chater (1991), for example, have the standpoint that human memory functions with formal rules that are unconnected to representations such as mental models. According to them, mental models are limited in the face of complex knowledge, where they become unmanageable in the process of making sense of the world. However, the storage capacity of the working memory is limited (Miller, 1956, Simon, 1969), in contrast to the almost endless capacity of the mid- or long-term memory (Simon, 1969). Hence, it is unlikely that humans are capable of developing new strategies every time they attempt to solve a problem. The mental model theory provides an explanation for the way humans can accomplish complex tasks. They use stored representations instead of creating new representations every time they face a challenge (Johnson-Laird, 1983, Moray, 1987). The theory takes into account that the representations are stereotypical and simplified, because exact representations are difficult to attain, especially when initial mental models are built (Wittgenstein, 1953). People do not include every logical step and possibility into their reasoning and often revert to recognising patterns and using heuristics (Johnson-Laird and Byrne, 2002).

### 3.3.2 Types of mental models

One of the reasons why mental models are understood in a variety of ways is the fact that they have been used in a number of domains. Because these domains require them to fulfil different purposes, the way mental models are seen and represented varies. This section exemplifies some of the major types of mental models, beginning with logical constructs for problem solving, continuing with linguistics and text comprehension as well as visual-spatial images and ending with actions in people's everyday behaviour.

*Logic, reasoning and problem solving*

Mental models have been used for studying human reasoning as people form conclusions and judgements using stored and perceived information (Garnham, 1997). Johnson-Laird and Byrne (1990) asserted that most people do not solve complex problems such as the knight and knaves puzzle[2] utilising elaborate and exact strategies. Due to their cognitive limitations they refrain from testing a long chain of hypotheses, for example. Instead, humans tend to find or invent simpler strategies and heuristics by approaching such problems with mental models, as described by Johnson-Laird (1983). He described problem solving based on truth conditions, which state whether a set of statements is defined as true (Johnson-Laird, 1983). The set of statements is judged as true if at least one mental model that satisfies its truth conditions can be mapped into the real world while preserving the content of the mental model.

People begin a deductive process by building an internal representation that is consistent with the problem's assertions. Such a representation can look as follows:

p q

The letter 'p' stands for a statement such as "Person A is a knight" and q for another statement such as "Person B is a knave". The model is then tested for potential conclusions. If none is found, the model is altered. In case a conclusion is found, the opposite is tested, with assertions such as "Person A is not a knight" and "Person B is not a knave". These negations are represented below:

¬p ¬q

If the counterexample arrives at a reasonable conclusion, too, the mental model needs to be altered or rejected. Otherwise, it is accepted.

*Linguistics, language processing and text comprehension*

Mental models have been extensively studied in the field of linguistics, particularly in semantics, the branch concerned with the meaning of words and sentences. One stream of thought, also called the true or realist perspective, is concerned with the search for the meanings that are as close to reality as possible (Putnam, 1975). In contrast, the psychologist perspective, inferring meaning from assertions only and therefore

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[2] The knights and knaves puzzle has been studied by Rips. In the puzzle it is assumed that two sorts of people exist, knights and knaves. Knights always tell the truth and knaves always lie. A problem can be formulated as follows: A says 'I am a knave and B is a knave.' B says 'A is a knave.' Please classify A and B into knights or knaves. The solution is that A is a knave and B is a knight. Rips, L. J. 1989. The psychology of knights and knaves. *Cognition,* 31**,** 85-116.

independently of reality, is in line with logical reasoning as related to Johnson-Laird (1983). On a broader scale, mental models have been applied to text and discourse comprehension (van Dijk and Kintsch, 1983), which is a field within linguistics and psychology. While texts have the main purpose to structure and convey information, discourse is defined as the use of language to perform an action (McGregor, 2009). The understanding of language and texts is one important stream in AI (McCarthy, 2007). Some early approaches of AI are based on basic representations and procedures, which are fed with new information and performed, respectively, as a text is understood (Charniak, 1972, Simmons, 1972, Winograd, 1972).

*Visual and spatial cognition*

Mental models have been concerned with visual geometrical aspects of the world. Brunswik has worked with perception and stated that humans do not perceive the world with its physical properties, but on probabilistic terms (Brunswik, 1934). In the 1950s Brunswik (1956) developed a lens model, which describes how reality is perceived via objective cues, which have uncertain relationships to the actual objects. One example is the lake scene in Figure 7 (Gifford, 1997), with several features in the front and in the back. People tend to perceive the objects that are important to them, and filter their perceptions according to their goals. If the goal is to judge the beauty of this scene, cues such as ‘colour of water’ form inferences such as ‘undisturbed’, ‘polluted’ and ‘striking’. They therefore form a judgement of perceived rather than objective beauty.

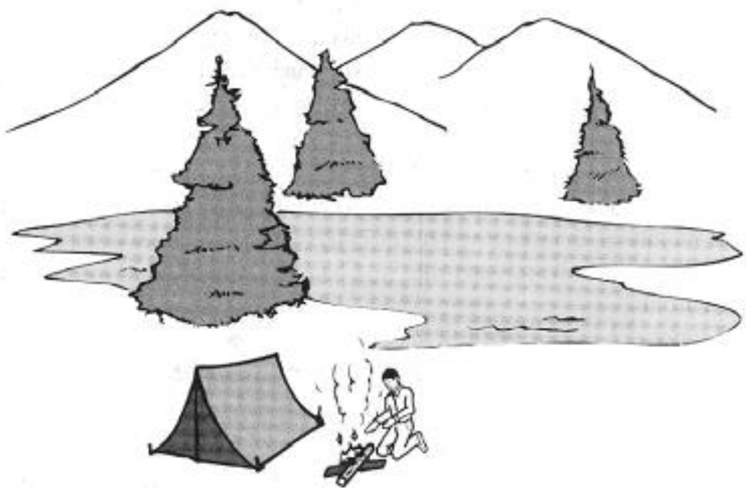

**Figure 7: Lake scene with perceptual cues (Gifford, 1997)**

This visual pattern of information processing can be applied in the field of pervasive technology, for example, as described by Heijs (2006). Through visual cues technology can make people conscious of their actions (Vallacher and Wegner, 1987), which then has the potential for enabling behaviour change.

*Everyday behaviour*

Mental models have been used to understand behaviour, for example the understanding of behavioural sequences in texts and learned action routines (Garnham, 1997, Rumelhart, 1980, Schank and Abelson, 1977). The scripts are stored in the memory and retrieved when they are recognised in perceived events. Of particular important for the current thesis are action sequences relevant for the performance by an individual, because these are the ones relevant for driving. For example, Georgeon et al. (2007) and Henning et al. (2008) modelled lane changes with their ABSTRACT method, further described in section 3.5.4.

In everyday behaviour, there are a number of different approaches to the way mental models function. For the research reported here it is assumed that humans store a library of mental models, which are generic enough to be used for the same type of situation. For example a mental model for a lane change can be used on different motorways, provided the traffic conditions are somewhat similar. As the driver perceives information and recognises the situation and the need for a lane change, the matching mental model is retrieved and fed with the variables of the current situation.

## 3.4 How do mental models come into being?

### 3.4.1 The creation of mental models

This section focusses on the way humans learn. There is a lot of agreement in the literature about the process of mental model building. Learning begins with the construction of a new mental model. Johnson-Laird (1988) wrote that as humans comprehend, they build mental models based on some of the information available to them and use default values to complete the models initially to create a coherent picture of the situation. Therefore, an initial mental model is potentially very naïve or even erroneous. With new information it is validated, changed or replaced and gradually mature (Johnson-Laird, 1988). In this section the creation of initial mental models is described from the point of view of different approaches and disciplines.

*Text and discourse comprehension*

Graesser et al. (1994) stated that text and discourse comprehension is thought to be similar to the way people experience and make sense of their daily lives. In order for people to comprehend a text they need to build new, and also retrieve existing representations (Zwaan and Radvansky, 1998). The topic of text comprehension was addressed specifically by van Dijk and Kitsch (1983) with situation models. As people read a text they create a coherent macrostructure for the text and draw inferences. This way this macrostructure is influenced by their existing knowledge, beliefs and goals. Within this structure representations are built on various levels of complexity, referring to words, clauses and sentences.

The idea that, as people learn and understand they construct mental models or situation models, was termed the constructionist approach (Graesser et al., 1994). This theory is in line with the principle of a search for meaning. A reader tries to make sense of the reasons why events, actions and states are mentioned in the text, often using more or less naive theories about these occurrences. Some inferences are made on-line, or during comprehension. In some cases these inferences are abandoned, for example if the text is judged 'inconsiderate', the reader lacks necessary background knowledge or the reader's goals do not require that kind of understanding, e.g. during proofreading. Off-line inferences are made during retrieval and are just as crucial for the sense-making process as on-line inferences.

*Visual-spatial comprehension*

The mental model approach has been utilised to research the way human beings create representations of visual geometrical aspects of the world. Bower and Morrow (1990) researched the understanding of stories using spatial mental models. When a person reads a text they are building multilevel representations of the information. Beginning with the surface structure, they extract an initial text base with the text's concepts, their relations and predicates, which are the main components of sentences apart from the subject (Collins English Dictionary, 2015). The mental model is then further modified based on clues in the text. When important elements in a story change, the mental model needs to be updated, which can require time and effort to process. In an experiment using the building layout in Figure 8 Morrow et al. (1987) found that readers of a story were able recall probes in the same room with the main character faster than probes in other rooms. This indicates that relevant mental models are activated, at least to a higher degree than less important mental models.

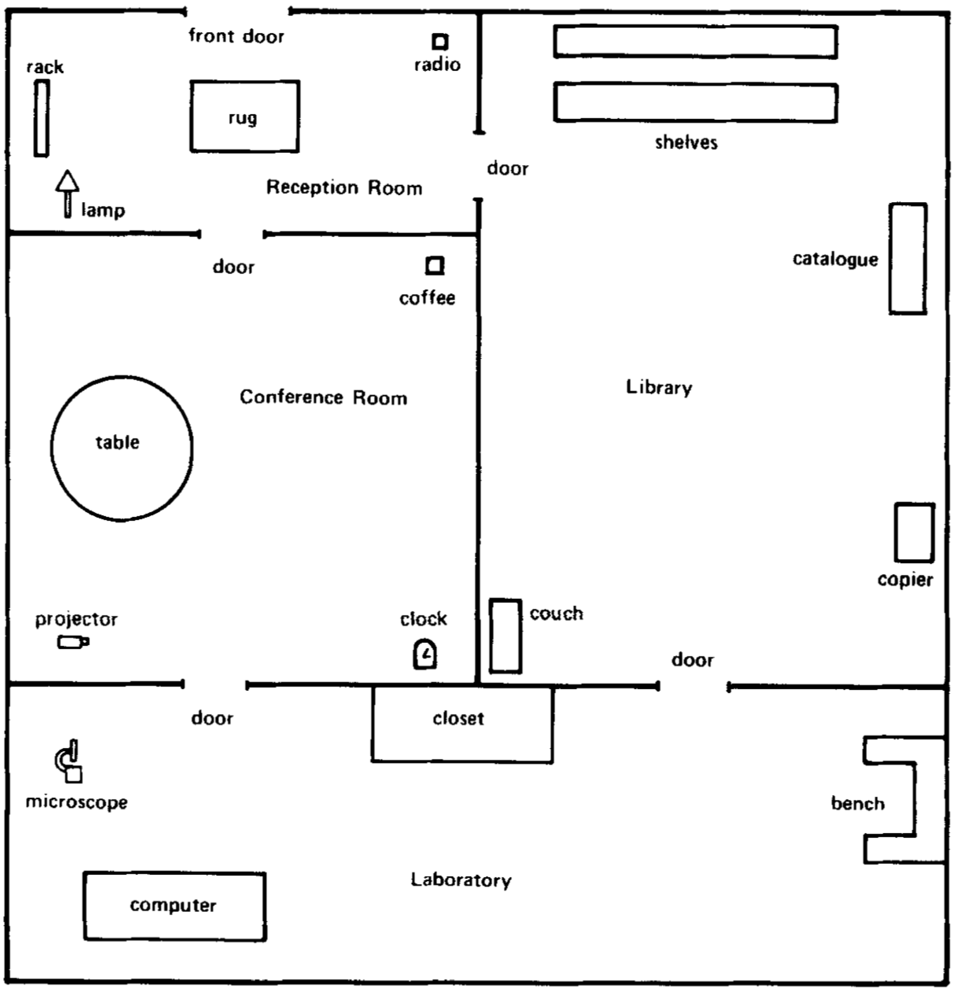


**Figure 8: Building layout from Morrow et al. (1987)[3]**

The concept of mental models is comparatively fathomable in the field of visual-spatial cognition in the real world, where humans literally create models of the way they understand a location.

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[3] Reprinted from Accessibility and situation models in narrative comprehension, Daniel G Morrow, Steven L Greenspan, Gordon H Bower, Copyright 1987, with permission from Elsevier.

*Theory building*

As humans learn about complex subjects such as mathematics and physics, they build mental models of them. These mental models are often abstract, naïve and contain flaws. Performance, especially when it comes to complex problem solving, often depends on appropriate mental models (Halasz and Moran, 1983).

It has been established that infants are able to create mental models from the age of 3 months (Baillargeon, 1987). In school, as children learn about complex subjects, their mental models can be very simplified and faulty at first. For example, some children believe the Earth is shaped as a flat disc. As children learn, they synthesise their mental models with socially accepted versions, until their mental models are not in conflict with these versions anymore (Vosniadou and Brewer, 1992).

*Driving*

When people drive a car for the first time the associated action sequences are new. Drivers build their initial mental model of, for example, a gear change on a high level, e.g. on the knowledge level in Rasmussen's hierarchy (Rasmussen, 1983), defined in section 3.2.2. The sequence consists of stepping on the clutch, putting the gear lever into the correct gear and then slowly releasing the clutch while gently pressing the accelerator pedal. As these actions are automatised with practise, the sequence is simply called 'gear change' and performed at once. Bellet et al. simulated the construction of driving mental models (Bellet et al., 2007, Bellet and Tattegrain-Veste, 1999). Similar to the understanding of mental models in other domains, these driving frames are constructed with perceptive information and knowledge from the long-term memory. However, in this definition they solely exist on the tactical level and incorporate the operative knowledge.

### 3.4.2 Learning, refinement and automation

Human beings learn by incorporating new situations into their knowledge (Minsky, 1974, Schank and Abelson, 1977). Learning begins with the creation of a mental model, and from there the mental models are improved. In case new information is in conflict with existing mental models, this new information causes the change or replacement of an old one. Alternatively, it induces the construction of a new mental model, as described in the previous section. Hence, during learning mental models are continuously evaluated, updated or reconstructed utilising information that is incompatible with the current set of mental models. If possible, humans are capable of linking mental models to each other (Radvansky and Zacks, 1997). This could generate different viewpoints about a topic, for example. However, existing mental models influence how information is perceived and therefore further learning processes. Learning is time-consuming, limited by the information processing capacity of human beings (Miller, 1956, Simon, 1969) and can trigger emotional responses (Schön, 1983). For this reason humans naturally tend to avoid the process, for example by ignoring contradictory information.

In the context of language and text comprehension, Rumelhart (1980), Garnham (1997), Schank and Abelson (1977) asserted that mental models are enhanced by listening and reading. Especially the combination of language and images can improve the construction of mental models. As a result, the better a person is able to construct a mental model the more they are able to understand an event (Halford, 1993, Wyer Jr and Radvansky, 1999).

Frequent maturations of mental models can result in richer mental models. On the other hand it is expected that human beings abstract or simplify their mental models (Johnson-Laird and Byrne, 2002). This is one type of optimisation, and was described by Arnold and Mettau (2006) as the formation and shifts of mental models within the hierarchy (c.f. Rasmussen, 1983). Rasmussen (1983) and Michon (1985) explained that as behaviours are trained, they are increasingly automated and move down in the hierarchy, towards control actions. In this process the mental models are made more efficient by removing unnecessary parts and making shortcuts. Distinct actions are thereby converted into procedures and connected to larger routines. In the ACT-R theory of Anderson (1982, Anderson et al., 2004) knowledge compilation is the process by which the skill transits from the declarative stage to the procedural stage. It consists of the subprocesses of composition, which collapses sequences of productions into single productions, and proceduralisation, which embeds factual knowledge into productions. Once proceduralised, further learning processes occur to make the productions more selective in their range of applications. The ecological interface design (EID) method (Rasmussen and Vicente, 1989) postulates that humans can learn with direct stimuli to the automated level, by bypassing the higher levels and the automatisation process (McIlroy and Stanton, 2014, McIlroy and Stanton, 2015, Milot et al., 2010).

Argyris and Schön (1974, 1978) use the concept of mental models in their concept of single-loop and double-loop learning. In single-loop learning people adjust their actions and still maintain existing governing variables. In double-loop learning people bring their mental models into consciousness and change the governing variables.

### 3.4.3 Enabling and activating mental models

In section 3.3.1 it was described how mental models are matched with currently perceived information and then instantiated. However, this match is not the only factor in choosing which mental model is activated. The concepts of priming, nudging and prompting show how more or less subtle messages can influence this process. These concepts go beyond simple information, which enables people to make decisions based on their preferences and goals. In this way, simple information is able to change behaviour. Primes, nudges and prompts, however, have the purpose to change behaviour into a particular direction.

*Priming*

Priming was defined by Fiske and Taylor (1984) as "the fact that recently and frequently activated ideas come to mind more easily than ideas that have not been activated" (p.231). Later Fiske and Taylor (2013) refined their definition of priming, clarifying that priming improves the accessibility of categories, assuming a network-like memory structure.[4] Hence, the effects of priming on the accessibility of constructs has traditionally been understood in the context of network-based theories of cognition. Roskos-Ewoldsen et al. (2002) argued, however, that mental models provide a framework that allows to research priming on a larger scale. Following up on this idea, subtle primes can cause the activation of mental models and

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[4] "the effects of prior context on the interpretation of new information, that is, the impact of a recently or frequently activated category on the processing of category-relevant information, typically interpreted in terms of category accessibility, within declarative (associative network) memory." p. 450, Fiske, S. T. & Taylor, S. E. 2013. *Social cognition: From brains to culture,* London, UK, Sage.

change subsequent judgements and behaviour (Brewer et al., 2003, Iyengar and Kinder, 1987). They especially enhance the accessibility of files stored in the long-term memory (Iyengar and Kinder, 1987).

It has been found that the attitudes that are more accessible can influence the way a person defines a situation (Fazio, 1986, Fazio et al., 1994), and therefore the mental models of the current situation and resulting behaviour. Which mental model is accessed depends on its match with the situation, but it also depends on its accessibility (Radvansky and Zacks, 1997, Wyer Jr and Radvansky, 1999). This means that mental models can be primed, for example by media. Examples of long-term media priming include an increased coverage of certain topics or violent TV programmes (Josephson, 1987). Another way is that priming can activate elements within a mental model is to increase the accessibility of particular information inside a mental model. This mechanism has been researched in the field of text comprehension, for example (Morrow et al., 1989, Morrow et al., 1987, Radvansky and Zacks, 1997).

Mental models are a useful approach for studying priming in two ways. On the one hand mental models can incorporate the information delivered with the prime (Wyer Jr and Radvansky, 1999, Zwaan and Radvansky, 1998). On the other primes increase the accessibility of the targeted mental model, which increases the likelihood if its activation (Brewer et al., 2003, Iyengar and Kinder, 1987).

A problem with priming is that it can effect contrasting behaviours (Herr, 1986, Herr et al., 1983, Martin, 1986), e.g. if the connection is too obvious and the intentions demystified (Erb et al., 2002) or in the case of extreme primes (Herr, 1986, Herr, 1989). However, even if participants notice the primes, but the desired effect on their choices remains unknown to them, the primes can affect their subsequent behaviour (Mandel and Johnson, 2002). Hence, primes are ideally delivered in a subliminal manner. For example, Fiske and Taylor (1984) stressed that in priming studies the primed interpretation must not be consciously connected to the stimulus to prevent the participants from pleasing the experimenter. However, this is difficult to achieve in practise, because the prime has to be shown for a very short duration and be hidden behind irrelevant cues. The timing of the primes can have effects as well. They can work in the short- and long-term, but function especially well at the point when a stimulus is encoded (Srull and Wyer, 1979, Srull and Wyer, 1980). Hence, primes tend to be more effective with close proximity between the prime and the stimulus, particularly for more inaccessible constructs (Bargh et al., 1988). Frequency and recency effects potentially occur (Higgins, 1989). Frequently primed constructs are more stable in the long-term. For example, when charities send regular newsletters, the receivers could be more likely to consider them the next time they want to make a donation. Recently primed concepts tend to dominate in the short-term (Higgins et al., 1985). If a construct is primed sufficiently, it becomes chronic (Bargh et al., 1986) and is used even without the person's intention (Higgins et al., 1982) or control (Bargh and Pratto, 1986). The reason is that primed concepts are often automated (Bargh, 1984, Payne and Iannuzzi, 2012). In contrast, if people are aware of the activation, they may invoke more conscious and controlled thoughts and behaviours instead.

In the second experiment in the current thesis, presented in chapter 5, the concept of primes was used, but not in a way that is as subtle and hidden as in some priming studies. Messages were created, which included the topic of eco-driving and were supposed to increase the presence of eco-driving in the receivers' minds. For another experimental group advice messages were created, which do also adhere to the concept of primes, because such advice does not involve direct encouragements. Because of the manifold nature of the experimental interventions, findings from literature from the fields of more overt methods such as nudging and prompting were employed as well during the design of the study. In the following discussion it will become more apparent that the definitions of primes, nudges and prompts are congruent in some aspects, and that the differences are mostly apparent in the academic disciplines in which these concepts are used.

*Nudging*

Nudges are defined by Thaler and Sunstein as "any aspect of the choice architecture that alters people's behaviour in a predictable way without forbidding any options or significantly changing their economic incentives. To count as a mere nudge, the intervention must be easy and cheap to avoid." (Thaler and Sunstein, 2008, p. 6). A typical example of a nudge is a canteen positioning healthy foods at eye level and sugary treats below them. This example shows how nudges preserve people's liberty by steering them in a particular direction, while taking their human limitations into account (Amir et al., 2005, Camerer et al., 2003). Nudges preserve the option for people to choose their own way (Sunstein, 2014). The example of the canteen also illustrates that nudges are primarily targeting behaviour in the short-term such as at the point of purchase. If the canteen reverses the positioning of the food items a week later, the sales of the sweets would most probably rise.

In comparison to campaigns or enforced restrictions, for example, nudges are potentially very cost effective. They were used to improve people's decisions regarding their pensions and health, for example. Reminders are one example of a nudge that is applicable for the research presented here, because they could overcome people's inertia towards eco-driving and competing demands. Reminders would adhere to the main goal of nudges, which is the retention of the option to behave in any other way. Nudges are not entirely different from primes in the sense that both approaches allow the receivers to act freely, and may be more or less subtle. One issue with governmental interventions is that indirect nudges can be perceived as deceptive. Several voices (Fischer and Lotz, 2014, Thaler and Sunstein, 2008) cautioned against subliminal messages. They suggested that nudges need to be delivered in a transparent manner instead.

In practise, this concept is primarily utilised in policy making. The examples known to the author are all intended to benefit the citizens by nudging them to make smarter choices, for instance in financial or health matters. The reasoning behind nudges is traditionally based on economic models. It assumes that humans are first and foremost as utility maximisers, whose utility functions are naturally flawed (Fischer and Lotz, 2014). The downside is that nudges are primarily momentary and do not take unconscious cognitive processes into account (Payne and Iannuzzi, 2012). Nevertheless, nudges help making sense of the results in the studies presented in this thesis, not least because the way mental models work can partly be explained with utility functions, as is done in satisficing decision theory below and in section 3.5.5.

*Prompting*

Prompting is based on reminders that are meant to draw the recipient's attention to a specific behaviour, whether it is desirable or not (Steg et al., 2012). They do not need to be subtle and are therefore easier to implement in experiments compared to studies using subtle primes. Prompts are suitable for campaigns, particularly in the field of environmentally friendly behaviours, where people can be asked to act in a more desirable way. They are usually formulated in a direct, imperative manner, for example in the form of a sign in a park asking visitors to drop their litter into the bins provided. Billboards along motorways prompting drivers to use their seatbelts or so adhere to the speed limit are further examples. Prompts have the advantage that they target conscious decision making and can therefore lead to automated behaviours being overruled (Steg et al., 2012). Prompting studies found that they tend to be most effective when delivered close to the desired behaviour (Balas et al., 2000) as well as in a simple and polite way (Geller et al., 1982). Hence, they can be implemented with experimental instructions in the research presented here, as discussed in chapter 5. In contrast to nudges, prompts are not closely related to economics and therefore utility functions, and can hitherto be interpreted in more flexible ways.

*Selection of mental models and Satisficing Decision Theory*

In Rasmussen’s hierarchy the selection and activation of mental models is conducted by higher-level mental models (Rasmussen, 1983). With the goals and strategies decided on the knowledge level, the rule-based mental models select which lower-level skills are activated. Hence, they decide which actions are consequently executed, and which of the skills receive attentional resources. Using perceptual input fed back from the skill level, the rule-based mental models then refine their decisions and control further actions (Boer et al., 1998). As an example, with perceptual information about traffic lights or the headway to a car in front, the mental model for longitudinal vehicle control on the rule-based level makes the instant decision, if cruising is acceptable or if a braking action needs to be initiated. It is possible for humans to consciously influence the rule-based mental models and skills by shifting them upwards in the hierarchy. This process, as explained in section 3.4.2, is connected with an increased effort. Distraction, on the other hand, occupies attentional resources and can interrupt such efforts, and cause the more automated behaviours to be activated, which is further explained in the following section. Figure 9 illustrated the interaction between knowledge-, rule- and skills with examples from the driving domain (Goodrich and Boer, 1998).

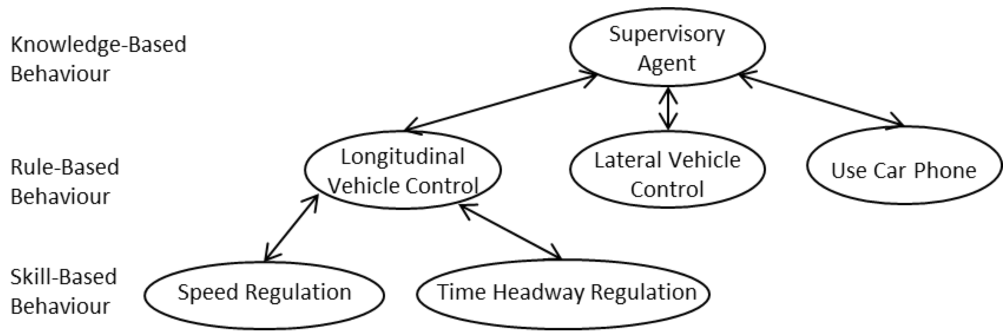


**Figure 9: Communication and Control with a Society of Mental Models, based on Rasmussen (1983) and adapted from © 1998 IEEE Goodrich and Boer (1998)**

The required attention of the skills is calculated using Model Predictive Control (Richalet, 1993). MPC is a system model designed to handle uncertain situations in constrained environments. According to the Satisficing Decision Theory (SDT) (Goodrich et al., 1998b) the choice of an action by the rule based-models is based on MPC. In SDT an action is chosen when it is good enough. 'Good enough' means that the sum of the benefits is higher than the sum of the costs for a given option. On this level making an optimal choice may be impossible or require too many resources, and therefore too much effort. Philosophically speaking, this is done to minimise error rather than seeking the absolute truth. Once decided, the eventual action is executed on the skill-based level. SDT assumes that humans usually do not make optimal decisions, but use a simpler heuristic instead. They search through the alternatives, here mental models, available to them and settle for the first one that meets a certain set of criteria, or is within a boundary. SDT is not based on the concept that humans maximise a single utility, as is the case in many economic theories. Instead, in epistemic utility theory it is assumed that humans compare two independent utilities, the benefits and costs (Levi, 1983). SDT also explains how drivers prefer a satisficing solution over investing further effort to find a better alternative. Particularly in the face of distraction, it can be expected that drivers abandon possibly secondary goals such as eco-driving and concentrate on maintaining solely safe driving behaviours.

### 3.4.4 The deactivation of mental models and regression

When an appropriate mental model is activated it can occur that, under certain conditions, a person reverts to more familiar and well-learned mental models (Rasmussen, 1979). Rasmussen stated that especially subconscious actions are vulnerable to interference by more automated mental models, and even more so when the actions are very similar. Weick (1990) described the return to more familiar and automated mental models with the term regression. Regression can have several causes. For example, it can occur due to mind-wandering during lengthy tasks (Rasmussen, 1979). A lack of transfer of a new mental model into the current situation can result in the use of a more familiar mental model (Perkins and Salomon, 1992).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). Stress can cause regression as well (Davis, 1958). Stress is believed to have played a major role in the events leading to a KLM airplane colliding with a Pan Am machine on Tenerife in 1977. As the situation became increasingly critical, the KLM pilot, the Pan Am crew as well as the air traffic controllers all appear to have reverted to more familiar routines (Weick, 1990).

In chapter 5 in the current thesis the topic of regression is discussed in the context of eco-driving. The question is whether it is possible to get a driver to revert to more familiar mental models by subjecting them to a workload task. Driver distraction is defined as “the diversion of attention away from activities critical for safe driving toward a competing activity” (Lee et al., 2009) and can therefore, with the means of a task, increase the drivers’ workload. In the case of the current study, distraction has the aim to divert the driver’s attention away from driving after eco-driving mental models were activated. This experiment was performed to find out whether, in the face a workload task, potentially more familiar ‘normal’ or safe driving mental models take precedence.

*Distraction tasks and their impact*

Distraction tasks have been used in driving studies and have shown to cause a variety of behavioural measures to change. Visual, auditory and cognitive tasks can affect speed (Funkhouser and Chrysler, 2007, Hatfield and Chamberlain, 2005, Salvucci et al., 2007, White et al., 2006), headway (Haigney et al., 2000, Kircher et al., 2004, White et al., 2006) and lateral variation (Engström et al., 2005, Haigney et al., 2000, Hatfield and Chamberlain, 2005, Kircher et al., 2004). In these studies, though, non-visual did not worsen performance in all cases. It can be agreed, however, that non-visual tasks increase reaction time (Hatfield and Chamberlain, 2005, Horberry et al., 2006, Kircher et al., 2004, Laberge et al., 2004). Adding a manual task to a visual task has a much stronger effect on driver performance that a visual or non-visual task alone. These types of distraction tasks have the highest impact on driving performance, on speed (Chiang et al., 2001, Engström et al., 2005, Tsimhoni et al., 2004, White et al., 2006), headway (White et al., 2006), particularly risky headways (Engström et al., 2005, Manser et al., 2004), lateral variance (Chiang et al., 2001, Engström et al., 2005, Kircher et al., 2004, Tsimhoni et al., 2004) and reaction times (Chisholm et al., 2007, Rouzikhah et al., 2013, White et al., 2006). Some of these effects are possibly related to the increase of the duration and number of glances towards an employed device during task completion (Chiang et al., 2001, Chisholm et al., 2007, Dingus et al., 1989, Tijerina et al., 1998). In a study by Young et al. (2012) a combined visual-manual task resulted in a reduction in words in think-aloud protocols, for a description and discussion of the method see section 4.3.2. Although the quality of the protocols was the same as in the control condition, the content was more geared towards control tasks, away from the vehicle's surroundings. The behavioural measures are relevant in the second study presented in this thesis, when drivers were subjected to a workload task while following a lead vehicle. In section 5.9.4 the effects on 'normal' and eco-driving were discussed.

## 3.5 The use of mental models in research and practise

### 3.5.1 Applications in communication and education

Mental models have been utilised to assess people's knowledge about health-related issues (e.g. Morgan et al., 2002, Vogt and Schaefer, 2012). When producing communications for patients it is often difficult to elicit what they already know and where the most potent knowledge gaps are. One approach using mental models involves the creation of expert mental models and their comparison with the mental models of the patients. This enables to better target communication and education material.

Vogt and Schaefer (2012) attempted to determine how well consumers understood contraceptive medication with respect to its risks and benefits by eliciting the patients' as well as experts' mental models. Morgan et al. (2002) conducted a similar approach to analyse a variety of risks to people's health, safety and the environment. de Bruin et al. (2007) used interviews and questionnaires to gain insights into mental models of risky sexual behaviour from adolescents, and based recommendations on uncertain and incorrect statements.

These approaches have been successful in the health education field. Mental models allow learning about humans, which can inform the design of targeted communication and education material. However, they can have limitations, as even expert mental models may not be correct and complete (Shai et al., 2008).

### 3.5.2 Applications in engineering and design

Mental models have been applied successfully in human machine interaction. In requirement engineering it is important to acquire sufficient knowledge about the domain the technology will be applied to. Mental models can give valuable insights into the way users perform tasks and where they need support. In addition, it is crucial that users have functioning mental models of the technology and technology itself needs to be able to provide the information that helps building them. In some cases, these mental models do not need to be correct. For example, the folder icon in Microsoft Windows conveys a mental model of a folder structure, as is common in a typical office, although a computer does not store information in this manner. However, such an understanding is practical in this case and does not impair the use of the system.

Whitten and Tygar (1999) showed that incorrect mental models of technology can lead to errors. They strongly suggest that technology communicates its way of functioning in a clear and simple way to users. A study with a software user interface providing such clues found that these lead to increased acceptance (Hasan and Ahmed, 2007). Ogden (2001) described an approach to improve user interaction using ecological interface design (Rasmussen and Vicente, 1989) based on mental models. Instead of providing a user interface communicating information about the actual physical level, the display can show a higher, functional and abstract level. This is meant to reduce the cognitive load on the user while allowing understanding of the underlying relations.

Crandall et al. (2006) have worked with cognitive task analysis (CTA) methods. They showed how the elicitation of cognitive requirements can improve system design. For example, CTA can help improve training material by providing insights into the existing knowledge of trainees as well as their needs. In a project involving a re-design of training material for firefighters it was found that they need to be made aware of the signs implying an imminent building collapse, instead of simply being told to 'be careful'. In this way CTA can lead to substantial improvements in decision making. Interviews and workshops are effective means to gather relevant information from professionals or drivers, as conducted by McIlroy and Stanton (2014). In addition, observations in the natural context of technology utilisation can provide necessary insights to identify asymmetries between the intended and interpreted mental model (Jelsma, 2006). Ideally users and technology have a common ground in order to foster effective collaboration (Feltovich et al., 2007).

Boer and Goodrich (2005) introduced a way to measure human understanding of their interaction with technology. When children or adults find themselves in a new context their perceptions and behavioural patterns are still very volatile. With practise and experience the behaviour becomes increasingly predictable. The authors defined this behavioural predictability as entropy, which can be observed with more systematic, consistent and predictable actions. In this way they provided a measure for human performance in areas such as driving or other technology interactions, or the effects of high workload or sleep apnoea.

### 3.5.3 Mental models and driving

Mental models are a suitable concept to understand the behaviour and thoughts of humans in a diverse range of contexts, and driving is one of them. Going back to the major pillars of psychology, as described in the history section 3.2.1, both introspection as well as behavioural data collected in experiments are expected to be relevant for the driving domain. Although this section introducing relevant concepts to the driving domain heavily relies on mathematical and behavioural approaches, qualitative and introspective research is crucial. Researchers need to be aware that drivers are able to verbalise a lot of relevant information when asked. Hence, adding qualitative and introspective methods to studies can sometimes replace expensive data collection in projects involving simulator experiments or FOTs, for example (Cotter and Mogilka, 2007).

There have been a number of different ways drivers’ mental models have been elicited. Behavioural methods have involved complex machine learning algorithms (e.g. Henning et al., 2008, Junell and Tumer, 2013), and qualitative methods have included interviews and focus groups (e.g. Birrell et al., 2011, Harvey et al., 2013, Hof et al., 2012).

### 3.5.4 Examples of mental model research in the driving domain

In this section two examples of elaborate theories involving mental models in the driving domain are introduced in order to provide an overview of the current relevant research. These examples constitute COSMODRIVE, a detailed model of driver cognition and behaviour, and the ABSTRACT method and tool for modelling distinct manoeuvres such as a lane change.

*COSMODRIVE*

COSMODRIVE was developed in order to simulate the drivers' cognition and to explain the reasons behind their behaviour (Bellet et al., 2007, Bellet and Tattegrain-Veste, 1999). In this approach a computational simulation of mental models was created. An experiment was conducted, showing videos of driving sequences that were abruptly stopped. The participants were asked to find differences on a modified version of the last picture shown. With the answers it was possible to visualise the mental representations of experienced as well as novice drivers. The emphasis of this experiment was on the anticipation of possible future events, which was better performed by experienced drivers.

*The ABSTRACT Method and Tool*

ABSTRACT is both a software and a method designed by Georgeon et al. (2007) to use a variety of sensory data to model drivers' behaviour and cognition. The researchers modelled mental models using data recorded with an instrumented car, tracking the movements of the car and the behaviour of the driver, e.g. eye movement and steering angle. These data were then enriched with inputs from an experimenter and interviews in which situations were assessed by the driver. The data were then validated and manipulated with the ABSTRACT software. With the software the researcher allocated numerical and textual properties to events, and then produce traces and ontologies. In this way lane changes were modelled on a high abstraction level and then tested with the original data. It was shown that for example a decision for a dangerous lane change can be recognised one second before the lane change is started. In a later study Henning et al.

(2008) modelled lane changes with a larger number of participants, trying to distinguish between lane changes that are well-planned and lane changes that are delayed due to a sudden obstacle. ABSTRACT is an example of using experimental data as the basis for modelling. It was developed primarily for ergonomists and designers of in-car technology. A downside is that the creation of models depends strongly on the individual using the software and method, but the models can later be tested and falsified. Wynn et al. (2008) conducted a study using models created with ABSTRACT to measure the occurrence of lane changes with different acceleration patterns. Although their study did not present significant results, the research is an important step towards the automated recognition of driver behaviour.

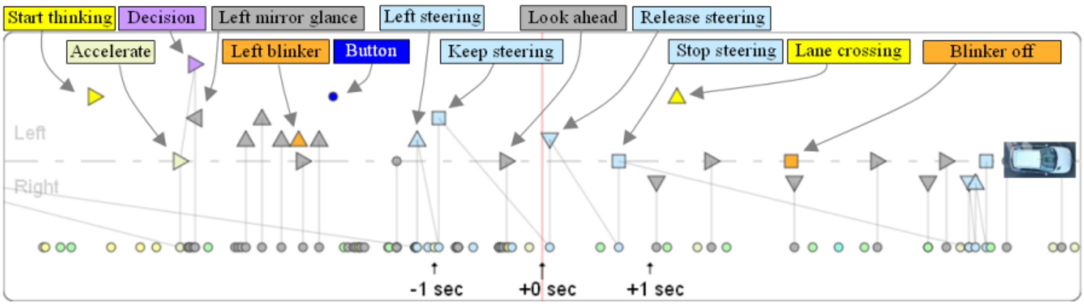


**Figure 10: Mental model schema of a lane change in ABSTRACT (Georgeon et al., 2007)[5]**

McCall et al. (2004) equipped a car with a number of devices to collect data about the driver's behaviour and the context. These devices included a GPS sensor, cameras capturing the driver and the surroundings and several systems to record the car's operation. Two researchers were placed in the car to prompt the driver for explanations and to record behaviour as well as other happenings related to the driving situation. Questionnaires and video-aided interview sessions a few days after the drives rounded up the data. For the analysis the data were represented in two ways, in a contextual view with different camera views synchronised with a map with GPS information and in a timeline view with several behavioural and context-based lanes, similar to the ABSTRACT method (Georgeon et al., 2007). The results show that combining ethnographic with engineering-focussed data allowed the identification of three different lane change configurations.

The advantages of these methods modelling mental models with large amounts of behavioural data, interviews and questionnaires are detailed insights into driver behaviour, which can be used to identify knowledge and skills of drivers. Support systems would then potentially be able to detect hazardous behaviours, for example, or personality traits (Stachl and Buehner, 2015). However, so far these methods have not been able to produce reliable results and the error rates may be too high for the design of warning systems.

### 3.5.5 A multiple mental model framework

The multiple mental model framework by Goodrich and Boer (1998) is based on Rasmussen’s knowledge-, rule- and skill-based taxonomy. The hierarchical structure is defined in section 3.2.2 and communication and control between mental models within this hierarchy are described in 3.3.1. The framework has been applied in a several studies aiming at the identification of natural driver behaviour. A set of experiments was conducted to inform the design of an acceptable and intuitive adaptive cruise control (ACC) system (Goodrich and Boer, 2003). An ACC takes over the car-following task by keeping a safe distance to the car in front and adjusting the speed slightly. Because the system is unable to perform strong braking actions, the human driver needs to take over control when active braking is required. Goodrich and Boer (2003) argue that this moment, when the switch from car-following to active braking occurs, needs to be as natural and human-like as possible in order for the driver to understand the take-over situation and to accept the system. In order to establish a boundary between car-following and active braking they subjected drivers to relevant situations and measured their reactions.

Goodrich and Boer (1998) measured boundaries of the mental models for car-following and active braking on the skill level. These boundaries represent those circumstances in which a currently activated skill ceases to be satisficing, and needs to be deactivated as well as replaced by another skill. In this example the rule-based mental model for longitudinal vehicle control is making the decisions regarding the skills. For their experiment the participants were asked to follow a preceding vehicle and therefore to execute the skill of car-following by regulating the time headway with manipulations of the gas pedal. The participants were presented with a number of cut-in events, in which another vehicle changed lanes, so it got into front of the host vehicle as displayed in Figure 11. If the participants changed their behaviour by stepping on the brake, it was assumed that car following now got 'not satisficing'. In this case the skill 'brake to avoid collision' was engaged instead.

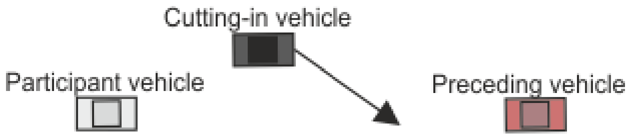


**Figure 11: Cut-in event**

This modelling exercise was applied in the first study in the present thesis. In order to analyse the mental model boundaries, critical decision points for the drivers were identified and counted as a case for either a braking (BRK) or a nominal (NOM) condition (cf. Goodrich et al., 1998a). These two points are considered the transition points, at which the switch from one skill to another occurs. In this case, distinct transitions can be identified, because a BRK condition is defined as an application of on the brake, whereas in the NOM condition the brake is not pressed. After each cut-in event the driver may consider the time headway and inverted time to collision not satisficing and step on the brake. In this case, the critical point for a BRK case is the initiation of the braking action. The end of the braking action is defined as a NOM case. Goodrich and Boer (1998) acknowledged that it may be possible, though, that the triggers for a transition from NOM to BRK and for the transition back from BRK to NOM are slightly different. However, for the sake of feasibility, such a distinction was not performed in the present research.

In the case of no braking response after a cut-in event, it is assumed that the driver considers the combination of time headway and inverted time to collision satisficing. In this case there are two critical points as well. The first NOM is marked by the beginning of the cut-in event, just when the antagonist begins to move towards the middle lane. Because of the fluctuating speed of the preceding vehicle, the second analysis point for a NOM cases is defined as the minimum time to collision in the ten seconds following the beginning of the event.

The theoretical basis for this modelling exercise is SDT (Goodrich et al., 1996, Goodrich et al., 1998b), explained in section 3.4.3. Goodrich et al. (1998b) created the concept of accuracy. It represents the value of the support of declaring a set of propositions as true (cf. Johnson-Laird, 1988). In the driving context $\mu_A$ is a utility representing benefits for the driver, such as safety and travel speed. The second concept, rejectability $\mu_R$, corresponds to the value of the rejection of a set of propositions (cf. Johnson-Laird, 1988). It is an anti-utility, or cost for the driver, such as accident risk and delays. In the case of the studied scenario, the inverted time to collision ($T_C^{-1}$) is more beneficial to the driver the smaller it is. Hence, a small value for $T_C^{-1}$ results in a high utility. Because utility always increases with decreasing values for $T_C^{-1}$, assuming that other things stay the same (ceteris paribus), the accurate states are strictly monotonic. By comparison, a smaller value for time headway ($T_h$) is associated with an increased crash risk and therefore considered a cost or anti-utility. Hence, it is assumed that, ceteris paribus, an increase in $T_h$ always results in a utility increase. Therefore, the rejectable states are strictly monotonic as well. These monotonicity assumptions are simplified for the sake of the feasibility of the modelling exercise presented here, and not always correct in real-life driving. For example, a large headway could tempt others to perform dangerous overtaking manoeuvres. It is also important to mention that limiting the assumptions about a driver's perceptual space to $T_h$ and $T_C^{-1}$ is another strong simplification. Although these measures have been empirically verified (Kiefer et al., 2003, Lee, 1976), it is expected that they change when the drivers' goals change, for example. For instance, during eco-driving drivers could attempt to keep their speed constant and therefore compromise on safety margins and accept closer distances to the car in front. Goals could also be based on achieving high speeds in order to arrive quicker at the destination.

The utilities are quantifiable as probabilities (Levi, 1983). Due to the monotonicity one can compute the accurate analysis points as a cumulative distribution function (cf. Goodrich and Boer, 1998). The function marks the probability of the binary variable 'surviving' over a continuous variable. For the NOM cases the function tells the probability $\mu_A$ of a driver not braking depending on $T_C^{-1}$. In comparison, for the BRK cases the function tells the probability $\mu_R$ of a driver braking at a given $T_h$, as explained below. The following equation tells the probability $\mu_A$ of a driver not braking at a given inverted time to collision.

$$\mu_A(T_C^{-1} = \tau) = 1 - F_{T_C^{-1}}(\tau|NOM) = 1 - \frac{N(T_C^{-1} \leq \tau|NOM)}{N(T_C^{-1} \leq \infty|NOM)}$$

A logistic regression with an accuracy function of the following form was performed for both the safe and the fuel-efficient run (cf. Goodrich and Boer, 1998)[6]:

$$\mu_A = \frac{1}{1 + e^{(-a\tau+b)}}$$

Because the monotonicity is valid for the rejectable states as well, a cumulative distribution function of the following form was computed (cf. Goodrich and Boer, 1998):

$$\mu_R(T_h = \tau) = 1 - F_{T_h}(\tau|BRK) = 1 - \frac{N(T_h \leq \tau|BRK)}{N(T_h \leq \infty|BRK)}$$

The function tells the probability μ of a driver not braking at a given $T_h$. A logistic regression with a rejectability function of the following form was performed for both the safe and the fuel-efficient run (cf. Goodrich and Boer, 1998):

$$\mu_R = \frac{1}{1 + e^{(-a\tau+b)}}$$

With the accuracy and rejectability functions the mental model boundary in the perceptual space of time headway and inverted time to collision was computed. The nominal analysis points, where ‘time headway regulation’ was satisficing, are indicated with a circle. The analysis points in case of braking are drawn as crosses. Figure 12 depicts these analysis points as well as the boundary line dividing them as well as possible.

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[6] The equation is presented in a different form in the cited paper. Nevertheless, the correctness of the form shown here was verified with the author.

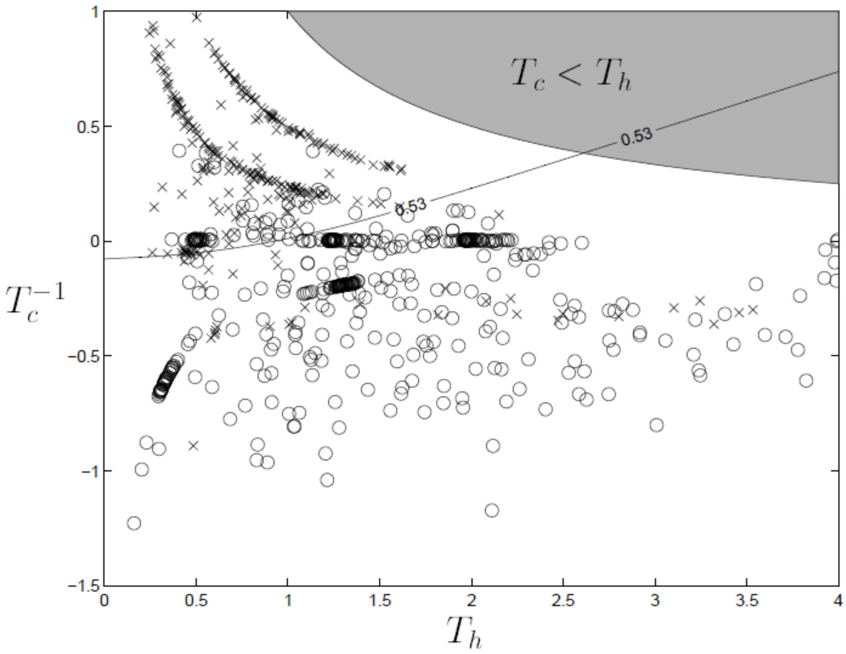



**Figure 12: Scatter plot with mental model boundaries in the perceptual space of time headway and inverted time to collision © 1998 IEEE (Goodrich and Boer, 1998)**

For nominal behaviour the accuracy function is larger than or equal to the rejectability function, because the benefits outweigh the costs (cf. Goodrich and Boer, 1998):

$$S_b = \{\theta_{RB} : \pi_A(T_C^{-1}) \geq b\mu_R(T_h)\}$$

For braking behaviour the opposite equation applies, as the rejectability function is larger than the accuracy function (cf. Goodrich and Boer, 1998):

$$S_b^C = \{\theta_{RB} : \pi_A(T_C^{-1}) < b\mu_R(T_h)\}$$

Combining the accuracy and rejectability functions, the following expression represents the line where behaviour is switched from nominal to braking (cf. Goodrich and Boer, 1998):

$$\pi_A(T_C^{-1}) = b\mu_R(T_h)$$

The coefficient b determines the boundaries' locations related to time headway ($T_h$) and inverted time to collision ($T_C^{-1}$). The classification is performed with a minimax algorithm, which minimises the maximum outcome of the following three functions (cf. Goodrich et al., 1998a). $J_1$ represents the total share of incorrectly classified analysis points, while $J_2$ stands for the share of incorrectly classified NOM and $J_3$ for the incorrectly classified BRK points.

$$J_1(\mathrm{b}) = \frac{\mathrm{N}\,[(\mathrm{NOM} \cap S_b^C) \cup (\mathrm{BRK} \cap S_b)]}{\mathrm{N}[\mathrm{NOM} \cup \mathrm{BRK}]}$$

$$J_2(\mathrm{b}) = \frac{\mathrm{N}\,[\mathrm{NOM} \cap S_b^C]}{\mathrm{N}[\mathrm{NOM}]}$$

$$J_3(\mathrm{b}) = \frac{\mathrm{N}\,[\mathrm{BRK} \cap S_b]}{\mathrm{N}[\mathrm{BRK}]}$$

The boundaries between car following and emergency braking could then be described in terms of $T_h$ and $T_C^{-1}$.

The multiple mental model framework by Goodrich and Boer (1998) is a way to measure decisions on the rule-based level in the mental model hierarchy (c.f. Rasmussen, 1983). However, this method only measures a small part of lower level mental models. The question arises whether it can be used to categorise driving styles. In the study described in this section it has been assumed, that mental model boundaries are general. It may be possible that they change, for example when drivers decide to drive very safely or fuel-efficiently. However, it is important to acknowledge the instantaneous nature of the multiple mental model framework. The concept itself does not account for behaviour change, but it is able to measure behaviour in different moments, which can then be compared in order to explore existing eco-driving mental models as in study 1.

### 3.5.6 Mental models of eco-driving

For the present thesis the theory of mental models provided the framework for studying eco-driving. Because mental models allow the investigation of drivers' cognition, ranging from conscious knowledge and strategies to automated behaviour, they are a means to investigate eco-driving in a high degree of detail.

To date, mental models have been researched by observing behaviour in experiments (e.g. Goodrich and Boer, 2003, Henning et al., 2008), but also by using questioning techniques and interviews (e.g. Bellet et al., 2007, Morgan et al., 2002). Both sets of methods were applied in the studies in the present thesis. Past research suggests that drivers possess eco-driving mental models. In experiments by Waters and Laker (1980) and van der Voort et al. (2001), as summarised in section 2.3.4, drivers were asked to eco-drive, without further explanations. The resulting behavioural changes indicate that these participants possess the necessary knowledge and skills they need to considerably reduce their fuel consumption. In the present thesis these findings were supplied with more detailed insights about the mental models responsible for eco-driving. The research gaps are explored in the relevant study chapters in the sections 4.2.3 and 5.2.3.

Some applications of mental model research in the general driving domain are potentially suitable for studying eco-driving. For example, the current thesis includes the modelling and comparison of mental model boundaries on the skill level (Goodrich and Boer, 2003, Rasmussen, 1983). Specifically the mental models for car-following, which is understood as time headway regulation, and active braking are of interest. This theoretical framework for mental model boundaries is explained in detail in the previous section 3.5.5. When the distance to the vehicle in front is within certain limits, car-following is satisficing, which means appropriate for the situation. Here the mental model for time headway regulation is activated. When certain thresholds are crossed, say the distance is becoming too short, car-following ceases to be satisficing and the corresponding mental model is deactivated. Instead, the driver is switching to active braking by stepping on the brake pedal in order to avoid a collision. In order to simplify the analysis, the switch from car-following to active braking as well as the switch back to car-following are examined at the same time. These boundaries can help explaining how drivers make decisions about safety margins during longitudinal vehicle control on the rule level. This method has not been used to compare intra-individual differences between boundaries varying with driving styles and goals, for example. Hence, in the first study in the present thesis, see section 4.4.7 for the results, it was investigated, if the boundary between car-following and active braking changes when people eco-drive.

## 3.6 Summary and conclusions

This chapter provided an overview of mental model theory and research, beginning with their historical and philosophical foundations and concluding with applied concepts in driver behaviour research. The purpose of this chapter was the definition of the concept of mental models and to provide an overview of its varied uses. It is not within the scope of the present thesis to arrive at definite conclusions about mental models, nor to mirror neurological processes in the human brain. Instead, mental models are viewed as a construct, enabling the exploration and understanding of human cognition, in this thesis particularly during driving.

The broad range of views and approaches discussed in this chapter were narrowed down to a set of main points that will form the basis of the present thesis. The major theoretical underpinning for the definition of mental models is drawn from works by Johnson-Laird. According to him, mental models are defined as representations of reality (Johnson-Laird, 1988), which are stored in people’s minds. These representations are stereotypical; they neither have to be correct, very elaborate nor exactly defined. Rasmussen provided a hierarchy of mental models (Rasmussen, 1983), organising them into knowledge-, rule- and skill-based levels. These levels allow studying people’s conscious thoughts, as well as ingrained, automated behaviours. Goodrich and Boer (2003) then brought this hierarchy into the driving domain, showing how drivers make decisions to switch from one skill to another.

Mental models enable the investigation of drivers’ cognition in a way that other psychological paradigms do not allow to the same degree. For example, common approaches for the study of eco-driving are based on the theory of planned behaviour (Ajzen, 1991), which are usually conducted with closed questions in questionnaires (e.g. Cristea et al., 2012, Schießl et al., 2010), and attempt to predict behaviour without considering the mechanisms leading to decision making (Stillwater and Kurani, 2013). Other approaches are based on economic assumptions, basically that humans are constantly optimising utility functions. Satisficing decision theory (Goodrich et al., 1998b) is based on two contrasting utility functions, but takes lower-level mental models as well as human limitations in decision making into account.

The existing literature that links mental models and driving is predominantly focussed on mathematical approaches and measurements of behaviour. Indeed, the major part of the work presented in the following chapters is based on quantitative measures. However, several qualitative elements were added in order to further explore drivers’ thoughts, knowledge and decisions. The associated methods include interviews, think-aloud protocols and open questions in questionnaires.

In the present thesis people’s driving behaviour was measured as they were asked to perform different driving styles. These measurements enabled making inferences on their automated behaviour as well as on their strategies they select to reduce fuel consumption. In addition, qualitative techniques were used to gather insights into the parts of eco-driving mental models that drivers are able to verbalise.

# 4 Study 1: Investigating drivers’ approaches to reducing fuel consumption: An experimental study on mental models of eco-driving

## 4.1 Introduction

In 2012 road transport accounted for 19% of the total carbon dioxide emissions in the EU (European Environment Agency, 2014). One promising means to reduce these emissions is eco-driving, which is a set of behaviours that drivers can implement to save fuel (Mensing et al., 2014). An overview of eco-driving behaviours that can be practised in a given passenger car on a given route is provided in section 2.2.2. It has been found that eco-driving is able to facilitate a decrease in fuel consumption and therefore carbon dioxide emissions of conventional internal combustion engines by 5 to 10% (Barkenbus, 2010).

Behavioural change is challenging, though, due to educational and motivational hindrances, which are discussed in section 2.3.2. However, fuel savings have been attained with in-vehicle technology providing continuous real-time feedback on parameters such as pedal pressure, gear or miles per gallon (e.g. Hibberd et al., 2013, Kim and Kim, 2012, Nouvelière et al., 2012, van der Voort et al., 2001). The underlying question of this study is the degree to which drivers need close guidance by complex support systems. Drivers may already have some understanding of eco-driving and therefore need guidance in a different form than currently assumed (Stillwater and Kurani, 2013). Using mental model research, this study was able to explore drivers’ knowledge and skills of eco-driving and to highlight their information requirements.

## 4.2 Background

### 4.2.1 Rationale and objectives

Eco-driving campaigns have traditionally been assuming a knowledge gap that needs to be filled (Delicado, 2012), and many support systems have been designed to closely guide drivers, fine-tuning their proficiency (e.g.

Wada et al., 2011). However, there has been evidence that drivers have some idea of eco-driving, indicated by behavioural changes when they are asked to drive fuel-efficiently (Birrell et al., 2010, van der Voort et al., 2001, Waters and Laker, 1980).

In this research eco-driving mental models were investigated in a driving simulator experiment supplemented with think aloud protocols and open interviews. The research presented here aimed to identify a set of mental models regular drivers have of eco-driving on different cognitive levels (cf. Rasmussen, 1983) by measuring changes in their behaviour and thoughts after being asked to drive in an eco-friendly manner. The measures were contrasted to their usual (Baseline) driving, but also safe driving behaviour. The Safe condition was added to contrast eco-driving with safe driving and identify conflicts between these driving styles. The Safe drive also enabled distinguishing the specific effects of eco-driving instructions from the simple introduction of any type of experimental instruction beyond 'drive normally'. The rationale is that instructions can possibly increase attentional resources and improve performance, as drivers deliberately control their behaviour (Trick and Enns, 2009). This study specifically examined longitudinal driving behaviour. Behavioural measures included acceleration, speed choice, coasting and braking behaviours. Decelerating measures consisted of the use of the brake pedal and coasting. Coasting was described by Beusen et al. (2009) as smooth deceleration by releasing the accelerator pedal while not pressing the brake pedal. Cruising is free-flow driving, with no car in front, whereas car-following was defined by Vogel (2002) as maintaining a headway to a car in front of a maximum of 6 seconds.

Study objectives:

- The investigation of the existence of mental models of eco-driving on different cognitive levels with a driving simulator experiment
- The measurement of changes in behaviours and focus when drivers are asked to drive fuel-efficiently
- The identification of eco-driving strategies and their comparison with baseline behaviours

### 4.2.2 The measurement of drivers' mental models

In order to explore mental models of eco-driving a range of methods were combined in this study. One part of the data collection was based on behavioural data measured with the controlled environment of a driving simulator. It provided the ability to compare human behaviour safely across different experimental conditions. This level of control was crucial, as the conditions differed only in a small part of the instructions given to the participants. The simulator recorded data of the drivers' actual behaviour, consciously or unconsciously controlled, and its consequences within the driving environment. These data allowed the exploration of the behavioural elements of mental models, especially the automated lower-level skills (cf. Rasmussen, 1983).

The behavioural measures were supplemented with verbal protocols and brief open interviews recorded during and after the experimental drives. Verbal data can provide information about the drivers' strategies, decisions and foci in the moment or, reflected, after driving. These data were important, as they revealed insights into what drivers consider eco-driving and where they mention safety-relevant issues and their conflicts with eco-driving. In some instances discrepancies between the participants' words and actions could be found as well. A discussion of these research methods is provided in section 4.3.2. Each of these types of data allowed the investigation of different aspects of the driving task.

### 4.2.3 Unique contribution and justification for approach

This research is unique, as there has been no other study found that specifically investigated whether drivers apply different behaviours and have different thoughts when they are asked to eco-drive compared to being asked to drive normally and safely. In several studies participants have been asked to eco-drive without further support, which resulted in behavioural changes and fuel savings. Birrell et al. (2010) focussed on the use of the accelerator pedal, in order to improve its use with haptic feedback. van der Voort et al. (2001) found that the reduction in fuel consumption was mostly due to altered gear changes. In order to test whether fuel reductions are possible without time losses, they instructed the participants to keep their trip time constant, which resulted in no significant effects for mean speed. In contrast, Waters and Laker (1980) found that drivers lowered their speed during eco-driving, and, by also using lower gears, managed to save fuel. These behavioural changes indicate that drivers possess mental models of eco-driving, and warrant an in-depth exploration, using quantitative as well as qualitative methods. In addition, it needed to be assured that the behavioural changes did not solely result from an exertion of more effort into ‘normal’ driving. In order to be able to associate such behavioural changes with the use of eco-driving knowledge and skills, an experimental condition focussing on ‘safe’ driving was added. This intervention provided the means to compare two potentially unusual driving styles with each other and ‘normal’ driving.

The research presented here used a combination of behavioural data, think aloud protocols and interviews. It was therefore able to identify mental models of eco-driving on several cognitive levels, ranging from knowledge and strategies to tactics in specific situations to automated behaviour. These insights could clarify in which areas where drivers already possess sufficient and effective knowledge and skills. Discrepancies between the ability to eco-drive and its actual practise could show where training and education for drivers is unnecessary, and thus where efforts should focus on an activation of eco-driving mental models instead. The current research may also identify gaps in the drivers’ proficiency and misconceptions, which then indicate in which aspects drivers need information, education and assistance. For example, drivers’ reluctance to eco-drive could be rooted in incorrect ideas about its implications for travel time (Eriksson et al., 2013). It was also studied whether some drivers prioritise fuel efficiency over safety during some of the experimental scenarios, and therefore increase their crash-risk in these instances. Such insights were able to help identifying situations where drivers can benefit from active safety systems that monitor following distances or remind drivers of safety.

Goodrich et al. (1998a) performed experiments in which participants drove an instrumented vehicle on a test track. The study was able to show that it is possible to model boundaries between mental models on the skill-level, see section 3.5.5. This method was later used to inform the design of an adaptive cruise control system with a model of natural human behaviour (Goodrich and Boer, 2003). This method has not been used to compare differences between boundaries in different experimental conditions, for example. In this study it was investigated, if the boundary between car-following and active braking changes when people eco-drive.

In section 3.6 it was concluded that the study of mental models is an established means to gain detailed insights into people’s knowledge and skills. Mental models investigate human cognition beyond the stimulus-response paradigm and help leverage cognitive processes that people are not able to access themselves. The results could shed light into the question whether drivers have mental models of eco-driving and what their content could look like. They were able to increase the understanding of the cognition of drivers utilising behavioural and verbal data. However, the scope of this research is limited. Although a large amount of information about eco-driving mental models could be collected, the resulting picture is neither complete nor conclusive. In addition, the design implications for EDSS are preliminary. Therefore the results of this study need to be extended and validated in future research.

## 4.3 Methodology and research environment

### 4.3.1 The University of Leeds Desktop Driving Simulator

This research consisted of an experiment using a desktop driving simulator, see Figure 13. According to the AIDE project (Rimini-Döring et al., 2005) this simulator can be classified as a type A, or low-level, system, which is usually equipped with a plasma screen and game-like controls. This simulator was ideal for the purposes of the current study, which required the collection of behavioural data to establish the existence and details about the content of eco-driving mental models. A driving simulator provides a highly controlled environment, in which variables such as weather and traffic flow can be held constant, thus each driver is faced with the same conditions (Boyle and Lee, 2010). The operational controls include a screen and steering wheel placed on a desk and a set of pedals for on the floor. This setup was sufficient to allow the participants to perform longitudinal vehicle control. The software has been continuously developed by the driving simulator team in the University of Leeds. The vehicle’s behaviour is determined by an engine model from a 2002 Jaguar X-type and braking data from a Ford Mondeo, assuming a normally aspirated 2l, V6 petrol engine. The vehicle’s reactions are based on its engine speed, accelerator position and the resulting engine torque output. The fuel consumption data was generated by the microscopic Passenger car and Heavy-duty Emission Model PHEM (Rexeis et al., 2005). For modelling realistic effects of driving behaviour on fuel consumption a more typically sized vehicle was assumed, a Ford Mondeo Ghia with a 16V, Euro 5 petrol engine.  The low-cost, flexible and rapid setup of the desktop simulator was beneficial particularly for this study. Every participant was subjected to four experimental conditions, each of these comprising an urban and a motorway section. This means that a session with a participant involved eight road layouts, which had to be loaded separately, and could be performed in this simulator by the experimenter.

Other possible research methods relevant for driver behaviour include studies in the real world. Naturalistic driving studies, for example, involve precise measurements and observations of vehicles driving in the real world without any experimental interventions. These studies are usually conducted over a long timeframe. For instance, the 100-car study in the United States (Dingus et al., 2006, Guo et al., 2010) included 100 vehicles, which were observed for 1 year. A more controlled, quasi-experimental method involving gathering driving data from real road conditions are field operational tests (FOT). FOT is defined as "*A study undertaken to evaluate a function, or functions, under normal operating conditions in road traffic environments typically encountered by the participants using study design so as to identify real world effect and benefits*" (FESTA, 2014). The Trafisafe project (Tarkiainen et al., 2013, Tarkiainen et al., 2014), for example, involved the fitting of driver support systems into 75 vehicles driven by young male drivers and their parents in Finland. Within a time period of about 10 months changes in the novice drivers' behaviour were measured and compared to a control group of 22 drivers without support system. In contrast to a driving simulator experiment, studies on real roads allow a more natural and richer data collection and their results are more generalisable for real-life settings. However, they are very costly and time-consuming. Extensive data collection is often necessary to gather a sufficient number of situations relevant for the aims of the research. Especially this study needed a controlled environment due to the nature of the experimental conditions, differing only by the instructions to the drivers. The real-world setting would not have been able to provide the stability between experimental drives and across the participants.

**Figure 13: The University of Leeds Desktop Driving Simulator**

For this research a comprehensive road layout needed to be built with the team at the University of Leeds Driving Simulator. The design of the road layout was based on an urban and rural as well as a motorway part. Urban and rural road elements contained one lane in each direction. These sections were suitable for junctions with traffic lights. Interactions with other vehicles were modelled on the motorway section with preceding vehicles driving and cutting in front of the participant. Several scenarios were designed to challenge the participants by creating a conflict between eco- and safe driving. These scenarios involved traffic lights that changed from green to amber when the participant's vehicle was in close proximity as well as vehicles cutting in the front of the participant on the motorway. These events were triggered with specified thresholds for TTC with the stopping line at the junction and the preceding vehicle in the adjacent lane, respectively.

### 4.3.2 Think aloud protocols and open interviews

In order to gain more detailed insights into the content of drivers' mental models, qualitative methods needed to be added to this study. These methods were intended to complement the behavioural data measured with the driving simulator. Think aloud protocols were one of these, because they allow the capture of people's momentary thoughts. For these protocols participants are instructed to speak out loud whatever is going through their minds while they perform a task. The participants are neither asked to explain nor focus on anything (Ericsson and Simon, 1980, van Someren et al., 1994). The resulting reports recorded during an experiment are understood to be verbalised excerpts from the working memory. This memory hosts mental models that are currently activated, which is explained in more detail in the sections 3.3.1 and 3.4.3. Hence, think aloud protocols represent parts of the mental models that the participants have retrieved from their long-term memory and instantiated with current information for the actual task.

The method is intended to gather themes that include higher-level goals and strategies as participants adhere to the experimenter’s instructions as well as their means to pursue them. With reference to the hierarchy of Rasmussen (1983), as introduced in section 3.3.1, this signifies that think aloud protocols measure mental models on the knowledge- and rule-levels. They are not expected to capture automated skills, because people are usually unable to verbalise them. Nevertheless, this method can aid people in verbalising thoughts they would normally not consciously access. As an indication for this, Ericsson and Simon (1980) inferred from their experience that people do not usually listen to their spoken thoughts when they think aloud. In contrast to conversational speech, they make grammatical errors and leave them uncorrected. In addition to the content of the mental models, the protocols provide information about the drivers’ perceptions and momentary foci. The uptake of sensory information in turn is guided by the currently activated mental models.

van Someren et al. (1994) provided instructions for experimenters planning to utilise think aloud protocols. It is crucial to ask participants solely to speak loudly while thinking. The reason why they are neither asked to explain nor to focus on certain themes is that conscious reflections can alter the participants’ thoughts (Ericsson and Simon, 1980). Instead, the participants need to be able to fully concentrate on their task. It is therefore sufficient to say ‘Tell me what is going through your mind.’ with the occasional hint ‘Keep talking.’ (van Someren et al., 1994). At times participants think and talk about other topics unrelated to the driving task. This is generally unproblematic, and indicates that the current behaviour is automated. Once the task is difficult enough, the speaking usually returns to it.

Think aloud protocols deliver only a part of the currently instantiated mental models, because they are inherently incomplete (Ericsson and Fox, 2011, Ericsson and Simon, 1980). They are not able to fully capture inchoate and incomplete thoughts (Ericsson and Simon, 1980), because these thoughts are usually not uttered. Synchronisation problems occur when it takes more time to say a thought out loud than to actually think it. In addition, many thoughts in the working memory are non-verbal. Typical indications for problems with think aloud protocols are complaints by participants and interruptions. If people are skilled enough in a task that it appears trivial, they are often unable to verbalise their thoughts. They could also feel obliged to bring lower-level mental models into consciousness, which can affect and especially slow down behaviour (Ford et al., 2005). Therefore tasks suitable for think aloud protocols need to be somewhat difficult for the participant. Hence, think aloud protocols are typically used for problem solving tasks (van Someren et al., 1994), but they could be adapted to the driving task in this study, because it involved instructions that were expected to be unusual for the driver.

For many people this type of speaking becomes natural after a few minutes and does not interfere significantly with the task itself. However, some scientists describe think aloud protocols as introspective and suspect that they affect the participants' thoughts and actions and therefore behavioural measures (Hutchins, 1995, Schooler, 2011). Fox et al. (2011) conducted a systematic review of 94 studies using think aloud protocols and found that the effect of think aloud protocols on the accuracy of the completed tasks was not significant. However this was valid only for those studies in which the experimenters were adhering to the recommendations given by Ericsson and Simon (1980), which are in line with those by van Someren et al. (1994). The experimenters needed to instruct their participants to speak out loud whatever went through their minds. Additional instructions for the participants, such as asking them to describe or to explain their thoughts, or to focus on a specific theme resulted in altered performance. However, even with carefully formulated instructions, it has been found that think aloud protocols can affect the speed of problem solving tasks (Fox et al., 2011). Hence, there could be effects on reaction times during driving, but such effects should be similar in each experimental condition. In addition, there are people who are not deemed suitable participants for think aloud protocols, for example people who have a different first language. Therefore the participants in this study needed to be sufficiently fluent in the English language.

Another qualitative method added to this study was the conduction of interviews with the participants after the experimental drives. Retrospection can allow information to be accessed from the long-term memory, which is more detailed than think aloud protocols. This way the researcher was able to identify reasons for ‘why’ drivers were performing certain actions, which think aloud protocols are not able to. However, retrospection is affected by the unreliability of memories. Memories are often reported in a more structured manner compared to the thoughts during a task. Furthermore people often interpret their memory and try to conform to expectations. Therefore, retrospection might lead to the ignorance of relevant information, especially unsuccessful steps towards solving a problem. Yet, retrospective interviews have been shown to be useful in gathering information about people’s mental models (Morgan et al., 2002). It was decided to pose open questions such as “What did you do?” and “What did you think?” These questions refer to people’s awareness of their actions and to their thoughts during these actions. As humans can regard behaviours on different cognitive levels (cf. Vallacher and Wegner, 1987), their answers are expected to cover a large variety of facets.

Another possible method to gather verbalisations is introspection, which involves the interruption of a task at several points and asking participants to report on it. This method is able to leverage people’s working memory. However, similar to retrospection, participants are often interpreting their thoughts. Due to the interruption they are disturbed in their task or given the opportunity to plan further actions, which would affect their behaviour. Hence, this type of introspection was not applied in the current study.

### 4.3.3 Apparatus

The experiment was conducted with the desktop driving simulator described in section 4.3.1. The version used in this research is equipped with a Logitech G27 Racing Wheel for steering. Placed on the floor were accelerator, brake and clutch pedals, but the clutch was not in use for this experiment. A sound system with a speaker mimicked the sound of the vehicle’s engine and other road noise. The simulator collected data at 60 Hz, which included data inferred from the driver’s inputs, such as steering wheel angle, brake pedal pressure and accelerator pedal angle, data describing the movement and position of the vehicle in the form of speed, acceleration and deceleration. Data related to other vehicles on the simulated roads included TTC and time headway to preceding vehicles. Specific time stamps, for example when the participant vehicle passed specified locations or when events were triggered, were recorded separately. A Sony voice recorder was placed next to the simulator to record all verbalisations. A picture puzzle forming the words ‘Institute for Transport Studies’ was arranged on a separate table.

### 4.3.4 Design

A three-way (4x2x2) mixed design was employed, with Instruction as a within-subjects factor with 4 levels. Each level corresponded to an experimental drive with different instructions (‘Baseline 1’, Safe’, ‘Eco’, and ‘Baseline 2’), Table 1.  The Baseline conditions were always conducted as the first and the last drive of the experiment. For these drives the participants were asked to drive ‘normally’, as they would every day, so these drives could provide data to measure people’s usual driving behaviour as well as to evaluate practice or boredom effects by comparing Baseline 1 with Baseline 2. For the ‘Safe’ and ‘Eco’ drives the participants were asked to drive safely or fuel-efficiently, respectively. No further explanations, for example what ‘fuel-efficient’ means, were provided with the instructions. One between-subjects factor Intervention (2 levels) refers to the sequence in which the second and third drives were completed. These were counterbalanced to account for order effects and the participants were randomly assigned to a Group. The second between-subjects level is Gender (2 levels).

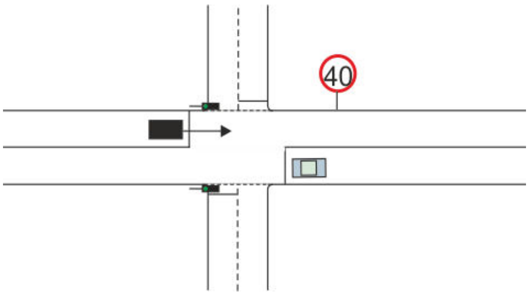
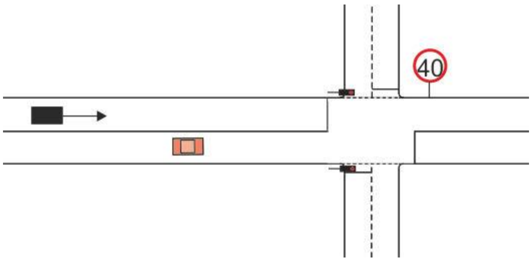
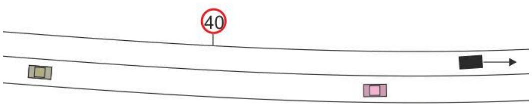
**Table 1: The order of instructions**

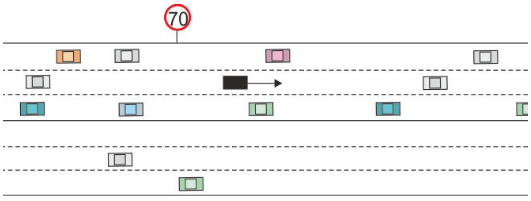
| Simulator drive | Group 1 | Group 2 |
|---|---|---|
| 1 | “Drive normally.” (Baseline 1) | “Drive normally.” (Baseline1) |
| 2 | “Drive safely.” (Safe) | “Drive fuel-efficiently.” (Eco) |
| 3 | “Drive fuel-efficiently.” (Eco) | “Drive safely.” (Safe) |
| 4 | “Drive normally.” (Baseline 2) | “Drive normally.” (Baseline2) |

### 4.3.5 Driving scenarios

A varied test layout was created with an urban and a motorway section with ambient traffic. The urban section consisted of a road with one lane in each direction, no traffic in the participant’s lane and several junctions. The posted speed limit was 40 mph (64 km/h). The motorway section comprised three lanes in each direction. The surrounding traffic was driving at or below the speed limits for UK motorways (UK Government, 2015b). Because the middle and right lanes are reserved for overtaking (UK Government, 2015a), the traffic in the right lane drove 70 mph (113 km/h), 65 mph (105 km/h) in the middle lane and 60 mph (97 km/h) in the left lane. Five scenarios were developed, as listed in Table 2. Most scenarios provided an opportunity for the drivers to practise eco-driving. These included the acceleration scenario to test whether the participants accelerate more smooth during eco-driving. The long-range braking and the two-junction scenarios allowed measuring whether the participants approached the junctions with a lower speed during eco-driving.  A cruising scenario with free-flow driving was added to test whether speed choice changed during safe and eco-driving and how smoothly the cruising speed was maintained. The expected eco-driving behaviours are hypothesised in section 4.3.7. Two scenarios were designed to challenge eco-driving behaviours with safety-critical situations. These scenarios tested whether the participants prioritised safety or took risks in order to maintain a constant speed. One of them was a short-notice braking scenario with a junction requiring sudden and strong braking when the traffic lights switch to red. The other scenario took place on a motorway and involved vehicles cutting in front of the participant at different values for TTC, some of which required immediate reactions as well. Unlike the scenarios described above, the safety-critical scenarios were not solely defined by their location on the road such as the acceleration scenario which began at a junction and ended about 350 meters after it. The reason is that the safety-critical scenarios involved critical events, which necessitated taking the host's speed into account in order to avoid that, for example, low speeds would not result in larger margins allowing much more reaction time. Hence, the beginning of the relevant data collection was triggered by the participant vehicle's TTC with either the stopping line at a junction or with a car in an adjacent lane on the motorway.

**Table 2: Driving scenarios**

| Road layout | Scenario description |
|---|---|
| Acceleration<br> | The acceleration scenario necessitated that the participant was stationary at a red traffic light that then switched to green. They then accelerated to the speed limit.<br>Data capture commenced when the traffic light turned green and ended approximately 350m later. |
| Braking<br> | The traffic lights were timed in two different ways. In the long-range braking scenario, the traffic lights were red from the point where the participant was 350m before them, whilst in the short-notice braking scenario turned red when the driver's the time to collision (TTC) with them was 3.5 seconds. The scenarios ended when the traffic lights turned green and therefore required drivers to bring the vehicle to a stop at a red traffic light. |
| Two-junction scenario<br> | The two-junction scenario began when the traffic lights at one junction turned green and in the same time the traffic lights of another junction, 252m further down the road, turned red and remained red until the participant stopped there. |
| Cruising<br> | The cruising scenario consisted of road sections with slight curves, 250m long. This scenario occurred several times in each urban section and had the secondary purpose to create space between the scenarios involving junctions. |

| Road layout | Scenario description |
|---|---|
| | Cruising involved free flow driving with no traffic lights present. |
| Motorway   | On the motorway the participants were required to drive into the middle lane and follow a lead vehicle. This motorway section included ten events whereby adjacent vehicles cut into the participants' lane ahead of them. |

Every drive included a combination of scenarios. Four sets of an urban and a motorway road layout were created. One of them is illustrated in Figure 14 and Figure 15. In each urban road layout the scenarios were positioned in a different sequence to avoid the participants getting familiar with the traffic light timings. The acceleration and braking scenarios occurred twice in each drive, and both instances were relevant for the analysis. For example, when the measure for average acceleration in the acceleration scenario was calculated, the average value from both occurrences within a drive was used. Accordingly, the measure for maximum acceleration was the largest accelerator pedal angle of both acceleration scenarios.


**Figure 14: Example of an urban section with acceleration, braking and cruising scenarios**


**Figure 15: Motorway section with car-following and cut-in scenarios**

The urban road layouts were allocated to the experimental drives using the Latin square method to control for order effects. Figure 16 depicts this allocation. The first line in the table shows that participant ‘1’ performed the first experimental drive with road layout ‘1’, the second experimental drive with road layout ‘2’ and so on. Participant ‘2’ had road layout ‘4’ assigned for the first experimental drive, then road layout ‘1’ for the second drive, counting the road layouts from here. This allocation ensured that the urban road layouts were evenly distributed among the drives and participants.

| Participant \ Experimental drive | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 1 | 2 | 3 | 4 |
| 2 | 4 | 1 | 2 | 3 |
| 3 | 3 | 4 | 1 | 2 |
| 4 | 2 | 3 | 4 | 1 |

**Figure 16: Distribution of urban road layouts using Latin squares**

### 4.3.6 Dependent variables

The data recorded in this study included objective, behavioural measures as well as subjective verbalisations. The speed measures, as well as the x- and y-positions of the vehicle on the road, were used to model the fuel consumption. Objective measures were recorded for entire road layouts, except for the start and end sections, as well as for the distinct scenarios taking place within each drive, which are relevant for each of the longitudinal measures of interest. Measures related to the drivers’ inputs were extracted. These included mean and maximum values for the accelerator pedal angle and brake pedal pressure. For scenarios involving braking, the points, where the foot was put on or taken off the brake pedal, were relevant as well. Mean and standard deviation values were calculated for speed, acceleration and deceleration. In addition, measures that relate the position of the participant vehicle to junctions and other vehicles were included in the analyses. These measures consisted of distance, time headway and TTC.

All verbalisations needed to be brought into a form that enabled quantitative analysis. Therefore the recordings of the think aloud protocols and interviews were transcribed and then further processed in NVivo. To date no existing theoretical framework suitable for coding the transcriptions of this study has been identified. Therefore it was decided to use a bottom-up approach. The first-level coding was performed with Initial Coding (Charmaz, 2006). The text was divided into small, but meaningful chunks, which were then assigned to suitable categories (nodes). These nodes were created and refined during this process. This way the whole of the transcriptions was coded into nodes of a fine granularity. For the second-level coding these nodes were summarised with Subcoding (Miles and Huberman, 1994) into higher-level categories, resulting in a tree-shaped structure. Simultaneous Coding (Miles and Huberman, 1994) was applied by allowing the assignment of multiple nodes to the same statements. This was necessary, because several statements were relevant for different categories.

### 4.3.7 Hypotheses

*Hypotheses for the quantitative analysis of driving behaviour*

The primary hypothesis tested in this study was based on earlier findings that drivers behave differently once they are asked to eco-drive (Birrell et al., 2010, van der Voort et al., 2001, Waters and Laker, 1980). This effect could be observed in different ways, depending on the eco-driving strategy that the drivers selected. Some drivers aim to accelerate swiftly to efficient speeds (cf. Mensing et al., 2013), which are then kept as constant as possible by the avoidance of unnecessary acceleration and braking (Andrieu and Pierre, 2012, Delhomme et al., 2013). Other drivers decide to accelerate as smoothly as possible (cf. Birrell et al., 2010, Johansson et al., 1999) and drive at lower cruising speeds (Harvey et al., 2013). For safe driving, too, it was expected that the participants would lower their speed limit or at least adhere more strictly to the speed limits (Cristea et al., 2012). In addition it was tested whether drivers attempted to smoothen their pedal actions during eco-driving. Such an effect could be shown with maximum values for pedal pressure and angle (af Wåhlberg, 2007, Birrell et al., 2014, Birrell et al., 2010, Ericsson, 2001) as well as the variability of positive and negative acceleration. A low variation of acceleration and deceleration implies fewer pedal corrections and therefore better eco-driving performance (cf. Hibberd et al., 2015). Time losses during eco-driving were expected, although they have been shown to be smaller than drivers typically estimate (Eriksson and Svenson, 2012).

The safety-critical scenarios were designed to present conflicts between safe and eco-driving (cf. Young et al., 2011). During the safe drive it was expected that the drivers would maintain high safety margins (Lee, 1976, Summala, 2005). In contrast, during eco-driving the participants were hypothesised to prioritise a constant speed at the expense of safety margins. They could apply more engine braking and postpone the use of the brake pedal, applying it at lower speeds and at shorter distances to a junction or hazard. This behaviour could result in the need to push the brakes hard to stop or to re-establish an acceptable car-following distance.

In an experiment by Graving et al. (2010) females increased their fuel efficiency when they were asked to, while males only changed their behaviour when provided with a continuous feedback system. Therefore Gender was added as a between-subjects variable to this study. In addition, it was tested whether the sequence of the experimental drives affected driving performance. Driving performance could change with the amount of driving due to practise and fatigue effects. In addition, it could matter if the participants were learning about the eco-driving focus of the study before or after the Safe drive.

*Hypotheses for the analysis of mental model boundaries*

For the current thesis an experiment by Goodrich and Boer (1998) was replicated. These researchers measured boundaries of the mental models for car-following and active braking. These boundaries represent those circumstances in which an activated skill is not considered satisficing anymore. Participants in their experiment were asked to follow a preceding vehicle and therefore execute the skill of ‘time headway regulation’ by pressing and releasing the gas pedal. The participants were presented with a number of cut-in events, in which another vehicle changed lanes, so it got into front of the host vehicle. If the participants changed their behaviour by stepping on the brake, it was assumed that the car following behaviour now got ‘not satisficing’, thus not good enough anymore. In this case the skill ‘brake to avoid collision’ was engaged instead. The method to model mental model boundaries by Goodrich and Boer (1998) is described in detail in section 3.5.5.

The principle hypothesis was that drivers accept lower safety margins during eco-driving compared to safe driving. This method was used with the data recorded during car-following in the motorway section, because this scenario was able to provide several similar situations, determined by varying distances to the momentary front vehicle, in which drivers had to make decisions. These situations provided a variety of data points, which enabled fitting equations to the data that predict the drivers' behaviour depending on the safety margins. In this example it was examined whether drivers pressed the brake pedal or not, and the measures for the safety margins, time headway ($T_h$) and inverted time to collision ($T_C^{-1}$), were recorded at critical points. Hence, it was expected that, for eco-driving, the mental model boundaries moved towards higher values for $T_C^{-1}$ and lower values for $T_h$, as drivers would consider closer car-following conditions satisficing, compared to safe driving.

*Hypotheses for interviews and think aloud protocols*

The verbal protocols should contain the strategies and tactics the drivers use to drive fuel-efficiently and safely. Hence, it was expected that the drivers talk about maintaining a constant speed during eco-driving, the means to achieve this and conflicts between eco- and safe driving. Both driving styles promote anticipation (Haworth and Symmons, 2001). However, it was expected that eco-driving results in an increased awareness of one's own behaviour, as the actions may not be as familiar as the Baseline and Safe driving behaviours (cf. Rasmussen, 1983).

*Summary of main hypotheses*

- When drivers are instructed to 'drive fuel-efficiently' they are expected to lower speeds as well as the variation of speed, acceleration and deceleration
- Drivers are expected to maintain a constant speed, also in safety-critical situations, and therefore apply the brake less strongly and closer to the junction, traffic sign or hazard, and lower the mean and variation of deceleration as well as do not lower their speed as much as in 'normal' driving
- Mental model boundaries shift towards smaller safety margins

- Interviews and think aloud protocols include constant speed, means to achieve this and conflicts with safety
- Focus and awareness increase towards the drivers' behaviour

### 4.3.8 Participants

Participants were recruited utilising the simulator database, printed adverts placed in different locations in the University of Leeds as well as snowball sampling. The group consisted of 16 drivers, between 26 and 43 years old, 8 of them male and 8 of them female. Their demographic information is listed in Table 3. Every participant drove at least 5000 miles per year (mean annual mileage was 8750 miles), and held a full EU license for at least two years (mean driving experience was 13.3 years). Eight of the 16 drivers had previous experience with a driving simulator, but none of them had driven the desktop simulator used in this study before. As a gesture of appreciation all participants were entered into a prize draw.

**Table 3: Participant demographic information**

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | Age (years) | Annual mileage (miles) | Driving experience (years) | Age (years) | Annual mileage (miles) | Driving experience (years) |
| Mean | 37.0 | 9000 | 16.0 | 30.6 | 8500 | 10.7 |
| Sd. | 5.5 | 2390 | 6.0 | 4.0 | 2000 | 4.6 |
| Max. | 43 | 14000 | 23 | 37 | 10000 | 20 |
| Min. | 26 | 6000 | 8 | 26 | 5000 | 5 |

### 4.3.9 Procedure

During recruitment the participants were told that the study was about 'driving styles', without mentioning the eco-driving focus, to prevent the participants preparing for the study. At the beginning of a session the participants were briefed and asked to sign a consent form. They were then given a puzzle with pictures representing letters. To practise the think aloud protocol, the participants were instructed as described by Ericsson and Simon (1980) and van Someren et al. (1994). Accordingly, they were asked to speak their thoughts out loud, while performing the simple, logical task of combining the letters to the words ‘Institute for Transport Studies’. The participants were not asked to focus on anything, just to verbalise whatever would go through their minds. If a participant was silent for several moments, they were reminded to keep talking. Further instructions and prompts were kept to a minimum to prevent any influence on the think aloud protocols. Subsequently, the participants performed a test drive to become familiar with the desktop driving simulator and with speaking during driving. The participants were told that the simulated car is equipped with a conventional petrol engine. For the experimental drives, each participant was asked to drive through an urban and a motorway section four times, according to the assigned Group. Hence, they were told to ‘Drive normally’, ‘Drive safely’ and ‘Drive fuel-efficiently’, without being given further explanations about the meaning of these driving styles. The participants were also asked to imagine that they are on the way to a meeting to avoid that they drive excessively slowly. Each drive lasted around 20 minutes. After each drive open interviews were conducted with questions such as “What did you do?” and “What did you think?” After all drives were completed, a debriefing took place, where the purpose of the study was explained and the participants had the opportunity to ask questions.

### 4.3.10 Analysis

The raw behavioural data collected by the driving simulator was processed in Matlab to extract the dependent variables, for the whole drives and separately for each scenario. Because the start and end sections had been implemented on roads where drivers would usually not stop, they were excluded from the analysis. The start section of the urban drive was about 500m long. The end section included a speed limit increase and a rural road stretch of about 900m. Data from the motorway section was used from 100 seconds after the drive began, until the end of the last cut-in scenario. The fuel consumption, as modelled with PHEM (Rexeis et al., 2005), was analysed in relation to the entire road layouts as well as separately for the cruising scenario.

In order to account for practise, fatigue and boredom effects, the Baseline 1 and the Baseline 2 drives were compared across all objective performance measures with paired-samples, two-tailed t-tests. The statistical comparison of the behavioural and verbal data of the Baseline 1 and Baseline 2 drives resulted in significant differences in 4 measures[7], Table 4. The variation of deceleration increased from Baseline 1 to Baseline 2, which could be due to the drivers anticipating the traffic light turning to red after being exposed to it three times beforehand. The decrease in mean acceleration in the short-notice braking scenario as well in the standard deviation of speed in the cut-in scenario could also be explained with a learning effect, and therefore milder reactions to the events over time. In sum, these differences did not suggest a consistent change in behaviours relevant for eco-driving between Baseline 1 and Baseline 2. Therefore it was assumed that there were no significant differences between these conditions and the Baseline 2 drive was chosen for the following analysis. ‘Baseline 2’ was referred to as ‘Baseline’ from now on. Results could have been affected by this decision, particularly with regards to the strong deceleration in the long-range braking scenario in Baseline 2, which could present a clearer contrast to the Eco condition.

**Table 4: Significant comparisons between Baseline 1 and Baseline 2**

| Variable | Scenario | Baseline 1 | Baseline 2 | p | r |
|---|---|---|---|---|---|
| Sd. of deceleration ($m/s^2$) | Long-range braking | 0.58 | 1.01 | .022 | .550 |
| Mean deceleration ($m/s^2$) | Short-notice braking | -1.75 | -1.49 | .016 | .575 |
| Sd. of speed (m/s) | Cut-in | 2.68 | 2.08 | .025 | .542 |
| Mean headway at braking termination (s) | Cut-in | 0.65 | 0.48 | .024 | .560 |

Subsequently, a mixed methods ANOVA with Bonferroni corrected post hoc pairwise comparisons was performed, with the within-subjects factor Instruction and the between-subjects factors Group and Gender. For violations of the sphericity assumption, the Greenhouse-Geisser correction was applied, because it is the most conservative method (Greenhouse and Geisser, 1959). When assumptions of parametric testing were violated, non-

[7] Differences were found in the standard deviation (sd.) of deceleration in the long-range braking scenario [t(15) = -2.55, p = .022], the mean deceleration in the short-notice braking scenario [t(15) = -2.72, p = .016], as well as the sd. of speed [t(15) = 2.50, p = .025] and the mean headway of braking termination [t(14) = 2.53, p = .024] in the cut-in scenario.

parametric methods were used. The Wilcoxon signed-rank test was applied for within-subjects factors and the p-value was corrected for multiple comparisons. The Mann-Whitney U-test was performed on between-subjects factors. Statistical significance was accepted at $p < 0.05$.

Mental model boundaries as described in section 3.5.5 were modelled using data from the motorway sections. These sections included ten cut-in events per drive and therefore provided data for several comparable situations that required the drivers to make decisions. Following the method of Goodrich et al. (1998a), these critical decision points were identified in the data. After each cut-in event on the motorway, there were two possible outcomes. One of these outcomes was that the driver considered the resulting combination of $T_h$ and $T_C^{-1}$ not satisficing and stepped on the brake (BRK). In this case, the critical decision points were the moment the participant began to depress the brake pedal as well as the moment the brake pedal was released. The second possible outcome was the case that the driver did not press the brake pedal, so either kept the accelerator pedal depressed or coasted. This behaviour was defined as nominal driving (NOM). In this case it was assumed that the driver considered the combination of $T_h$ and $T_C^{-1}$ satisficing. Two analysis points, which mark examples of acceptable states, were defined for the NOM states as well. The first one was defined as the beginning of the cut-in event, just when the vehicle performing the cut-in manoeuvre began to move from the right or the left towards the middle lane. Because of the fluctuating speed of the preceding vehicle, the second analysis point for nominal cases was defined as the minimum TTC in the ten seconds window following the onset of the cut-in event. It was assumed that after this time window the participant did not react to the event anymore and regularly followed the lead car instead.

For the first steps of the analysis the observed NOM and BRK points were regarded separately. Each set of points was shaped into a cumulative distribution function, giving each point a cumulative probability for not braking $\mu$, and this probability ranged from 0 to 1. The independent variables were $T_h$ for BRK cases and $T_C^{-1}$ for the NOM cases, represented in the accuracy ($\mu_A$) and rejectability ($\mu_R$) functions below with the term $\tau$.

$$\mu_A = \frac{1}{1 + e^{(-a\tau+b)}}$$

$$\mu_R = \frac{1}{1 + e^{(-a\tau + b)}}$$

The computation of these functions was performed using a least squares fit. The coefficients a and b resulting from the fit were then utilised for a classification of all NOM and BRK measurement points, leading to a boundary function. These coefficients were compared with a t-test. The boundary functions of the Eco, Safe and Baseline drives were then visually compared and discussed.

The verbal recordings the think aloud protocols and interviews were transcribed and processed with NVivo using a bottom-up approach. The first-level coding was performed personally by the author with Initial Coding (Charmaz, 2006). For Initial Coding the text was divided into small, but meaningful chunks, which were then assigned to categories (nodes). In order to clarify which statement belonged into which node, definitions and qualifying questions were added to the descriptions of the nodes. The content of the nodes were read regularly to ensure consistency, and statements were recoded if needed. One challenge was that several statements of the drivers included more than one aspect of driving. Hence, it was necessary to apply Simultaneous Coding (Miles and Huberman, 1994) by allowing the assignment of multiple nodes to the same statements. About 20 to 30% of the transcripts needed to be coded in multiple nodes. At the end of the first-level coding the entirety of the transcriptions was coded into nodes of a fine granularity. For the second-level coding these nodes were summarised using Subcoding (Miles and Huberman, 1994) into higher-level categories.

During detailed coding and subsequent categorisation five relevant categories were established. The category FUEL EFFICIENCY AND ECO DRIVING contains statements about eco-driving. The vast majority of these statements were uttered in the Eco condition, and only sporadically in other conditions, for example in order to draw a comparison (“`I’m just doing a bit of driving and […] focus less on the speed`”). Therefore a statistical comparison of the presence of statements in this category among the conditions was neither feasible nor meaningful. During the drives and the interviews afterwards people talked about their eco-driving strategies and evaluated their actions accordingly. It can be assumed that the drivers mentioned eco-driving when they activated eco-driving mental models. In order to closer examine the category, mentioned eco-driving strategies and techniques were counted and regarded in detail. Here the think aloud protocols and interviews provided clues about the explicit eco-driving know-how on the knowledge- and rule-based levels of Rasmussen's mental model hierarchy (Rasmussen, 1983).

The higher-level categories ACTION, SAFETY AND VIGILANCE and SURROUNDINGS were created during the coding process. The ACTION category includes every statement related to what the participant was doing, either at the moment ("`brake a bit`") or as a strategy for the drive ("`I do really need to stick to the speed limit`"). It comprises information about controlling the simulator ("`Just getting used to the controls`") as well as actions in the simulated world ("`I'm gonna accelerate to join the motorway`"). These types of actions are things the participants decided or considered to do, and they are therefore relevant for the driving styles researched in the current study. In addition to actual actions, the category includes decisions against actions ("`I'm not going to go faster`"). A large proportion of this category is about speed maintenance, car following and the selection of speed including increasing and decreasing it. The node SAFETY AND VIGILANCE includes statements about the driving environment as well as the driver's focus ("`So I keep my eye on them`"), anticipation and validation, the location and position of the participant vehicle ("`Driving behind the car in front`") as well as expressions of surprise. The SURROUNDINGS category is a subcategory of SAFETY AND VIGILANCE and includes any features in the environment that the drivers mention, for example other road users ("`He's just moving along`"), the traffic lights, the road, road and landscape features as well as events ("`Yellow to red`").

These categories facilitated the analysis of the verbalisations during driving, thus of the think aloud protocols. For each experimental condition it was determined how many words in a participant's transcriptions were coded in a category, as a percentage of the total number of their words within that drive. One participant remained silent during the Baseline 2 drive and was therefore excluded from the analysis of the verbal protocols. These percentages were subjected to ANOVAs as described for the behavioural measures above. In addition, the post-test interviews were used to gain further insights into the strategies the drivers used for eco-driving. Regularly mentioned practises were identified in an eco-driving category and counted. The number of participants who mentioned a particular technique to eco-drive was subjected to a simple non-statistical comparison and the findings of the interviews were compared to actual behaviours and discussed.

## 4.4 Results

### 4.4.1 Fuel consumption and travel time effects

The total driving time and fuel consumption were calculated separately for the urban and motorway sections. Figure 17 shows a median split of the participants by their fuel consumption in urban areas in the Baseline drive. One can see that both sides of the median, those using a high amount of fuel and those using less fuel during ‘normal’ driving manage to reduce their fuel consumption down to a similar average. In fact, every single participant achieved a reduction in fuel consumption in the urban section. A main effect [$F(2,24) = 10.89$, $p < .001$, $\eta^2 = .476$] of Instruction was found; the difference was on average 7.7%, and 6.3% compared to the Safe condition. During the Safe drive the participants used 1.7% less fuel than during the Baseline drive. Post-hoc pairwise comparisons prove these differences to be significant. An examination of the cruising scenario in isolation resulted in a strong reduction of the fuel consumption for the Eco compared to the Baseline drive, with 12.6%. The main effect was significant [$F(2,24) = 4.01$, $p = .029$, $\eta^2 = .255$], although post-hoc comparisons did not reveal a significant difference. For the motorway driving less fuel was consumed during the Eco condition compared to the Baseline condition [$F(2,24) = 8.99$, $p = .001$, $\eta^2 = .428$]. However the reduction in fuel consumption was less (2.8%). There was a main effect of Group, with the Group performing the Safe before the Eco drive consuming more fuel in every motorway drive than the Group having the Eco drive first [$F(1,12) = 5.22$, $p = .041$, $\eta^2 = .303$]. There were neither Gender nor interaction effects.

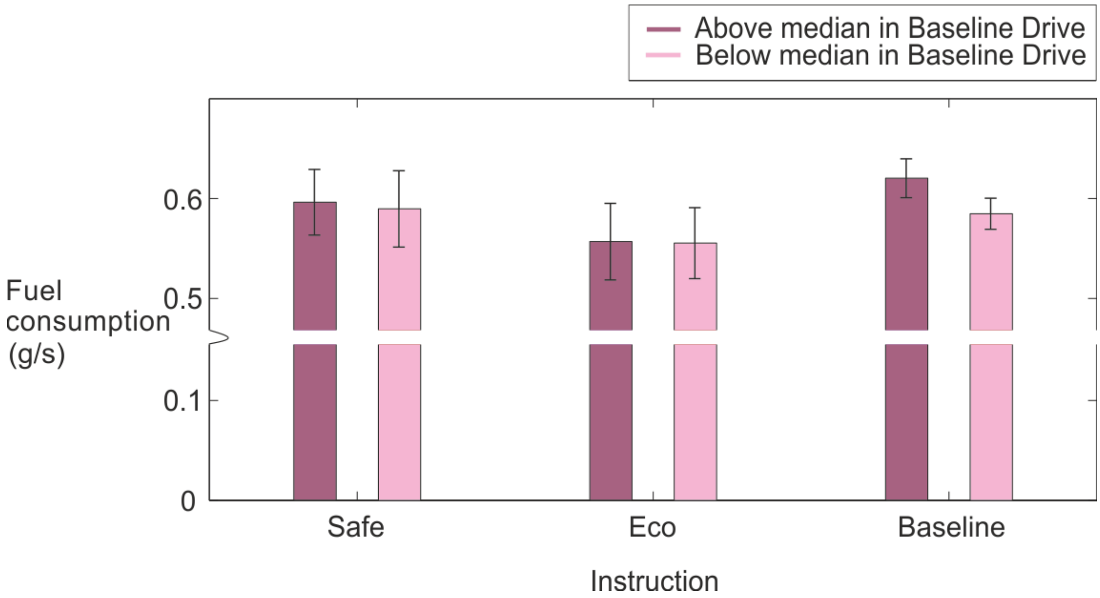



**Figure 17: Fuel consumption for participants split by the median fuel consumption in the Baseline drive**

The travel times were analysed. The urban sections took 48 seconds longer during the Eco drive compared to the Baseline drive, which lasted 7 minutes and 48 seconds [$F(1.4,16.7) = 7.84$, $p = .008$, $\eta^2 = .395$]. In the cruising scenario the Eco drive resulted in a longer time compared to Baseline (15 seconds) and Safe (11 seconds) drives [$F(2,24) = 8.55$, $p = .002$, $\eta^2 = .416$], see Figure 18 and Table 5. There were no effects for between-subjects variables and no interaction effects. In the motorway section the Eco drive lasted on average 50 seconds longer than the Safe drive [$Z = -2.482$, $p = .039$, $r = -1.433$]. Because the length of the motorway section depended on the completion of the cut-in events, this result was regarded with caution and did not inform the major conclusions of the present study.

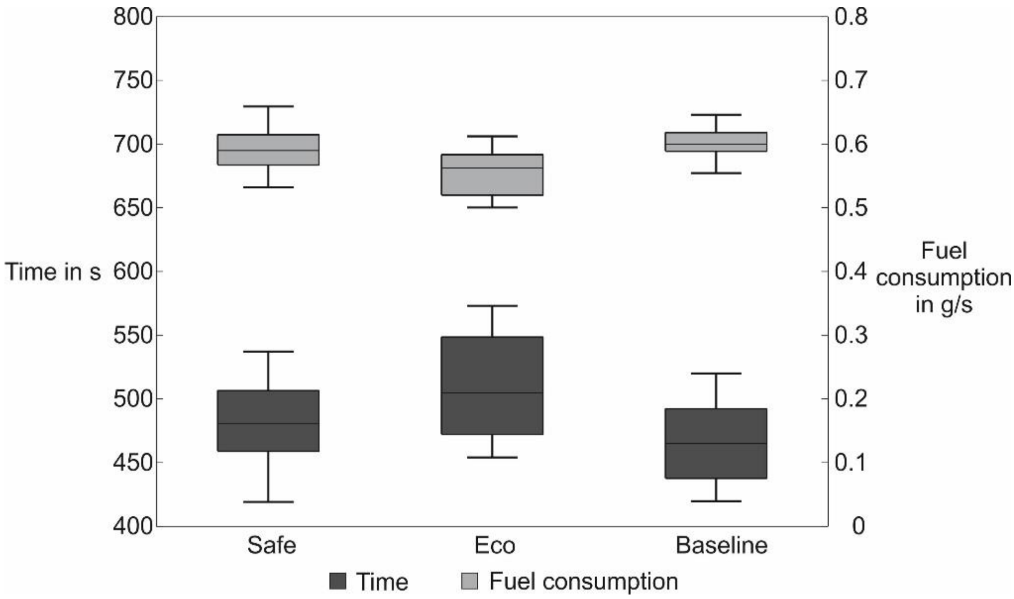



**Figure 18: Fuel consumption and total time for the urban section of the experimental drives**

**Table 5: Overall results for the urban, motorway and cruising sections**

| Variable | Safe | Eco | Baseline | Post-hoc tests | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Fuel consumption urban (g/s) | 0.59 | 0.56 | 0.60 | Eco < all other | <.001 | .476 |
| Fuel consumption cruising scenario (g/s) | 0.70 | 0.64 | 0.73 | none | .029 | .255 |
| Fuel consumption motorway (g/s) | 0.67 | 0.66 | 0.68 | Eco < Baseline | .001 | .428 |
| Time urban (min:sec) | 8:00 | 8:30 | 7:48 | Eco > Baseline | .008 | .395 |
| Time cruising scenario (min:sec) | 3:05 | 3:16 | 3:01 | Eco > all other | .002 | .416 |
| Time motorway (min:sec) | 6:14 | 7:04 | 6:31 | Eco > Safe | .039, .765 | -1.43, n/a |

### 4.4.2 Acceleration scenario

Main effects were found for all three measures of accelerator pedal angle. Fifteen of 16 drivers were accelerating with a lower standard deviation in the Eco condition compared to the Baseline drive and the effect was significant

[$F(2,24) = 8.98$, $p = .001$, $\eta^2 = .428$]. On average they achieved 25% and 28% less variation compared to the Safe and the Baseline drives, respectively. Accordingly, in the speed profiles in Figure 19 it can be seen that the speed increased gradually during eco-driving. In addition, the speed increase was less steep at the beginning and the resulting cruising speed was slightly lower, too. The spread in the middle 50% for the Safe and the Eco drives suggests a relatively high individual variation with the lower quartile of the participants accelerating extremely mildly. The statistics support that the participants accelerated less harshly on average [$F(2,24) = 10.25$, $p = .001$, $\eta^2 = .461$] with 0.34 $m/s^2$ compared to the Baseline and with 0.3 $m/s^2$ compared to the Safe drive. It is possible that the lower speed at the end of the scenario affects the previous findings. However, it was established that the drivers accelerated with less tendency to “put their foot down” [$F(2,24) = 7.10$, $p = .004$, $\eta^2 = .372$], compared to the other drives, as the maximum accelerator pedal angle was 20° lower than during the Baseline drive. In order to further explore the acceleration behaviour, the time spent with the accelerator pedal angle pressed at an angle of at least 30°, which is about a third of pedal range, was examined. It was found that during the Baseline drive the participants pressed the pedal past that point on average more than 7 times longer than in the Eco drive [$Z = 3.180$, $p = .003$, $r = .795$], and more than 5 times longer than in the Safe drive [$Z = 2.824$, $p = .015$, $r = .706$]. In order to control for cruising speed, an ANCOVA was conducted with mean acceleration. The mean cruising speed from the Eco condition was chosen as covariate, because it is the most relevant speed variable regarding effects from the eco-driving instructions. The inclusion of the speed negated a main affect ($p = .483$). Hence, differences in acceleration are indeed related to the cruising speed during eco-driving. There were significant effects neither for Gender nor for Group, and no interaction effects.

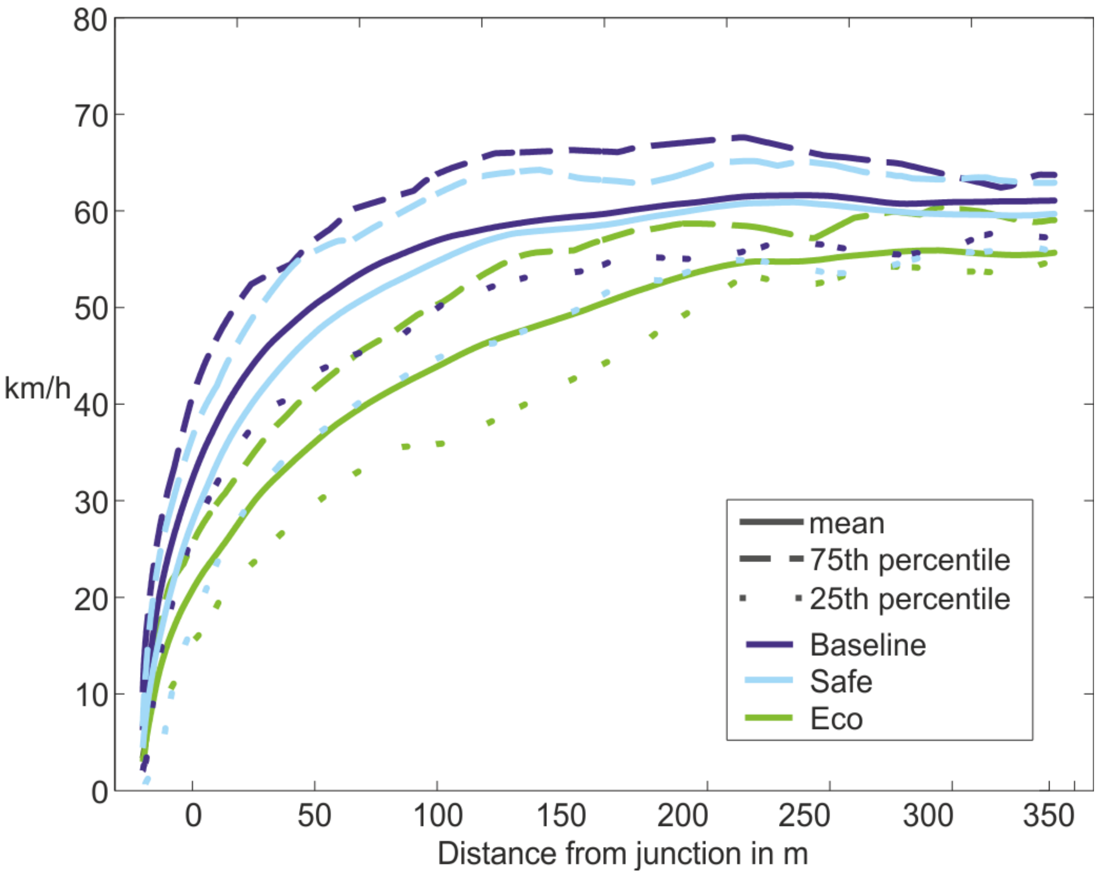



**Figure 19: Speed profile of the acceleration scenario**

**Table 6: Results for the acceleration scenario**

| Variable | Safe | Eco | Baseline | Post-hoc tests | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Mean acceleration ($m/s^2$) | 1.03 | 0.73 | 1.07 | Eco < all other | .001 | .461 |
| Time with accelerator pedal angle above 30° (s) | 2.31 | 0.46 | 3.43 | Eco < all other | .015, .003 | .706, .795 |
| Max. accelerator pedal angle (°) | 44 | 27 | 47 | Eco < all other | .004 | .372 |
| Sd. of acceleration ($m/s^2$) | 0.93 | 0.70 | 0.97 | Eco < all other | .001 | .428 |

### 4.4.3 Braking scenario

In the long-range braking scenario, where drivers had extended preview of the red traffic light, the speed profiles in Figure 20 suggest that the participants began to decelerate earlier and in a less steep manner during the Eco drive compared to the Baseline drive. During the former, all participants reduced their mean deceleration and a main effect of Instruction was found [$F(1.3,15.3) = 14.30$, $p = .001$, $\eta^2 = .543$]; post-hoc testing revealed that with -0.56 $m/s^2$ it was significantly lower in the eco-drive condition compared to the others (Safe: -0.68 $m/s^2$, Baseline: -.072 $m/s^2$), Table 7. Similar results were found for variation in deceleration with drivers instructed to drive fuel-efficiently braking more smoothly (0.76 $m/s^2$) than when instructed to drive normally (1.01 $m/s^2$) and safely (0.95 $m/s^2$) [$F(2,24) = 16.30$, $p < .001$, $\eta^2 = .576$]. No significant effects were found for measures relating to activation of the brake pedal (mean speed and time to contact with the stopping line at braking initiation and maximum brake pressure).

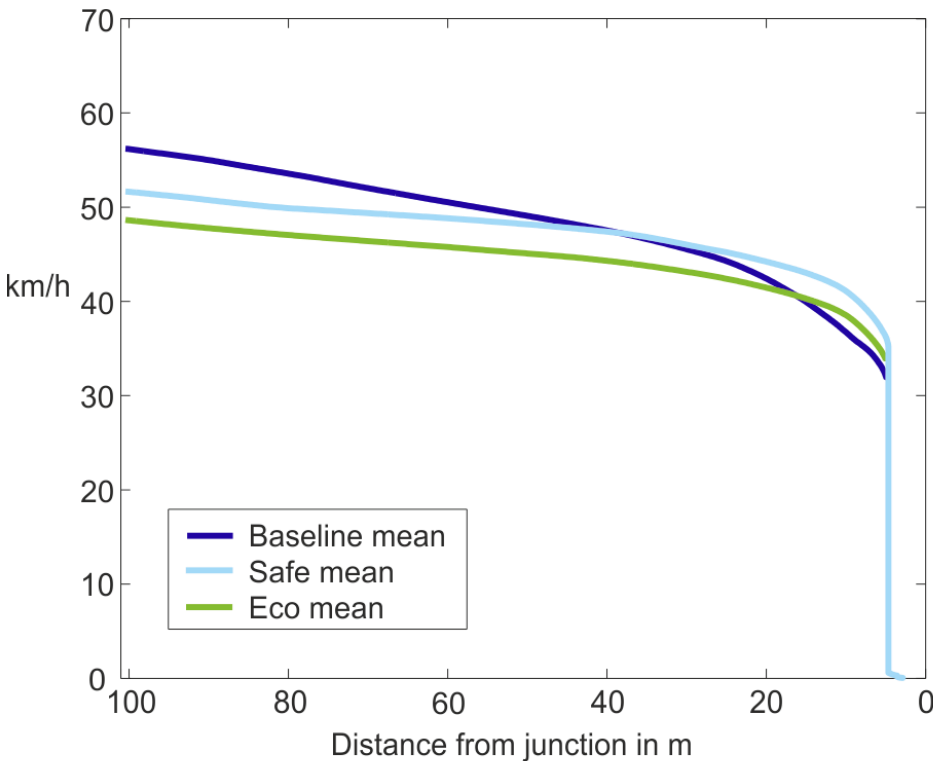



**Figure 20: Speed profile of the long-range braking scenario**

**Table 7: Results for the long-range braking scenario**

| Variable | Safe | Eco | Baseline | Post-hoc tests | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Mean deceleration ($m/s^2$) | -0.68 | -0.56 | -0.72 | Eco < all other | .001 | .543 |
| Sd. of deceleration ($m/s^2$) | 0.95 | 0.76 | 1.01 | Eco < Safe | <.001 | .576 |
| Mean speed at braking initiation (m/s) (mph in brackets) | 10.28 (23.0) | 8.74 (19.6) | 9.95 (22.3) | none | .084 | n/a |
| Time to contact with stopping line at braking initiation (s) | 6.61 | 7.38 | 6.11 | none | .227 | n/a |
| Max. brake pressure (N) | 136 | 108 | 150 | none | .150, .072 | n/a, n/a |

There was no statistically significant two-way interaction, but a three-way interaction between Instruction, Group and Gender for the standard deviation of deceleration [$F(2, 24) = 8.27$, $p = .002$, $\eta_p^2 = .408$]. This means that there was an interaction effect between Group and Instruction that was only significant for males, as shown in Figure 21. The males in the Group instructed to eco-drive before driving safely had a much more smooth deceleration in the Safe drive compared to those performing the Safe drive before the Eco drive.

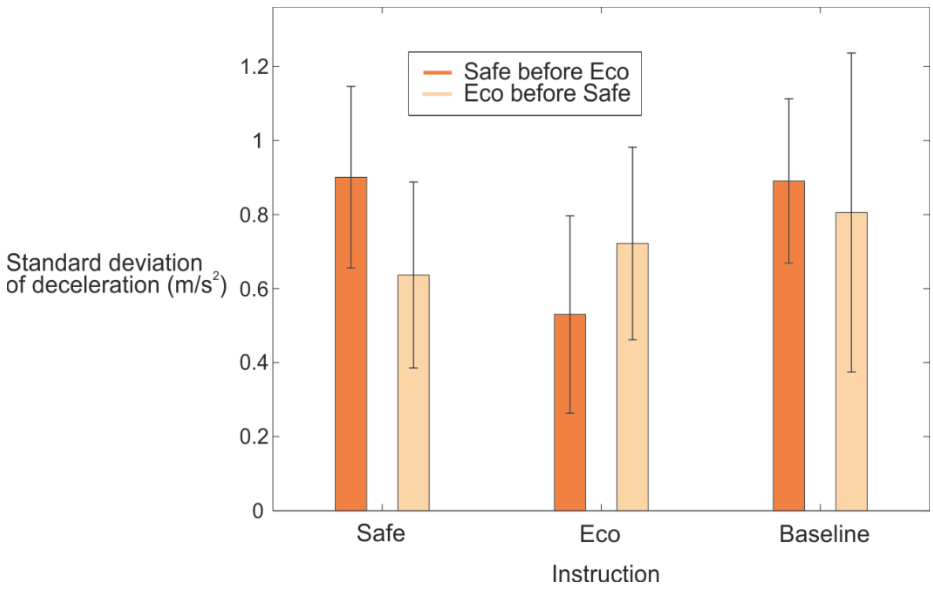



**Figure 21: Interaction effects for the sd. of deceleration for males only**

In the short-notice braking scenario the traffic lights switched to red at a time to contact of the participant vehicle with the stopping line of 3.5 seconds. During the Eco drive one participant drove through both occurrences of this scenario without stopping. An ANOVA with the deceleration parameters of the other 15 participants indicated neither a difference in mean deceleration nor in maximum brake pressure. However, the average maximum brake pedal pressure for eco-driving was 10 N lower compared to the Baseline and 6 N lower compared to the Safe condition (159 N). These results are summarised in Table 8. For the Baseline drive it was found, that with an average of 195 N females pushed the brake pedal harder than males, by 136 N ($U = 55.5$, $p = .030$, $r = 0.645$). No effects were found for Group nor for interactions.

**Table 8: Results for the short-notice braking scenario**

| Variable | Safe | Eco | Baseline | Post-hoc tests | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Mean deceleration (m/s²) | -1.49 | -1.51 | -1.49 | none | .997 | n/a |
| Max. brake pressure (N) | 159 | 153 | 163 | none | 1.038, .417 | n/a, n/a |

### 4.4.4 Two-junction scenario

The two-junction scenario occurred once in every second drive to reduce the likelihood of the participants recognising it and adjusting their behaviour accordingly. Therefore every participant was faced with this scenario in either Baseline 1 or the Baseline 2 as well as in either the Safe or the Eco drive. In this case, both Baseline drives were combined into one 'Baseline' condition, and then compared with the Eco drive using a paired-samples t-test. Because each participant experienced the two-junction scenario in either the Safe or the Eco drive, these drives were analysed with an independent-samples t-test. For each test, p-values were Bonferroni-corrected.

Figure 22 depicts the speed profiles for this scenario. The drives appear to differ considerably at the beginning of the scenario when the participants were increasing their speed. Indeed, during the Eco drive the mean acceleration was about 30% lower on average than in the Baseline condition and this difference prove to be significant ($t(7) = -3.90$, $p = .006$, $r = 0.827$). This difference in acceleration is reflected in the maximum accelerator pedal angle, which was on average 37% lower during the Eco drive compared to the Baseline drive ($t(7) = -6.80$, $p < .001$, $r = .932$). In fact, all of the 8 participants faced with the two-junction scenario during their Eco drive achieved a lower maximum accelerator pedal angle than in their Baseline drive. There were no significant effects for the maximum speed the participants achieved between the junctions. Instead, the speed profiles indicate a wide spread between the participants, illustrated by the lower and higher quartiles of the Safe and Eco drives towards the second junction. However, there was a tendency; and the maximum speed was about 19 % lower on average for the Eco drive compared to the Baseline drive.

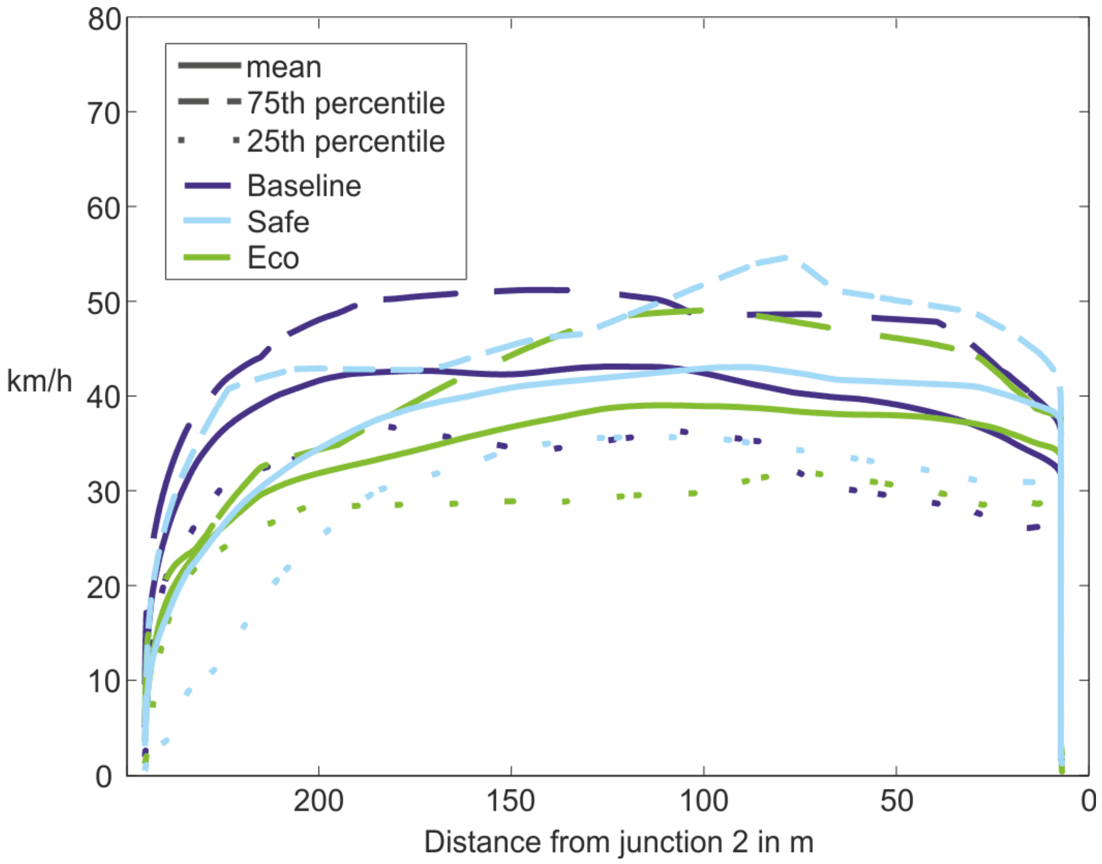



**Figure 22: Speed profile of the two-junction scenario**

It was analysed whether the participants released the accelerator pedal at different speeds during the experimental drives. A significant effect was found for the Eco drive, in which participants terminated the acceleration on average at lower speeds compared to the Baseline condition ($t(14) = 3.254$, $p = .042$, $r = .776$). These results are listed in Table 9. There were no significant effects for between-subjects variables, nor could any interaction effects be identified.

**Table 9: Results for the two-junction scenario**

| Variable | Safe | Eco | Baseline | Post-hoc | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Mean acceleration ($m/s^2$) | .93 | .82 | 1.17 | Eco < Baseline | .449, .006 | n/a, .827 |
| Max. accelerator pedal angle (°) | 27 | 22 | 35 | Eco < Baseline | <.001 | .932 |
| Max. speed (m/s) (mph in brackets) | 13.4 (30) | 11.6 (26) | 14.4 (32) | none | .279, .051 | n/a, n/a |
| Speed at first termination of acceleration (m/s) (mph in brackets) | 10.8 (24) | 10.6 (24) | 13.6 (30) | Eco < Baseline | .931, .042 | n/a, .776 |

### 4.4.5 Cruising scenario

The results for the cruising scenario are summarised in Table 10. Fifteen of all 16 participants lowered their mean speed in the Eco drive compared to the Baseline drive. There was indeed a significant main effect of Instruction on this measure [$F(2,24) = 20.7$, $p < .001$, $\eta^2 = .633$]. Post-hoc analysis indicated that for the Eco drive the mean speed was significantly slower than for all other conditions, about 5% lower than Safe and 7% lower than Baseline driving. There was no main effect of Instruction on the standard deviation of speed, so the speed was not kept more constant during eco-driving. However, there was a main effect on the standard deviation of acceleration [$F(2,24) = 15.2$, $p < .001$, $\eta^2 = .505$]. Post-hoc comparisons revealed that with 0.28 $m/s^2$ the acceleration was more smooth during eco-driving than in the other drives (Safe: 0.36 $m/s^2$, Baseline: 0.41 $m/s^2$). There were no effects for Gender.

**Table 10: Results for the cruising scenario**

| Variable | Safe | Eco | Baseline | Post-hoc | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets) | 17.5 (39) | 16.6 (37) | 17.9 (40) | Eco < all other | <.001 | .633 |
| Sd. of speed (m/s) (mph in brackets) | 1.40 (3.13) | 1.54 (3.44) | 1.36 (3.04) | none | .402, .189 | n/a, n/a |
| Sd. of acceleration ($m/s^2$) | 0.36 | 0.28 | 0.41 | Eco < all other | <.001 | .505 |

There was a significant interaction effect for the variation of acceleration between Group and Instruction [$F(2, 24) = 3.54$, $p = .045$, $\eta_p^2 = .228$]. Figure 23 indicates that those who performed the Safe drive before the Eco drive subsequently had a 33% higher variation in their acceleration in the Baseline drive.

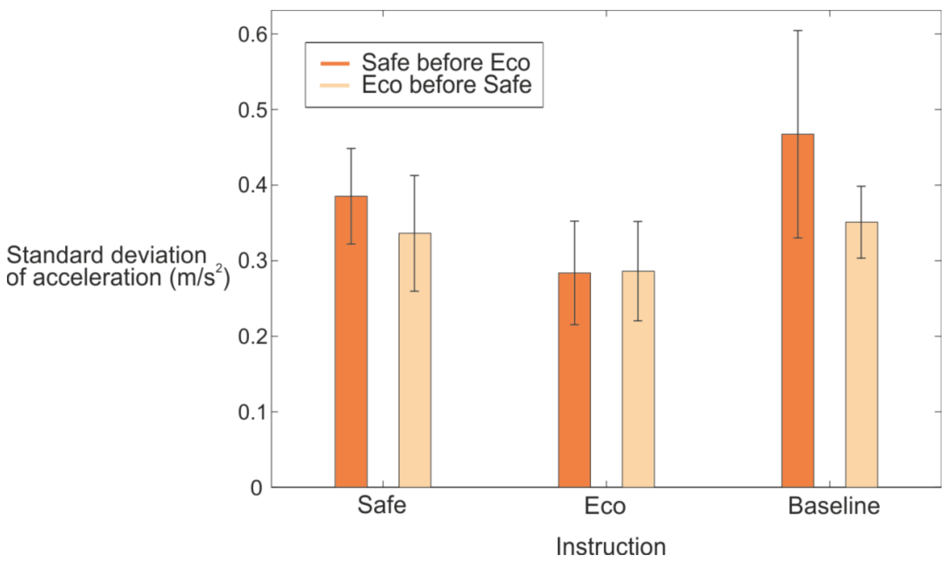



**Figure 23: Interaction effect between Group and Instruction in the cruising scenario**

### 4.4.6 Motorway scenario

Figure 24 shows the distribution of mean time headways, split into bins with the length of 1 second, in the Safe, Eco and Baseline conditions. It can be seen that there is a greater range of headways in the Eco condition, and a main effect of Instruction was found [Eco/Safe: $Z = -2.637$, $p = .024$, $r = -1.522$; Eco/Baseline: $Z = -3.154$, $p = .006$, $r = -1.821$]. The mean headway was on average 1 second longer than in the Safe and 1.15 seconds longer than in the Baseline condition, Table 11. In addition, the standard deviation of time headway was significantly larger during the Eco drive compared to the Safe and Baseline drives [Eco/Safe: $Z = -2.534$, $p = .033$, $r = -1.463$; Eco/Baseline: $Z = -3.258$, $p = .003$, $r = -1.881$]. However, by limiting the analysed data to headways with a maximum of 6 seconds, which is an approximation for car-following using findings by Vogel (2002), the effect diminished. Nevertheless, Figure 25 depicts the distribution of mean time headways smaller than 2 seconds. Within 2 seconds, assuming a speed of 65 mph, which is the average speed of the ambient traffic in the middle lane, one would travel about 58 metres. In case of an event, it can take at least 1 second until an initial accelerator pedal release and at least another second until the brake pedal is depressed (McGehee et al., 2000), these time ranges indicate safety-critical differences between the drives. It supports the finding that the headways tended to be largest during the Eco condition, and the tendency that headways were slightly larger for Safe than for Baseline driving. Tests with standard deviation values show that accelerations were smoothest in the Eco condition [$F(2,24) = 10.73$, $p < .001$, $\eta^2 = .472$], and decelerations were more smooth in the Eco than in the Safe condition [$Z = -2.430$, $p = .045$, $r = -1.403$]. For the Group performing the Eco before the Safe drive, the variation of deceleration was significantly lower during the Baseline drive compared to the other Group ($U = 7.00$, $p = .021$, $r = -0.657$). During the Eco drive the decelerations the variations was significantly lower for males compared to females with a difference of 43 % ($U = 55.0$, $p = .045$, $r = 0.604$).

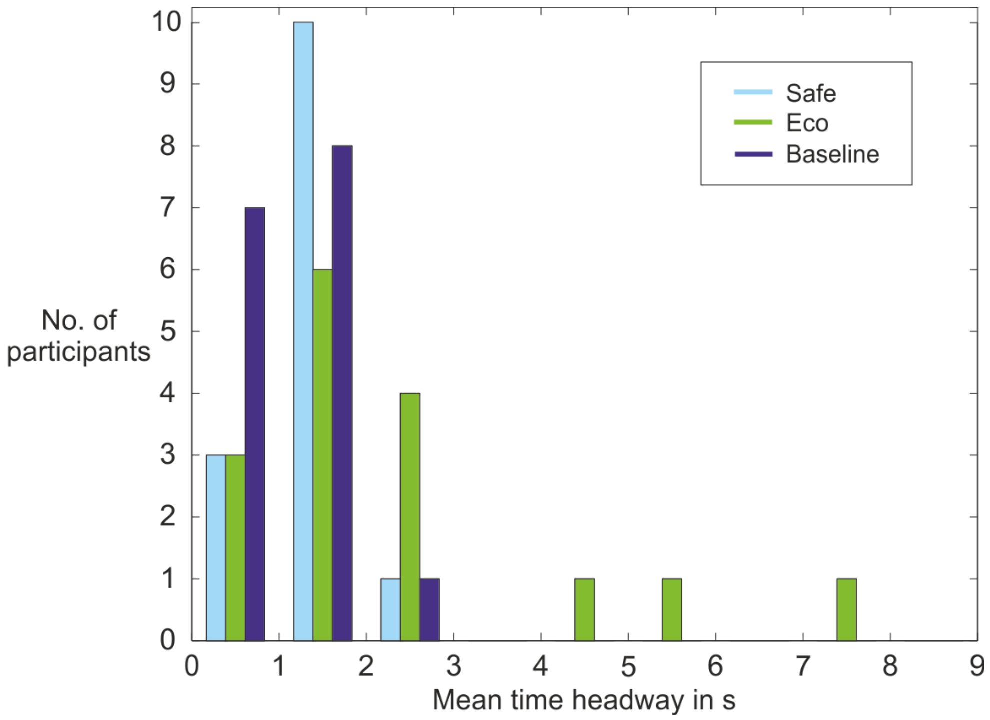



**Figure 24: Distribution of the mean time headway for the car-following scenario**

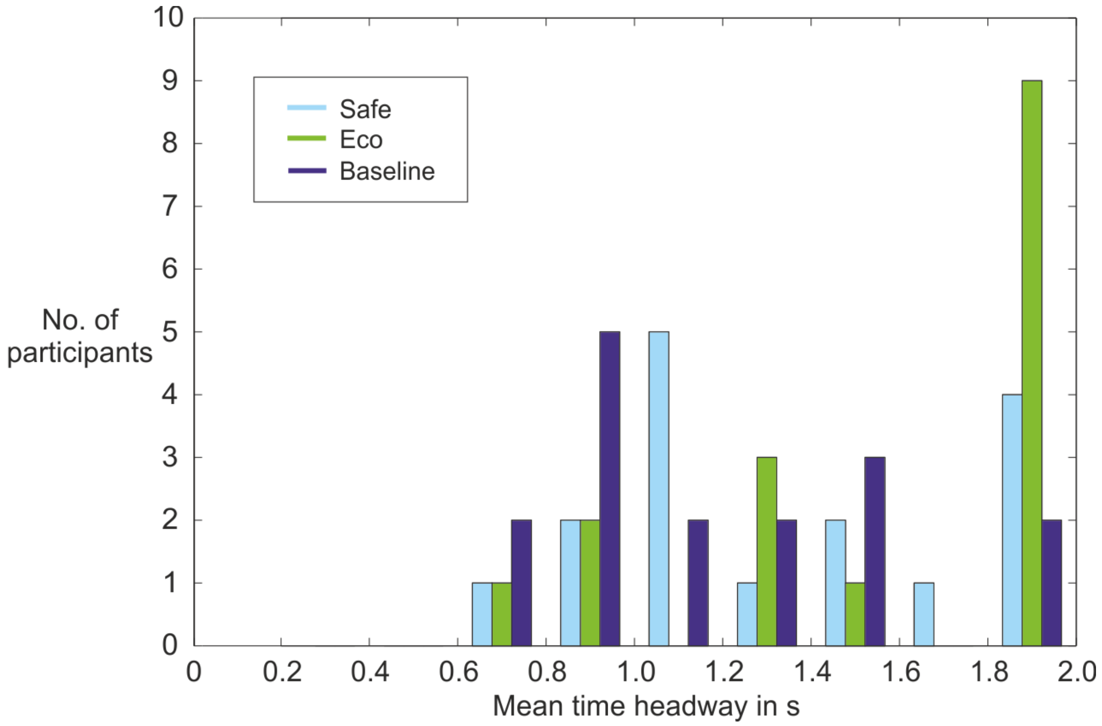



**Figure 25: Distribution of small mean time headway measures for the car-following scenario**

**Table 11: Results for the car-following scenario**

| Variable | Safe | Eco | Baseline | Post-hoc tests | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Sd. of speed (m/s) (mph in brackets) | 1.29 (2.89) | 1.22 (2.73) | 1.30 (2.91) | none | 1.314, .363 | n/a, n/a |
| Mean headway (s) | 1.37 | 2.37 | 1.22 | Eco > all other | .024, .006 | -1.522, -1.821 |
| Sd. of headway (s) | 0.67 | 1.89 | 0.73 | Eco > all other | .033, .003 | -1.463, -1.881 |
| Sd. of acceleration ($m/s^2$) | 0.31 | 0.25 | 0.35 | Eco < Baseline | < .001 | .472 |
| Sd. of deceleration ($m/s^2$) | .22 | .15 | .21 | Eco < Safe | .045, .078 | -1.403, n/a |

Several interaction effects could be identified, and these are depicted in Figure 26. Instruction had a stronger effect on mean time headway of the Group having the Safe drive first; it was about 2.4 times as long during the Eco drive compared to the Baseline drive [Z = -2.521, p = .036, r = -0.630]. In contrast, the other Group had a 2.1 times higher variation of time headway in the Eco drive [Z = -2.521, p = .036, r = -0.630]. Instruction also had a stronger effect on males, whose mean time headway during the Eco drive was 60% longer than during the Baseline drive [Z = -2.521, p = .036, r = -0.630], and whose variation of time headway was about 2.3 larger in the Eco drive as well [Z = -2.521, p = .036, r = -0.630].

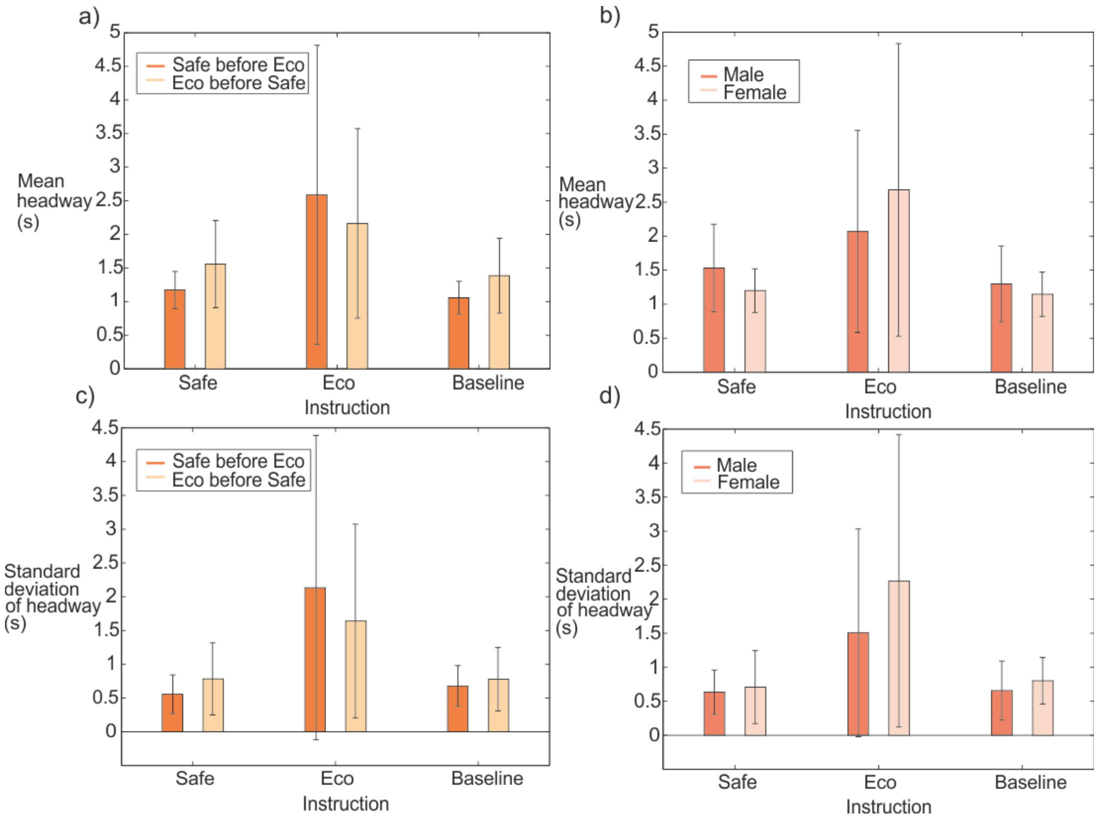



**Figure 26: Interaction effects for the mean and standard deviation of time headway in the car-following scenario**

Analysing cut-in events on the motorway, as shown in Table 12, it was found that the standard deviation of speed was significantly lower, by about 33%, during the Eco compared to the Baseline condition [Z = -2.999, p = .009, r = -1.731]. Hence, the participants kept their speed more constant during eco-driving. One possible explanation could be a longer time headway, which was about 0.26 seconds longer during the Eco drive [Z = -2.844, p = .012, r = -1.642]. With an examination of the data with a maximum headway of 6 seconds (cf. Vogel, 2002) the effect of the speed variation barely remained [F(1.342, 16.102) = 4.532, p = .040, $\eta_p^2$ = .274]. In order to examine safety-critical behaviours, the braking actions were further examined, specifically the speed and headway when braking actions were initiated and terminated. These tests revealed that the mean time headway, when braking was terminated, was significantly lower for the Eco drive, about 0.12 seconds, compared to the Safe [Z = -2.497, p = .039, r = -1.442] and 0.18 seconds lower than the Baseline drives [Z = -2.803, p = .015, r = -1.618]. It was higher for the Group performing the Safe before the Eco drive (U = 4.00, p = .012, r = -0.551). In addition, in every drive males terminated their braking actions at higher speeds compared to females ($F(1) = 8.12$, $p = .029$, $\eta_p^2 = .575$).

**Table 12: Results for the cut-in scenario**

| Variable | Safe | Eco | Baseline | Post-hoc tests | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Sd. of speed (m/s) | 1.74 | 1.40 | 2.08 | Eco < Baseline | .078, .009 | -1.283 -1.731 |
| Mean headway (s) | 0.89 | 1.06 | 0.82 | Eco > Baseline | .132, .012 | n/a, -1.642 |
| Mean speed at braking initiation (m/s) (mph in brackets) | 29.5 (66) | 29.1 (65) | 29.6 (66) | none | .473 | n/a |
| Mean speed at braking termination (m/s) (mph in brackets) | 26.6 (59) | 25.4 (57) | 25.9 (58) | none | .701 | n/a |
| Mean headway at braking initiation (s) | 0.93 | 1.71 | 0.79 | none | 2.634, 1.938 | n/a, n/a |
| Mean headway at braking termination (s) | 0.54 | 0.36 | 0.48 | Eco < all other | .039, .015 | -1.442 -1.618 |

Several interaction effects could be found. The Group that drove the Safe drive before the Eco drive had a 40% lower variation of speed in the Eco compared to the Safe drive [$Z = -2.521$, $p = .036$, $r = -0.630$], illustrated in Figure 27.

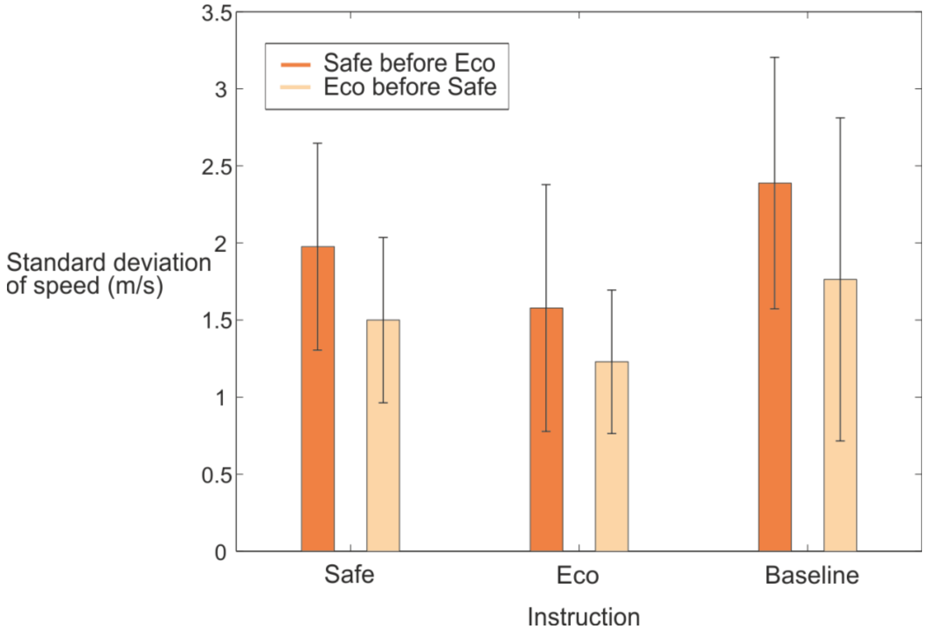



**Figure 27: Group*Instruction interaction effect in the cut-in scenario**

Females were significantly influenced by Instruction, as their mean time headway was 34% higher in the Eco than in the Baseline drive [Z = -2.521, p = .036, r = -0.630], but not males, as shown in Figure 28.

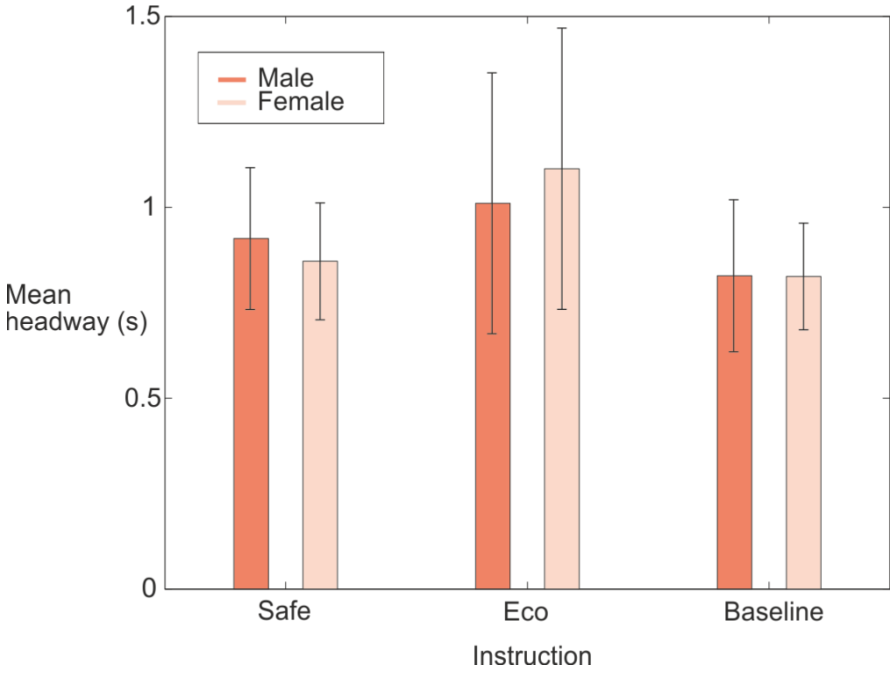



**Figure 28: Gender*Instruction interaction effect in the cut-in scenario**

### 4.4.7 Mental model boundaries

A fit of an accuracy function was performed to attain classification functions for the Safe, Eco and Baseline drives (cf. Goodrich and Boer, 1998). The concept is explained in detail in section 3.5.5. In brief, accuracy $\mu_A$ is a utility and therefore measures benefits for the driver, such as safety and travel speed. In satisficing decision theory, accuracy represents satisficing states (Goodrich et al., 1998b). In this example accurate, or satisficing, states signify that the driver perceives the current distance to a car in front as high enough, so a braking action is not necessary. In epistemic utility theory (Levi, 1983) utility is represented as probability. Hence, the accuracy function determines the probability $\mu_A$, ranging from 0 to 1, of a driver not braking depending on $T_C^{-1}$. Goodrich and Boer (1998) brought their collected data into a cumulative distribution function and then found that a function of the following form could be fitted to them:

$$\mu_A = \frac{1}{1 + e^{(-a\tau + b)}}$$

The NOM cases for the accuracy function are displayed in Table 13. The probability of the driver not braking decreases as $T_C^{-1}$ increases. Expressed differently, the probability of the driver braking increases with an increasing value for $T_C^{-1}$, or with a smaller TTC. Accordingly, the slopes of the functions in Table 13 are negative. On the left side of the function $T_C^{-1}$ is considered small enough (TTC is large enough), so the driver does not brake. As one moves towards the right, the probability for not braking decreases with a higher $T_C^{-1}$. This probability is smaller for the Eco drive compared to the Safe drive, indicating that during eco-driving the drivers were more likely to brake at a given $T_C^{-1}$. The differences were significant between the Baseline and the Eco drive for both the a and b coefficients [a: $t(183) = 7.56$, $p = .003$, $r = .488$, b: $t(183) = 3.92$, $p = .003$, $r = .278$].

Rejectability $\mu_R$ is a disutility representing costs for the driver, such as crash risk, but it can also stand for delays, for example. In satisficing decision theory rejectability represents non-satisficing states (Goodrich et al., 1998b). In this study rejectable, or non-satisficing, states mean that the driver perceives the current distance to a car in front as too low, and therefore decides to step on the brake pedal. In accordance with utility, disutility is represented as probability (Levi, 1983). Hence, the rejectability function determines the probability $\mu_R$, ranging from 0 to 1, of a driver not braking depending on $T_h$. To begin with, the BRK points were shaped into a cumulative distribution function. Subsequently, a least squares fit with a rejectability function of the following form was performed for the Safe, Eco and Baseline drives (cf. Goodrich and Boer, 1998):

$$\mu_R = \frac{1}{1 + e^{(-a\tau+b)}}$$

The BRK cases are displayed in the two lower rows in Table 13. Similar to the accuracy functions, the tendency suggested by the coefficients for a can be interpreted for the rejectability functions as well. With a negative a, the probability of the driver braking decreases as $T_h$ increases. This effect is much less pronounced for the Eco drive compared to the Safe drive. This means that the participants tended to brake at large headways in the Eco condition. This behaviour can indicate more anticipation during eco-driving, with the goal to retain larger headways in order to avoid stronger braking later on. For the a and b coefficients the differences are significant between the Baseline and the Eco drive [a: t(184) = 17.3, p = .003, r = .786, b: t(184) = 10.9, p = .003, r = .628], as well as between the Safe and the Eco drive [a: t(178) = 14.1, p = .003, r = .726, b: t(178) = 8.92, p = .003, r = .556].

**Table 13: Coefficients for regression functions**

| Coefficients | Safe | Eco | Baseline | Sign. diff. | t | p | r |
|---|---|---|---|---|---|---|---|
| a accuracy | -11.85 | -10.16 | -15.12 | Eco < all others | 2.56, 7.56 | .03, .003 | .189, .488 |
| b accuracy | 0.93 | 0.84 | 0.59 | Eco < Baseline | 1.35, 3.92 | .06, .003 | n/a, .278 |
| a rejectability | -3.99 | -1.17 | -5.75 | Eco < all others | 14.1, 17.3 | .003, .003 | .726, .786 |
| b rejectability | -3.10 | -1.49 | -3.69 | Eco < all others | 8.92, 10.9 | .003, .003 | .556, .628 |

Because the BRK cases include situations with very large headways, the analysis was repeated for data with a maximum headway of 6 seconds, which corresponds to the car-following definition by Vogel (2002). The resulting coefficients are listed in Table 14. The differences for the accuracy function are significant between the Baseline and the Eco drive for both the a and b coefficients [a: t(184) = 7.18, p = .003, r = .468, b: t(184) = 3.75, p = .003, r = .266]. With regards to the rejectability function the differences are significant between the Baseline and the Eco drive [a: t(184) = 10.5, p = .003, r = .611, b: t(184) = 10.8, p = .003, r = .622], as well as between the Safe and the Eco drives [a: t(178) = 4.61, p = .003, r = .326, b: t(178) = 7.71, p = .003, r = .501].

**Table 14: Coefficients for regression functions with a maximum headway of 6 seconds**

| Coefficients | Safe | Eco | Baseline | Sign. diff. | t | p | r |
|---|---|---|---|---|---|---|---|
| a accuracy | -11.85 | -10.16 | -14.90 | Eco < Baseline | 2.56, 7.18 | .06, .003 | n/a, .468 |
| b accuracy | 0.93 | 0.84 | 0.60 | Eco < Baseline | 1.34, 3.75 | .6, .003 | n/a, .266 |
| a rejectability | -4.77 | -3.45 | -6.77 | Eco < all others | 4.61, 10.5 | .003, .003 | .326, .611 |
| b rejectability | -3.42 | -2.12 | -4.09 | Eco < all others | 7.72, 10.8 | .003, .003 | .501, .622 |

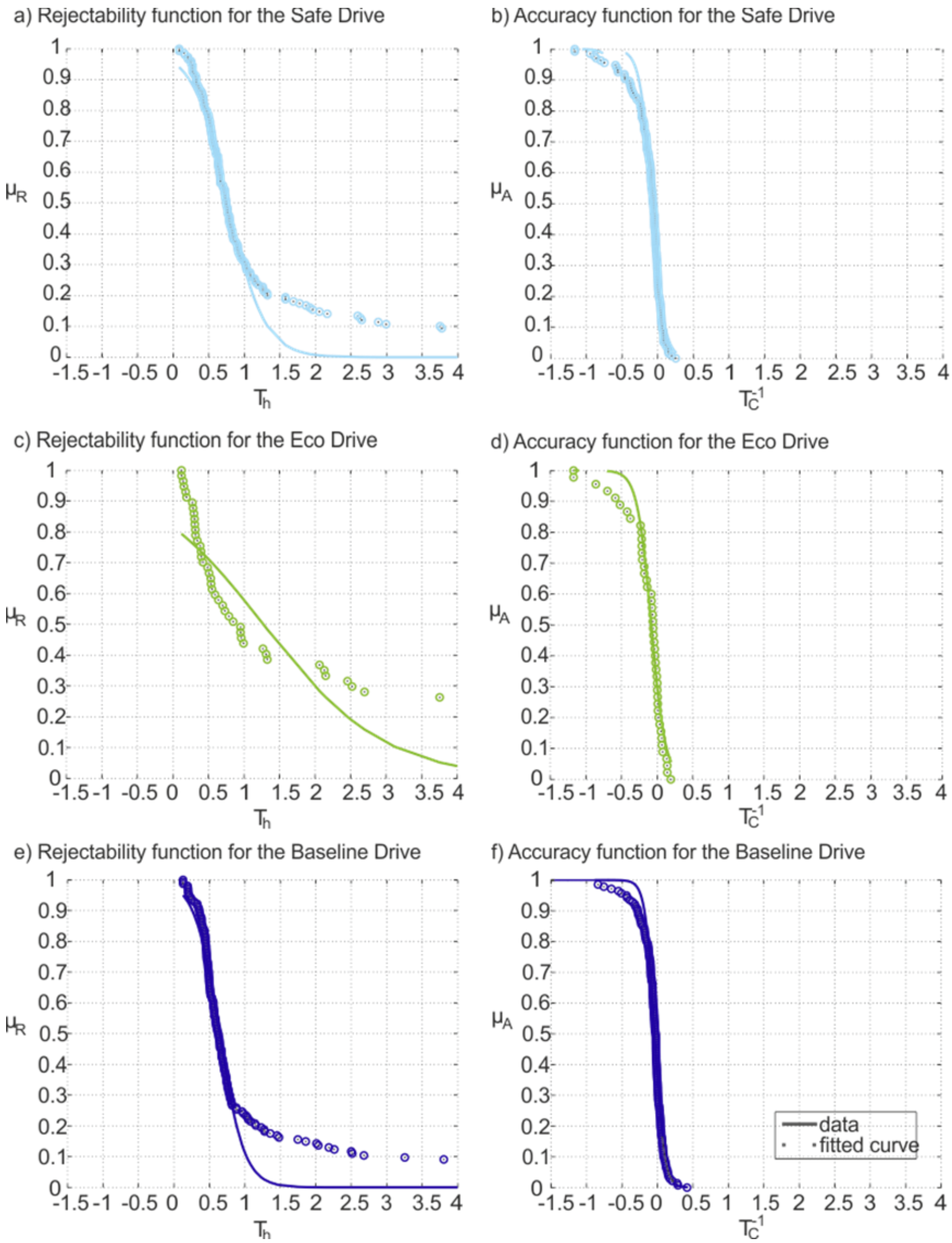



**Figure 29: Fitted rejectability and accuracy functions**

With the accuracy and rejectability functions the mental model boundaries in the perceptual space of $T_h$ and $T_C^{-1}$ could be computed. For illustration purposes the scatterplots of NOM and BRK states are illustrated in Figure 30. The nominal analysis points, where 'time headway regulation' was satisficing, are indicated with a circle. The analysis points in case of braking are drawn as crosses.

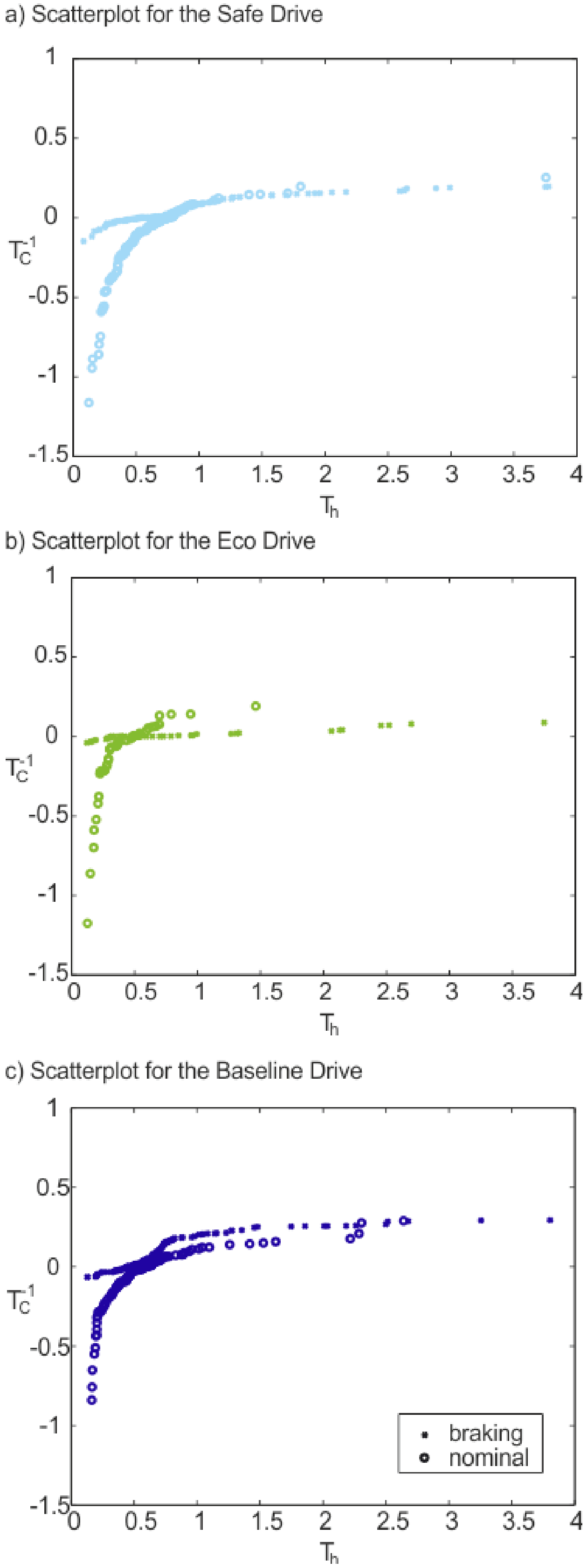



**Figure 30: Scatterplots of the experimental drives**

In order to make sense of the scatterplots, a boundary dividing the NOM and BRK cases for each experimental condition was fitted. The following function represents this line, telling where behaviour was switched from nominal car-following to active braking (cf. Goodrich and Boer, 1998):

$$\pi_A(T_C^{-1}) = b\mu_R(T_h)$$

The coefficient b determines the boundaries' locations related to $T_C^{-1}$ and $T_h$. The classification was performed by minimising the maximum outcome of three misclassification equations (cf. Goodrich et al., 1998a). $J_1$ represents the share of all incorrectly classified analysis points, while $J_2$ stands for the incorrectly classified NOM and $J_3$ for the incorrectly classified BRK points:

$$J_1(\mathrm{b}) = \frac{\mathrm{N}\,[(\mathrm{NOM} \cap S_b^C) \cup (\mathrm{BRK} \cap S_b)]}{\mathrm{N}[\mathrm{NOM} \cup \mathrm{BRK}]}$$

$$J_2(\mathrm{b}) = \frac{\mathrm{N}\,[\mathrm{NOM} \cap S_b^C]}{\mathrm{N}[\mathrm{NOM}]}$$

$$J_3(\mathrm{b}) = \frac{\mathrm{N}\,[\mathrm{BRK} \cap S_b]}{\mathrm{N}[\mathrm{BRK}]}$$

The optimal coefficient b is 0.50 for the Safe condition, 0.49 for the Eco condition and 0.59 for the Baseline drive. The resulting boundary functions for the drives are drawn in Figure 31. The area below a boundary represents the combinations for $T_C^{-1}$ and $T_h$ in which car-following is satisficing and the driver does not step on the brake pedal. If these measures change, for instance in the event of a close cut-in, and cross the boundary, the situation ceases to be satisficing and the driver is likely to brake actively. The grey area in this figure is not defined, because there the time to collision is larger than the $T_h$. This means that for low values for $T_h$ the boundary between acceptable and unacceptable states is only marginally higher for the Eco drive compared to the Safe. This indicates that there is not a large difference in the drivers' braking behaviour during car-following. This finding is partly in line with the statistical comparison of the cut-in scenario in section 4.4.6, where some behavioural differences lessened or diminished when the analysis was limited to data with a time headway of 6 seconds.

For larger $T_h$ the slope of the boundary function is a lot less steep for the Eco drive compared to the other drives. This can mean that $T_h$ had less influence on braking behaviour during eco-driving. However, the result can also stem from the large values for $T_h$ in the Eco condition, which provided the measurement points for this modelling exercise.

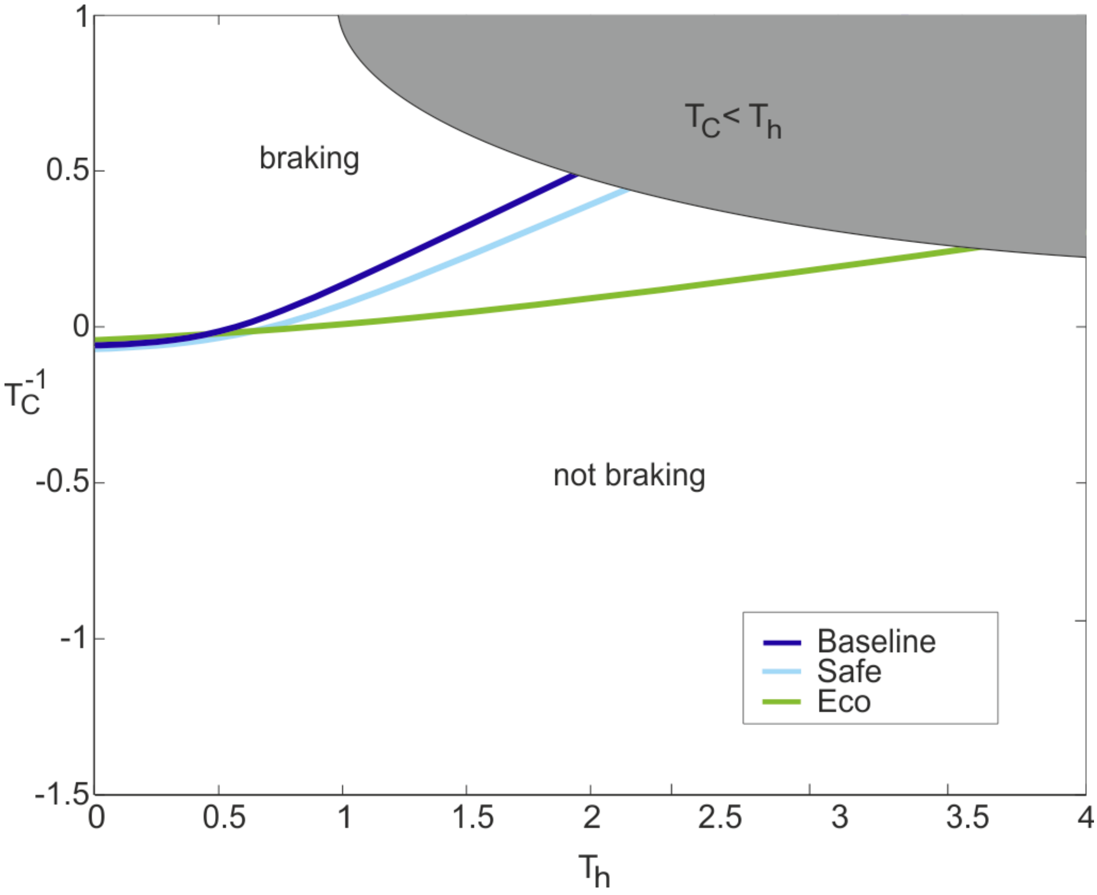



**Figure 31: Boundaries for each experimental condition**

When $T_h$ is limited to 6 seconds the boundaries are closer together, Figure 32. After modelling boundaries for the filtered data b is 0.49 for the Safe condition, 0.47 for the Eco condition and 0.58 for the Baseline drive.

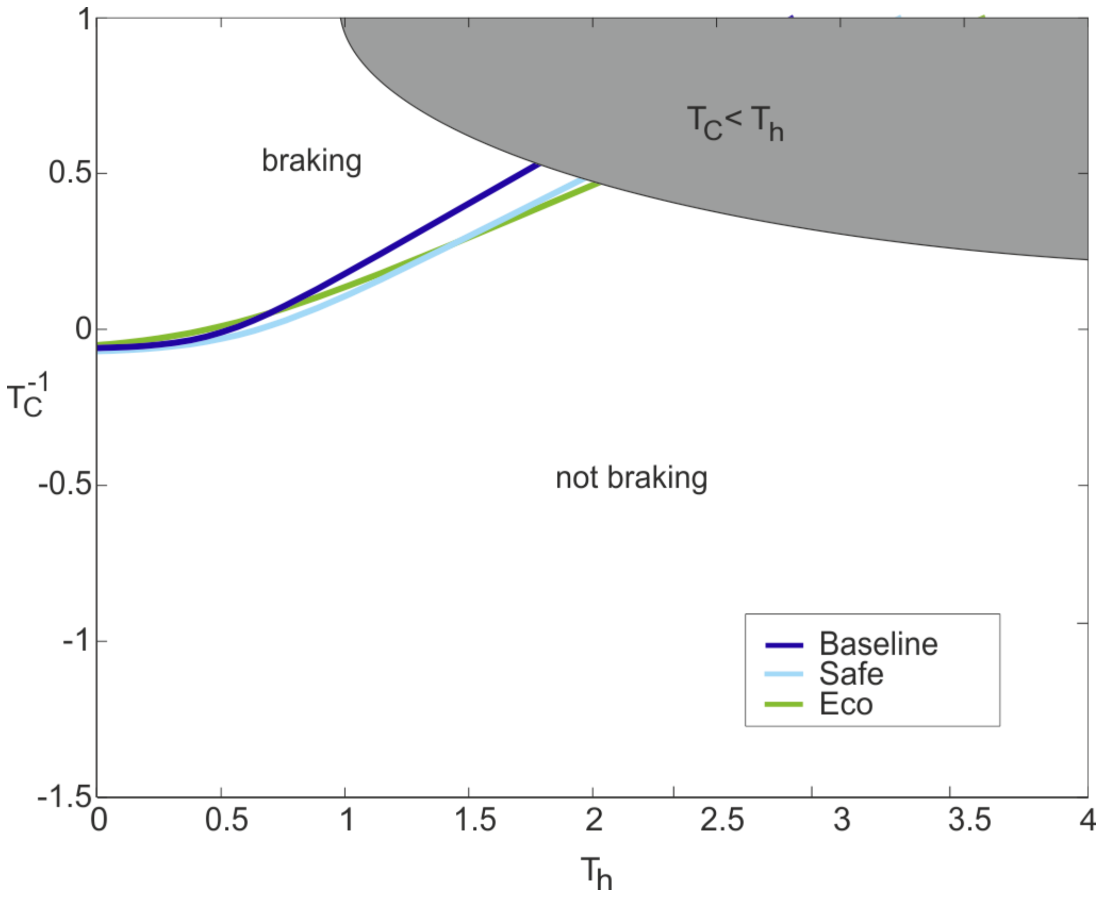



**Figure 32: Boundaries for each experimental condition with headways of max. 6 seconds**

### 4.4.8 Verbal recordings

It prove to be relatively easy to code the transcripts for the first participant. However, it was a challenge to make the resulting coding scheme suitable for subsequent participants, as each person was expressing themselves in different ways. Hence, during this process the nodes were created and refined, and regular re-coding had to be performed in order to create categories and subcategories to which the statements could be linked distinctly. This process resulted in a tree-shaped structure, as depicted in Table 15. Statements were generally coded into the lowest available node. For example, when a participant talked about slowing down, the words were assigned to the third-level node ‘Slowing down’, but when a brake was mentioned, or coasting, the other relevant nodes on the same level were used, but not exclusively. All these examples were then automatically also coded in the second-level node ‘Speed decrease.’

**Table 15: Hierarchy of coded nodes**

| Name | Ref. | Description |
|---|---|---|
| **1 Action** | 1414 | What is the driver doing? ("I'll go ahead and slow down") |
| 1.1 Controlling the simulator | 391 | Related to the simulator and experimental situation ("And again I'd be doing a mirror check") |
| 1.2 Latitudinal behaviour | 61 | ("Gonna move into the middle lane now") |
| 1.3 Speed decrease | 506 | Anything related to a decrease in one's speed ("Slowing") |
| 1.3.1 Braking | 178 | Step on the brake ("And then I brake slowly") |
| 1.3.2 Coasting | 93 | Foot off the accelerator ("Getting off the gas") |
| 1.3.3 Slowing down | 348 | The driver slows down ("Okay I've just slowed") |
| 1.3.4 Stopping and waiting | 113 | The driver is stopping/coming to a halt or considering it ("I'm gonna stop at these") |
| 1.4 Speed increase | 312 | Anything related to an increase in speed ("and up until forty") |
| 1.4.1 Acceleration | 231 | From lower speed to higher speed ("Now I need to speed up") |
| 1.4.2 Start driving | 104 | From standing ("Okay off again") |
| 1.5 Speed maintenance | 799 | Includes adjustments to other cars and the selection of a new cruising speed ("keep my foot on the gas") |
| 1.5.1 Adjustment to vehicle in other lane | 22 | ("I shouldn't undertake") |
| 1.5.2 Car following | 375 | Adjust speed to a vehicle in front ("Just catching up gradually") |
| 1.5.3 Continue driving | 76 | Not stopping (although sometimes not clear) ("Just carry on straight") |
| 1.5.4 Selection of speed | 427 | "Here I drive forty" "a bit less than seventy" excludes creeping up to traffic lights |
| 1.5.5 Speed regulation or cruising | 203 | Maintaining cruising speed ("Still doing a reasonable speed") |
| **2 Other** | 214 | Seemingly unrelated to the driving task ("Get to the meeting") |
| 2.1 Comparison to real life | 80 | "When I drive home to … sometimes" |
| 2.2 Memories | 2 | Incidents and critical situations in the past ("That's the problem I had last week with my car") |
| 2.3 Unrelated | 133 | Thoughts about food, family, friends, work etc. ("Friday fish and chips day") |

| Name | Ref. | Description |
| --- | --- | --- |
| **3 Safety and vigilance** | 1944 | Situation awareness, visibility and control (“And don’t really want to hit anyone”) |
| 3.1 Anticipation | 321 | What could happen (“Or anything else that people might do”) |
| 3.2 Avoidance | 239 | The driver is preventing something from happening (“Make sure no one is behind me or beside”) |
| 3.3 Surroundings | 1539 | What is around the driver? (“And other cars”) |
| 3.3.1 Event | 447 | What is happening now in the environment or what happened (“Just swerved right in”) |
| 3.3.2 Landscape and simulator specific features | 228 | Comments on simulated environment, (“random shops on the side”) |
| 3.3.3 Road and road features | 429 | Observations about the road incl. junctions, curves (“Okay so there’s the slip road”) |
| 3.3.5 Road users | 880 | Other cars, people (potentially) using the road (“Oh red car”) |
| 3.3.6 Traffic lights | 438 | Traffic lights are mentioned (“And we come up to some lights again”) |
| 3.4 Expectations and Instructions to others | 100 | Telling other road users what to do (“Come on!”) |
| 3.5 Focus | 448 | Looks, focus, incl. ‘mirrors’ (“Have to look out for other cars”) |
| 3.6 Judgement of own behaviour and situation | 298 | Negative assessment (opposite of validation) (“Oh going fast”) |
| 3.7 Location and position | 952 | Drivers locate themselves (“Okay I’m in the centre lane”) |
| 3.7.1 Position related to road features and place | 434 | The driver’s position relative to traffic lights, lines, junctions or road (“Just so I am waiting at the line”) |
| 3.7.2 Position related to road users | 576 | E.g. headway to vehicle in front or adjacent lane, “Somebody changing into my lane” |
| 3.8 Panic, shocks and surprises | 139 | Unexpected situations (“Oh gosh isn’t it”) |
| 3.9 Validation | 421 | Driver is validating current situation (“Okay”) |
| **4 Strategic decisions** | 331 | Higher level goals (“I’m trying to keep my speed fairly constant”) |
| 4.1 Fuel efficiency or eco driving | 154 | Fuel efficiency or eco driving are mentioned talked about (“This time no hard acceleration”) |
| 4.2 Strategy | 240 | Something the driver does with a goal in mind or an explanation of behaviour (“Trying to anticipate well ahead”) |

| Name | Ref. | Description |
|---|---|---|
| 4.3 Safety | 121 | Safety is mentioned (“I’m quite careful”) |

The category FUEL EFFICIENCY AND ECO DRIVING contains statements about eco-driving. It can be assumed that the drivers mentioned eco-driving when they activated eco-driving mental models. A statistical analysis was conducted with the remaining three categories, ACTION, SAFETY AND VIGILANCE and SURROUNDINGS. These categories are illustrated in Figure 33 and listed in Table 16. Due to the Simultaneous Coding approach, the sum of the percentages exceeds 100%. The order of instructions did not have significant effects on the percentage of the categories in each drive.

Each participant contributed to the category FUEL EFFICIENCY AND ECO DRIVING during the Eco drive and therefore had some idea of eco-driving. The answers were compared with behavioural measures that approximate the stated actions, from the Eco and the second Baseline condition. Most mentioned the goal of keeping a constant speed. Fourteen of 16 participants said that they tried to avoid large speed fluctuations at traffic lights, and indeed every single participant decreased their mean negative acceleration in the long-range braking scenario during eco-driving. Eleven wanted to do so when other cars were cutting in front of them on the motorway, but only of them 8 lowered the speed variation when car-following. Ten said specifically that they try to closely control their speed by keeping their foot steady on the throttle. Only one of them did not accelerate more smooth when cruising in the Eco condition. Most participants declared that they wanted to avoid stepping on the brake, 13 at junctions in the urban part, with 10 of them managing to decelerate with less variation in this scenario. Fourteen wanted to avoid strong decelerations on the motorway (“Touching the brakes as little as possible”), and 11 of them achieved this. In order to leave room for a steady speed, eight participants mentioned, and maintained, a longer headway during the motorway part in the Eco drive (“I was leaving more space”). Speed choice was another frequently mentioned topic. Thirteen drivers wanted to keep a lower speed, but only 3 of them said it during the urban part, where the speed limit was 40 mph (“Tried not to go as fast so I kept it down towards thirty”). For these 3, and indeed altogether 15, participants a lower cruising speed was reported. Nine drivers said that they wanted to drive more slowly than the speed limit of 70 mph on the motorway, and 7 of them drove more slowly during car-following. One participant explained that he had not planned to drive more slowly during the Eco drive, but his mild acceleration unintentionally resulted in a lower speed. Indeed, thirteen drivers mentioned slower acceleration in the urban section (“`I shouldn’t be using too much gas`”), with 12 of them lowering their mean acceleration in the acceleration scenario. Nine wanted to curb their acceleration on the motorway, and 7 of them managed this around the cut-in events.

For the percentage of the think aloud protocols coded in ACTION it was found that for the Eco drive the percentage of verbalisations was 35.1% and significantly higher than for the Safe condition with 27.5% [$F(1.3,14.5) = 4.52$, $p = .043$, $\eta^2 = .291$]. A repeated measures ANOVA indicated that for the Eco drive the percentage of verbalisations coded in SAFETY AND VIGILANCE was at 47.2% significantly lower than for the Safe condition, in which it was 60.4% [$F(2,22) = 4.71$, $p = .020$, $\eta^2 = .300$]. To investigate the shares of the SURROUNDINGS category within the think aloud protocols a repeated measures ANOVA clarified that for the Eco drive the percentage of verbalisations coded in SURROUNDINGS, at 32.2%, was significantly lower than for the other conditions (Safe: 42.2%, Baseline: 40.8%) [$F(2,22) = 5.08$, $p = .015$, $\eta^2 = .316$]. None of these ANOVAs revealed a significant effect for Gender or for Group. Nor were any interaction effects found.

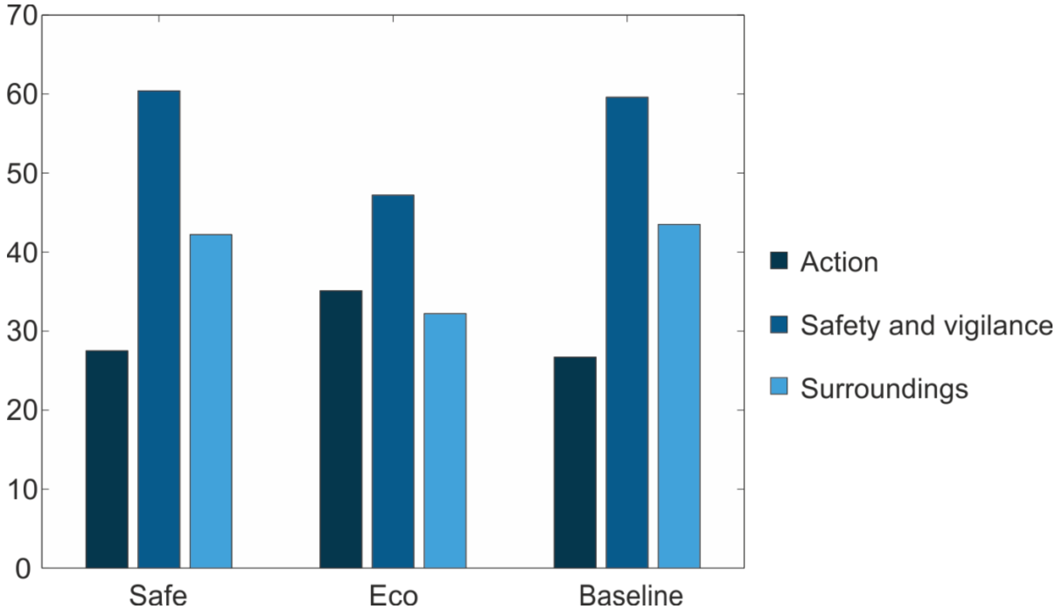



**Figure 33: Percentages of coded categories**

**Table 16: Results for the verbal categories**

| Variable | Safe | Eco | Baseline | Post-hoc tests | p | $\eta_p^2$/r |
|---|---|---|---|---|---|---|
| Action (%) | 27.5 | 35.1 | 25.0 | Eco > Safe | .043 | .291 |
| Safety and vigilance (%) | 60.4 | 47.2 | 55.9 | Safe > Eco | .020 | .300 |
| Surroundings (%) | 42.2 | 32.2 | 40.8 | Safe > Eco | .015 | .316 |

In order to further examine goals, subgoals and the means to achieve them, a means-end analysis (Newell and Simon, 1961) was conducted. Statements about eco-driving were regarded further by dividing them into pairs of needs and actions, Table 17. As an example, the first participant in the table mentioned being ‘fuel-efficient’ as a need and stated as resulting actions the avoidance of braking and accelerating (“I don’t wanna be braking and accelerating”). The behavioural data show that the increased coasting in both braking scenarios, and started braking at a lower speed during eco-driving compared to the other conditions. She then in turn expressed the avoidance of braking as a goal (“if I do happen to need […] the brake then that would just need […] some more petrol”) and said that she addressed this need by moderating her speed (“I’m just not gonna drive that quickly”). Indeed, in the Eco drive she drove with the lowest speed compared to the other conditions. The majority of statements about eco-driving was related to the goal of a constant speed, potentially achieved with the avoidance of braking and subsequent acceleration. The participant who crossed the junction in the short-notice braking scenario reasoned with a constant speed (“That was again to maintain fuel efficiency; that was so that I keep a constant speed”), which is consistent with his behavioural data. The other participants avoided braking with safer measures such as using coasting when slowing down, and also by choosing a lower speed, anticipation and larger headways. Some participants have incorrect ideas about eco-driving. Participant 3, for example, mentioned that coasting “is free petrol” and that he saved fuel as he “kept it down towards thirty“. His mean speed in the cruising scenario was about 33 mph, the lowest of all participants. In sum, this means-end analysis divided up eco-driving into goals and sub-goals, highlighting behaviours on different levels of mental models. It gave additional insights into the content of mental models, which was consistent with the measured behaviours, except for maintaining a constant speed in the cruising scenario.

**Table 17: Need-action pairs in the FUEL EFFICIENCY node**

| Participant | Need | Action |
|---|---|---|
| Participant 1, Female, 27 years old | So fuel-efficient… | … which basically to me<br>Means I don't wanna be braking and accelerating<br>Like not a lot<br>So I'll just drive as I normally do<br>…<br>So I just coast |
| Participant 1, Female, 27 years old | Cause if I do happen to need (?) the brake<br>Then that would just need (?) some more petrol | I'm just not gonna drive that quickly right now |
| Participant 1, Female, 27 years old | Which is even better in fuel-efficiency | go through the light |
| Participant 1, Female, 27 years old | … because that's more fuel-efficient than speeding up and slowing down constantly | And and as I reach speed<br>Then I just keep it constant… |
| Participant 2, Male, 39 years old | If you want fuel efficiency… | … you want to sort of avoid fast acceleration or heavy braking |
| Participant 2, Male, 39 years old | … so I can slow down and avoid stopping if I can | But what I'm gonna try and do is perhaps anticipate the lights a little more… |
| Participant 2, Male, 39 years old | … in the hope ? not stopping completely<br>Just to keep that bit of momentum going is<br>It's actually good for your fuel efficiency I understand and also it does mean you get away at the lights | I'm like gradually decreasing my speed as I approach… |

| Participant | Need | Action |
|---|---|---|
| | quicker as well when they do change | |
| Participant 3, Male, 37 years old | … I have been reading somewhere that this is free petrol | Coasting… |
| Participant 3, Male, 37 years old | to drive fuel-efficiently… | … I did not accelerate as hard; I did coast a bit more often; didn't go as fast or tried not to go as fast; So I kept it down towards thirty; watched the revs rather than the accelerator, more than the speeder |
| Participant 3, Male, 37 years old | Cause if I want to say save petrol And just go tootle along… | … I go in the inside lane |
| Participant 3, Male, 37 years old | Then economy | So I need to drive a bit slower |
| Participant 4, Male, 39 years old | … rather than stopping as much as possible in order to get back up to speed I need to expends more fuel | I kind of kept the a constant speed as much as I could… |
| Participant 4, Male, 39 years old | So that cars that were going to pull out from the left I wouldn't have to brake | In the motorway run I was leaving more space |
| Participant 4, Male, 39 years old | … that was again to maintain fuel efficiency; that was so that I keep a constant speed | I went through lights that were on amber… |
| Participant 5, Male, 40 years old | Got a full tank but it has to last me for three months… | … so drive easy |
| Participant 5, Male, 40 years old | I say fifty six is about an economical speed… | … so I try for that |

Conflicts between safety and fuel-efficiency were regarded separately, as listed in Table 18. Avoiding braking was a recurrent topic. One participant solved this conflict with a lower speed ("driving slightly under the speed limit") in order to maintain a longer margin to the car in front, and drove about 37 mph on average in the cruising scenario. Another driver decided to increase his risk by crossing a junction despite an amber traffic light. Most statements, however, signify that, when in critical situations, most participants decided for the safe option, which is in line with the behaviour in the short-notice braking and cut-in scenarios.

**Table 18: Conflicts between Safety and Fuel Efficiency**

| Participant | Need/Conflict | Action |
|---|---|---|
| Participant 1, Female, 27 years old | Oh I don't wanna brake<br>I don't wanna accelerate very often<br>But it is not about me so much (?)<br>As what other vehicles do | So I think what I try<br>Is driving slightly under the speed limit<br>It probably gives me more reaction time |
| Participant 2, Male, 39 years old | So I'm just letting it coast down<br>Just take my foot off the gas | I'm having to brake a bit here<br>And yeah I'm probably<br>I'm going to have to stop altogether |
| Participant 4, Male, 39 years old | That was again to maintain fuel efficiency<br>That was so that I keep a constant speed | For the suburban run there was moments<br>Where I would<br>I went through lights that were on amber |
| Participant 5, Male, 40 years old | On the motorway I will usually sixty to seventy<br>My car seems to like between sixty to seventy<br>Probably I'd have to have to brake a lot<br>Well I thought I had to brake a lot | What I probably would have done was actually<br>To say that I go a little bit faster and go to the outside lane<br>So I didn't have to brake all the time |
| Participant 6, Male, 40 years old | But I do feel I'm a little bit too far behind him<br>But any more than what I'm doing would be over the speed limit | Get up the speed slightly to get behind him |

### 4.4.9 Summary of main results

- When drivers are instructed to 'drive fuel-efficiently' they changed their behaviour
- Behaviour changes involved acceleration, speed choice and smoothness of actions
- A constant speed was not prioritised over safety in most situations
- Mental model boundaries did not shift towards smaller safety margins
- Interviews and think aloud protocols included constant speed, means to achieve this and conflicts with safety
- Focus and awareness increased towards the drivers' behaviour, particularly in comparison to 'safe' driving

## 4.5 Discussion

This research aimed to investigate the existence and the content of mental models that regular drivers employ during eco-driving on different cognitive levels. For this purpose a driving simulator experiment with a varied road layout comprising urban and motorway sections was designed and enriched with think aloud protocols and open interviews. The study used simple driving task instructions to investigate changes in the participants' behaviour as well as focus in three conditions. Sixteen drivers were asked to 'Drive normally', 'Drive safely' or 'Drive fuel-efficiently'. Behavioural measures and verbalisations were compared and analysed. The emphasis of this study was on eco-driving relevant indicators such as accelerating, braking, coasting and car-following. This study identified eco-driving mental models and was able to derive design recommendations for driver support systems.

### 4.5.1 The existence of eco-driving mental models

The results support that each participant in this study has a set of eco-driving mental models. Their existence became evident, first of all, as these drivers changed their behaviour when they were asked to eco-drive, resulting in a reduction of fuel consumption in the urban section of the road layout for each participant. Additional consistent behaviour changes included a reduced mean acceleration when approaching a red traffic light. For all 8 drivers faced with the scenario, a reduction occurred in the maximum accelerator pedal angle when setting off from a junction while another junction with red traffic lights was visible. In addition, fifteen of all 16 drivers chose a lower cruising speed. These patterns, as well as the results of statistical tests are consistent with previous studies (Birrell et al., 2010, van der Voort et al., 2001, Waters and Laker, 1980). This behaviour was not just different from the normal drives, but also from what they did when asked to drive safely. In fact, for no measure, instructing the participants to drive safely resulted in significant differences to the normal condition. Hence, the behaviour change in the Eco drives cannot solely be explained by an allocation of additional attentional resources to the driving task. Furthermore, the results from modelling mental model boundaries and the analysis of the think aloud protocols and interviews indicate that the participants activated eco-driving mental models. However, the mental models vary in their content and effectiveness. For instance, the reduction in fuel consumption was not significant in the cruising scenario and was relatively low in the motorway sections (only changed by 2.8%).

Differences in behaviours between the Eco and the other conditions indicate an existence of eco-driving mental models. The direction of the behaviour as well as statements in the drivers' verbalisations could provide insights into their content, as well as some incongruity on several levels. For example, the speed during cruising and car-following was not kept more constant in the Eco condition, although 10 participants mentioned a steady speed as part of their strategy and lower variations in speed can indeed affect fuel savings positively (cited in Haworth and Symmons, 2001, Nairn and Partners et al., 1994). Drivers can have problems consciously influencing the lower-level mental models, such as the usually highly automated control of the accelerator pedal (Goodrich and Boer, 2003, Rasmussen, 1983). The only exception was the cut-in scenario on the motorway, where the participants managed to keep their speed more constant during the Eco drives compared to the Baseline condition. The steadiness of the speed can be partly explained with longer headways in the Eco condition. Some of these effects lessened when headways with a maximum of 6 seconds were regarded. This indicates that drivers tend to facilitate eco-driving with larger headways and prioritise safety when the safety margins are shorter. However, in the cut-in scenario drivers tended to terminate their braking actions at lower time headways during eco-driving compared to the other conditions. This implies that they braked, but with less effect and accepted lower safety margins during eco-driving in order to retain a steadier speed.

### 4.5.2 Driving parameters

The mean cruising speed during eco-driving was slower than during normal and safe driving, although only 3 participants specifically mentioned a lower speed during the urban section. In the literature it has been argued that slower driving is considered safe (Elvik et al., 2004, Nilsson, 2004, Taylor et al., 2000, Taylor et al., 2002). However, a review of studies about factors predicting accident risk concluded that a definite link is not yet established (Wang et al., 2013). For example, Baruya (1998) as well as Taylor et al. (Taylor et al., 2000), for rural roads, found an inverse relationship between speed and accident risk. Possible explanations include the quality of the road as well as caution while driving at higher speeds. Hence, it might not necessarily be safer to drive more slowly during eco-driving. This argument is supported by the fact that the average speed during ‘safe’ driving was 1mph below the speed limit, and therefore expected to be sufficiently safe. The time needed to complete the urban part of the Eco drive was 9% longer than the Baseline drive, and this difference was significant. In an experiment by Birrell and Young (2011) drivers were reducing their speeds as well, although the tested system did not encourage them to do so. It has been shown that drivers tend to associate eco-driving with slow driving (Harvey et al., 2013, van der Voort et al., 2001, Waters and Laker, 1980). In fact, efficient speeds range from 37 mph (60km/h) to 50mph (80 km/h) (Samaras and Ntziachristos, 1998), which would allow staying at around an urban speed limit of 40 mph (64 km/h) and suggest driving below the motorway speed limit of 70 mph (113 km/h). The speed reduction in the cruising scenario of the urban section implies that drivers overestimate the speed reduction needed for fuel savings, in line with findings by Eriksson and Svenson (2012), which can discourage them from eco-driving. Hence, the speed choice on roads with speed limits below 40 to 50 mph is an aspect in mental models of eco-driving that can benefit from corrections. In several experiments where participants used in-vehicle, eco-driving feedback devices, time losses were either low or not present at all (Birrell et al., 2014, Birrell and Young, 2011, Birrell et al., 2010, van der Voort et al., 2001). However, it has been found that asking people to eco-drive may cause an increased workload which could have contributed to the reduction in speed (Haigney et al., 2000).

The mean acceleration in the acceleration scenario was lowered during eco-driving and 13 participants said they would do so. Lower cruising speeds confound this behaviour change slightly. From a closer examination of the accelerator pedal use it was found, though, that the participants spent a small fraction of the time with the pedal pressed more than a third of its range, compared to the Baseline drive. Furthermore, the maximum accelerator pedal angle decreased substantially. These actions, supported by intentional statements, indicate that many drivers have low acceleration rates in the higher, more conscious levels of their eco-driving mental models. The effectiveness is, however, only partly supported by research. In some studies it has indeed been found that lower acceleration rates can result in fuel reductions (Ericsson, 2001, Waters and Laker, 1980), but other studies suggest a swift, but not aggressive acceleration up to an efficient speed (Mensing et al., 2014, Mensing et al., 2013). With regards to behaviours associated with lower levels of driving mental models, it was found that the acceleration was less erratic for the Eco drive than for the other drives. When a second junction with a red light was in sight the participants tended to terminate their accelerations at lower speeds, possibly anticipating these traffic lights to switch to green before arriving at the junction. In the braking scenario the mean deceleration decreased significantly during the Eco drives and the participants attempted to avoid stopping at the traffic lights. Anticipation in order to limit speed fluctuations at junctions is an effective way to save fuel (Johansson et al., 2003) and therefore suggests an effective part of eco-driving mental models. The lack of behavioural changes at the short-notice braking scenario suggests that in this critical situation most participants prioritised safety, which indicates that their eco-driving mental models do not lead them to compromise on safety margins. This could either mean that eco-driving mental models include safe driving behaviours, or that safe driving mental models take precedence in critical situations. The avoidance of large changes in speed could increase driving safety, as the Power Model (Nilsson, 2004) postulates. This relationship between speed variance and accident risk is supported by an analysis of US road data by Lave (1985), for example. However, Davis (2002) argued that Lave was aggregating data on a large scale, which does not allow conclusions for individual risk. A more recent analysis of road data, using the Power Model, found that effects of speed changes depend on the traffic environment (Cameron and Elvik, 2010). In addition, the risk appears to increase with the initial speed, with stronger effects at higher initial speeds (Elvik, 2013). In sum, it cannot clearly be established whether the lower speed changes during eco-driving are increasing driving safety. Nevertheless, at speeds of 40 mph, such effects would be relatively small.

The prioritisation of safety in safety-critical scenarios was not unified. The fact that one participant compromised on safety by crossing a junction with amber traffic lights in order to maintain a steady speed during the Eco condition indicates individual differences in eco-driving mental models and possibly riskier behaviour in some people.

There were a few differences for Gender related to braking actions, as females tended to brake stronger in the short-notice braking scenario and on the motorway. For some measures related to time headway to the car in front females displayed stronger differences between the Eco and Baseline drives. Interaction effects between Group and Instruction display a similar pattern. For measures related to smooth acceleration and deceleration as well as headway it appeared that the Group doing the Safe before the Eco and then the Baseline drive performed relatively strong behaviour changes, especially between the Eco and the Baseline drive. These differences could indicate negative spill-over effects, or boredom effects, and one can assume that eco-driving mental models were deactivated for the last drive. In contrast, a few positive spill-over effects were appearing for the Safe drive if the Eco drive took was placed before it. These Gender and interaction effects, however, are not as consistent as the eco-driving behaviours found above, and not backed up by earlier findings in the literature. In addition, the strong variability between participants suggests that there might not be a consistent pattern, and that such effects could have occurred due to the plethora of measures and tests performed in this study.

### 4.5.3 Boundaries of eco-driving mental models

Instead of assuming a situation-specific full activation and deactivation of eco-driving mental models, the handling of lower-level skills during driving was considered. Therefore, boundaries between the mental models for car-following and active braking were calibrated. It was tested whether the boundaries shifted across the experimental conditions in this study. For this exercise it was possible to use the cut-in events on the motorway section to extract a sufficient number of cases with either acceptable or unacceptable values for time headway and time to collision. These cases were used for modelling acceptability and rejectability functions and then an equation for the mental model boundary. A visual inspection of the boundary functions shows that these boundaries did not differ much for close car-following conditions, which signify safety-critical situations. The differences for both function coefficients were significant between the Eco and the Baseline conditions, though. Contrary to expectations, the drivers did not accept lower safety margins for eco-driving. On the opposite, it appears that the drivers attempted to maintain larger following distances in order to avoid speed fluctuations. Similar to the statistical analysis of the cut-in scenario, the differences between the boundaries lessened when data with headways of 6 seconds or less were examined. The largest difference between the Safe and the Eco drives was visible in the rejectability function, which is based on cases in which the drivers began to apply the brake. It showed that during eco-driving some participants braked at headways larger than 6 seconds. This behaviour strongly influenced the shape of the boundaries.

In conclusion, computing mental model boundaries enabled an objective identification of a change in safety-critical behaviour during eco-driving. It was found that when other vehicles drove into the participants' lane, and the values for time headway and time to collision became very small, the participants tended not to compromise on their driving safety and braked using similar safety margins for their judgements. This finding is in line with the results from the short-notice braking scenario, in which all participants, except for one, did not change their behaviour significantly in the Eco condition. Hence, safe driving mental models could have bene activated instead of eco-driving mental models in the safety-critical situations. However, it is also possible that eco-driving mental models have the same or similar safety margins in place as 'normal' or safe driving mental models. For example, if a person is eco-driving on a longer trip, and has to brake due to a sudden hazard, the driver is not quitting eco-driving, but merely braking and then resuming eco-driving techniques once it is safe to do so.

### 4.5.4 Findings of interviews and think aloud protocols

The interviews and think aloud protocols ascertain that every participant had some idea of eco-driving and was able to mention at least a few behaviours that are effective in reducing fuel consumption. With regard to strategies and goals, most of the 16 participants mentioned the maintenance of a constant speed, for example by avoiding large speed fluctuations at traffic lights and on the motorway, when other cars were cutting in front of them. Referring to specific actions, 10 drivers said that they tried to closely control their speed by keeping their foot steady on the throttle, and most participants declared that they wanted to avoid stepping on the brake. In order to leave room for a steady speed, eight participants mentioned a longer headway during the motorway part in the Eco drive ("I was leaving more space"). Speed choice was another frequently mentioned topic. Thirteen drivers wanted to keep a lower speed, and 9 drivers said that they wanted to drive more slowly than the speed limit of 70 mph on the motorway. One participant explained that he had not planned to drive more slowly during the Eco drive, but his mild acceleration unintentionally resulted in a lower speed. Indeed, thirteen drivers mentioned slower acceleration in the urban section (“I shouldn’t be using too much gas”). Nine wanted to curb their acceleration on the motorway.

The results of statistically analysing the verbal data indicate a shift in the focus of the drivers when they attempted to eco-drive, although most significant differences were found between the Eco and the Safe condition. The increased focus on one’s own actions and away from the surroundings can denote an increased workload. In fact, Birrell et al. (2010) found that asking people to eco-drive without further support can have such an effect. Rasmussen’s taxonomy (Rasmussen, 1983) suggests that the drivers brought mental models of the rule- and skill-level that would otherwise not have been considered into consciousness. At the same time the focus was partly taken off the surroundings and other safety-critical themes, which could mean a safety risk for unassisted eco-driving.

Comparing verbal with behavioural data indicated that most of the drivers’ actions followed their words. In addition, the mismatches were well distributed among the participant base. Accelerating mildly at junctions keeping the speed lower and more constant appeared to have been feasible for the drivers. However, this effect was more applicable when the participants’ lane was free from other traffic, and when traffic lights switched to amber and red when the host had time to respond. A particular case is the cruising speed in the urban section, were the speed limit was posted at 40 mph. Although only 3 participants said that they would lower it, 15 of 16 participants did so. The former include the person who drove faster. It is possible that the avoidance of accelerations led the drivers to maintain speeds that were lower than intended, as one driver explained.

### 4.5.5 Limitations

This study has several limitations. Firstly, the sensitive nature of the desktop simulator controls could have caused the participants to drive in more erratic ways than they would in more realistic vehicles (Jamson and Jamson, 2010). This lack of control and feedback by the pedals might have inhibited the maintenance of a constant speed. On the other hand, this lack could have provided the potential to easily improve the variation of acceleration and deceleration in the Eco drive. The absence of safety-related consequences can change drivers' diligence. Furthermore, motivations for participating in an experiment are related to contributing to the research, curiosity about its outcomes and financial rewards (Stunkel and Grady, 2011). In the real world people drive for reasons such as commuting to work or travelling to leisure destinations, or the enjoyment of driving itself. Jamson and Jamson (2010) found that a desktop simulator can result in a lack of lateral control, more time in shorter headways, and worse self-reported performance ratings. Hence, values measured with a simulator may not represent values in the real world. Therefore, absolute results cannot be generated, and results need to be interpreted as relative, as suggested by Rook and Hogema (2005). In addition, the brake pedals may have caused problems for people with smaller feet, and therefore the stronger braking actions of the female participants. In fact, there are no studies known to the author that have found similar behaviours. Secondly, the simulator required the model PHEM to approximate fuel consumption with a small number of input variables as well as a different, albeit similar, vehicle, which could have led to estimation errors. Regarding the validity of the findings, it needs to be kept in mind that this study was conducted with a small sample of 16 participants to allow a rich data collection per participant. Its findings have to be validated with a larger sample size and more realistic driving conditions.

The mental model approach has allowed to gain valuable insights, but it is focussed on people's cognition and takes neither emotional nor social factors into account. In the context of researching drivers' knowledge and skills, this approach is sufficient, although there is still a need to further understand other factors that influence behaviour. The think aloud protocol allowed capturing momentary thoughts, but the downside of the method is the incompleteness of the verbalisations. In some places a mismatch between what the drivers said they intended to do and the behavioural data, which indicates an eco-driving strategy, but the absence of a lower-level skill to execute it. Lastly, modelling mental model boundaries was based on a method using a binary function, which only measures a small part of the variety of data collected for mental models in this study. Further possible applications of this method can be measuring boundaries between stopping at amber traffic lights and driving through the junction or testing whether there are visual cues related to the size of the car in front that lead a driver to brake. The fact that data of all participants are included means that the method indicates individual differences, where a statistical analysis would not flag up a significant effect.

### 4.5.6 Implications for subsequent studies

The results of the first study in this thesis indicate that regular drivers have mental models of eco-driving, but do not usually use them in their every-day driving. In this study they were activated following simple, straightforward instructions by the experimenter.

*Limitations of education*: The results support the idea that drivers know more about eco-driving than they are often given credit for (Delicado, 2012). Hence, educating drivers how to eco-drive does not address the underlying problem, the fact that drivers do not fully utilise their existing knowledge and skills. Further research can be conducted regarding the reasons why eco-driving mental models are not activated. It can be assumed that many drivers are sufficiently motivated to eco-drive, as outlined in section 2.3.1, with regards to financial rewards, as well as the sense of acting environmentally friendly.

*Improvement of mental models*: The mental models of eco-driving that were identified in the present study include some misconceptions, such as believing that slow driving and very mild accelerations are always necessary to save fuel (cf. Harvey et al., 2013, van der Voort et al., 2001, Waters and Laker, 1980). In these matters informing and educating drivers could mend weaknesses and improve the existing eco-driving mental models. Showing that eco-driving does not necessarily result in time losses, better practises can make it more attractive to drivers.

*Activating eco-driving mental models*: Knowing that drivers possess eco-driving mental models leads to a new question: How can these mental models be activated? In a study by Dogan et al. (2014) reminding drivers of the reasons to eco-drive, financially or environmentally, was not as effective as feedback. In fact, many people tend to be very aware of environmental issues, particularly drivers (Stradling et al., 2008), and keen to reduce their fuel expenses (Boriboonsomsin et al., 2010). In the present study simple instructions by the experimenter were sufficient to get participants to activate their eco-driving mental models. These instructions involved asking the participants to ‘drive fuel-efficiently’ with neither further explanations nor tangible incentives. The question arises whether this effect can be replicated by delivering the instruction in different ways, and even be repeated on a regular basis in order to achieve stable behavioural change.

*Long-term behavioural change*: The activation of eco-driving mental models was achieved in the experimental drive that immediately followed the experimental instructions. Afterwards, when the participants were then instructed to drive ‘normally’, these behaviour changes diminished. The question arises whether it is possible to change driver behaviour in the long-term, so the eco-driving mental models become the ‘normal’ driving mental models. It has been shown that repeated reminders are effective in changing behaviour sustainably, regarding environmentally friendly behaviours (Seligman et al., 1981) and eco-driving in particular (af Wåhlberg, 2007, Siero et al., 1989). Hence, it may be possible to achieve behavioural changes by an activation of eco-driving mental models over a period of time. The following study, presented in chapter 5 is based on eco-driving primes. Such primes could be a tool to make eco-driving more present in the minds of drivers and thus cause them to change their behaviour sustainably.

## 4.6 Conclusion

This study investigated whether drivers apply different behaviours and have different thoughts when they are asked to eco-drive compared to being asked to drive normally and safely. This study made a unique contribution, as no other study has been found that specifically investigated mental models of eco-driving. The results showed that all participants had mental models of eco-driving, which were effective in reducing their fuel consumption in the Eco drive. The mental models were ranging from higher-level knowledge-based to tactical rule-based to lower-level skills-based behaviour. Drivers were accelerating and braking in smooth ways as well as driving slower. They were not, however, keeping the cruising and car-following speed more constant than in other driving styles. With the behavioural changes, each participant managed to reduce their fuel consumption in the urban section compared to the Baseline drive. In addition, every driver mentioned some idea about eco-driving during the interviews and think aloud protocols. The analysis also pointed out individual differences in eco-driving mental models, in areas such as the understanding of acceleration and speed choice, and their application in safety-critical situations. Hence, every participant carried eco-driving mental models, and it became evident that these mental models were different in some, but also consistent in many aspects. However, none of the drivers used these to their full ability the Baseline drive, when they were instructed to ‘Drive normally’. Although eco-driving mental models are present, there is a need to improve these mental models, especially with regards to effortful behaviours such as accelerating at low rates and choosing low speeds.

The present study marked a step towards understanding the cognition of drivers by measuring mental models with behavioural data, think aloud protocols and open interviews. Further studies will be necessary to validate the findings with a larger number of participants and to extrapolate the conclusions into the real world as well as other transport domains.

# 5 Study 2: The activation of eco-driving mental models

## 5.1 Introduction

Eco-driving has the potential to reduce fuel consumption by 5 to 10% (Barkenbus, 2010) and therefore carbon dioxide ($CO_2$) emissions considerably. Studies that tried to encourage eco-driving behaviours to be adopted indicate that drivers carry more relevant knowledge and skills than they are given credit for (cf. Delicado, 2012). In the previous experiment of the current thesis, reported in chapter 4, it was concluded that drivers possess eco-driving mental models, but do not activate them to their full potential during usual, everyday driving. Although some mental models carry potential for improvement, their existing mental models were effective in reducing fuel consumption in a simulated urban environment. Other studies too found effects that support the presence of eco-driving mental models in drivers' minds. For example, an eco-driving support system (EDSS) tested by Birrell and Young (2011) did not advise on speed choice, but participants decreased mean speed and the time spent speeding. A study investigating the effects of an eco-driving training course found behaviour changes, not only in the intervention group, but in the control group as well (af Wåhlberg, 2007). 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. Hence, it is assumed that eco-driving mental models exist in drivers' minds, but are not activated to their full potential in usual and unsupported driving conditions.

There are several possible reasons for the lack of an activation of eco-driving mental models. Barriers for behaviour change, as discussed in section 2.3.2, include a lack of awareness and knowledge; one's self-identity and status as well as ingrained habits. Training courses provide knowledge, but their effects on fuel consumption wane over time (af Wåhlberg, 2007, Beusen et al., 2009). EDSS could generate long-lasting effects by providing regular feedback and reminders during driving (Hiraoka et al., 2010), both of which are able to change old habits (Jackson, 2005). However, these systems can be complex and expensive to build, and potentially distracting to use. Visual systems, for example, result in more time with the eyes off the road (Engström et al., 2005, Hibberd et al., 2015) and can increase workload (van Erp and van Veen, 2004). Auditory signals, on the other hand, could annoy drivers (Meschtscherjakov et al., 2009).

The question arises whether and how it is possible to activate existing eco-driving mental models with regular prime and advice messages. As discussed in section 2.3.1, it has been shown that repeated reminders are effective in changing behaviour sustainably, regarding environmentally friendly behaviours (Seligman et al., 1981) and eco-driving in particular (af Wåhlberg, 2007, Siero et al., 1989). The eco-driving mental models identified in study 1 were effective, and enabled the drivers to reduce their fuel consumption. However, some of the drivers displayed behaviours that could still be improved, for example by driving at efficient rather than excessively low speeds and accelerating in a swift, but not aggressive manner. Therefore, advice messages could not only remind, but address the misconceptions found in the eco-driving mental models in study 1. It was expected that educational information can improve mental models by addressing the shortcomings identified in the previous experiment, and ideally invoke behaviour change as well (cf. Abrahamse et al., 2005). In sum, it may be possible to activate and improve eco-driving mental models with primes and advice in the form of simple, repeated text messages. Text messages on mobile phones, with interesting eco-driving content, could be a cost-effective tool to make eco-driving more present in the minds of drivers and thus cause them to activate the relevant mental models.

## 5.2 Background

### 5.2.1 Rationale and objectives

In the first study in the present thesis it was found that the participating drivers had eco-driving mental models, but they did not activate them to their full potential during every-day driving. Consequently, for this study it was expected that at least a subgroup of the participants carry eco-driving mental models as well, with different degrees of maturation and correctness. The aim of the research presented in this chapter was to investigate the effects of differing text message interventions on the subsequent activation of eco-driving mental models and thus changes in driver behaviour. With text messages it was tested whether it is possible to encourage the usage of existing eco-driving knowledge and skills, and to improve them. Methods that are primarily designed to teach drivers may be built on the assumption that the lack of eco-driving is the direct result of a knowledge gap (Delicado, 2012). Hence, these methods could be more complex and expensive than necessary, and potentially distracting. In order to further explore reasons for a lack of eco-driving, the study was supplemented with a questionnaire about attitudes towards green behaviours, safety, comfort and enjoyment and innovation, part of them related to driving. Open questions probed the participants about their knowledge of eco-driving and asked for their suggestions to motivate and help them.

For the current study the activation of eco-driving mental models was attempted with regular reminders. Because it was important that the reminders reliably reached the participants, and that they did not need to attend to them during driving, these were sent in the form of text messages. The messages included primes and advice about eco-driving. In order to compare possible behaviour changes, the experiment also included conditions with primes related to driving safety and direct, verbal instructions by the experimenter. The aim was to find out whether and to which degree these four levels of interventions changed eco- and safe driving behaviour, implying an activation of all or a subset of the relevant mental models. Driving behaviour was measured with a variety of scenarios in a motion-based driving simulator before and after the interventions. In order to test whether safe or eco-driving behaviours were more prevalent during the experimental drives, a number of scenarios were designed to offset these goals against each other.

Assuming that the interventions effect an activation of eco-driving mental models, the question arose whether this activation would be stable in the face of conditions such as unrelated thoughts or stress. Hence, it was attempted to challenge the strength of the activated mental models with a moderate workload task. 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 ‘normal’ driving, and not as convenient. One reason is that eco-driving can require more effort and increase workload, especially when unsupported (Birrell et al., 2010, Birrell et al., 2013). Hence, it is expected that once drivers have activated their eco-driving mental models, they might abandon the fuel-saving goal when competing demands for their attention arise (cf. Dogan et al., 2011).

Study objectives:

- The activation of all or a subset of existing eco-driving mental models
- The comparison of interventions using repeated text messages with general primes, educational information and direct instructions
- Challenging of the strength of the activation of eco-driving mental models with a cognitive workload task

### 5.2.2 The activation and deactivation of mental models

In this study it was examined whether eco-driving mental models can be activated with repeated primes, defined in section 3.4.3. For this experiment it was attempted to activate eco-driving mental models with text messages sent to the mobile phones of the participants. It was tested whether there is a possibility of using the concept of repeated primes to activate eco-driving mental models in a cost efficient way.

One of the objectives of the current study was to test whether eco-driving mental models, provided they are activated, can then be easily deactivated with a cognitive workload task. Rasmussen (1979) explained that a reversal to old behaviours can occur under certain conditions such as mind wandering, or stress (Davis, 1958). Weick (1990) coined the term regression for the return to more habitual, familiar and automated actions. Unfamiliar and therefore higher-level mental models (cf. Rasmussen, 1983) usually require more cognitive effort, and are therefore vulnerable to interference by more automated mental models, particularly when the actions are very similar. For example, if the investigation of an infrequent type of error in a process plant is disrupted, and the disruption includes cues that remind the operator of familiar situations, the operator could settle for an activation of more automated mental models and ignore conflicting information. Weick (1990) argued that regression to well-learned, but momentarily unsuitable mental models can have severe consequences, and played a role in a number of aviation accidents. In this research the effects of a cognitive workload task on activated, but likely unfamiliar eco-driving mental models was tested.

### 5.2.3 Unique contribution and justification for approach

This research is unique as to date there is no other study known to the author that specifically investigated the activation of eco-driving mental models, for example with regular eco-driving primes. The present research particularly assumes that drivers already possess a set of eco-driving mental models that need to be activated. In several studies in the past it occurred that drivers used their existing eco-driving knowledge and skills, although some of the behaviour changes had not been directly encouraged (af Wåhlberg, 2007, Birrell and Young, 2011, Tarkiainen et al., 2014). The present experiment was designed to test whether regular primes are able to induce the activation of eco-driving mental models. With one experimental group it was attempted to improve these mental models with eco-driving advice messages. The outcomes of these interventions were compared to the effects of safety-related primes as well as direct verbal instructions by the experimenter. The potential activation of mental models following these interventions was then challenged with a workload task.

In order to conduct the study with a solid theoretical underpinning, the mental model approach was applied. Mental models, covered in detail in chapter 3, are a suitable framework to investigate the activation and deactivation of eco-driving knowledge and skills. Mental models allow distinguishing conscious and automated actions. They furthermore provide an understanding of learning and the application of the acquired knowledge and skills in a variety of settings. This theoretical foundation helps explaining why drivers change their behaviour, fully or partly, and whether and why they revert back to old behaviours in certain situations.

## 5.3 Methodology and research environment

### 5.3.1 The University of Leeds Driving Simulator

This second study used a realistic driving environment with a broad range of scenarios. The main reason to use a motion-based simulator is that it is able to measure smaller, more subtle behaviour changes, which could occur due to primes, compared to experimental instructions. In addition, this simulator is more suitable for a valid measurement of latitudinal data (Jamson and Jamson, 2010), which was now required due a sharp bend scenario as well as a workload task on slightly curvy roads. In general, driving behaviour in different scenarios, relevant for both eco- and safe driving were of interest. Because a workload task can appear artificial (cf. Iqbal et al., 2004), it was necessary to create a realistic setting around it. This realistic environment also enhances the ecological validity of the findings.

This research employed the motion-based version of the University of Leeds Driving Simulator (University of Leeds, 2013). The simulator has been involved in a number of projects, such as ecoDriver, funded by the EU (Hibberd et al., 2013), and Temporary Traffic Management, commissioned by Highways England. Previous research has been conducted on topics such as driver support systems (Hibberd et al., 2013, Jamson et al., 2012), automation (Merat et al., 2012) and road infrastructure (Jamson et al., 2010). According to the AIDE project (Rimini-Döring et al., 2005) the simulator can be classified as a type E, or advanced, system. It is based on a 2005 Jaguar S-type vehicle with fully operational controls, including a real steering wheel with force feedback and pedals, as well as rear view and side mirrors. This is facilitated with a vehicle cab placed inside a dome, shown in Figure 34, which provides the projection area for a spherical screen, showing the road environment at 60 Hz and a resolution of 3 x 1920 x 1200 to the front and 1024 x 768 in the peripheral and rear views. The drivers face a horizontal field view of 266°. The rear view and side mirrors provide a field view of 42°, which is displayed on and therefore only visible through these mirrors. While driving, the participant can perceive forces caused by braking and cornering, as well as rough patches on roads and bumps. An immersive sound system with a speaker mimics the sound of the vehicle’s engine and other road noise. The dome is attached to a hexapod plus X-Y table motion platform with eight degrees-of-freedom. Within the Cartesian frame the motion system is able to move the dome in six orthogonal degrees-of-freedom (3 linear, 3 rotational). In addition, rails allow further 5m of movement to the front and side to better simulate acceleration and deceleration movements in the longitudinal and lateral directions. The vehicle’s software is the same as used for the desktop simulator in study 1, with the additional control by a motion PC. The software assumes an engine model from a 2002 Jaguar X-type and braking data from a Ford Mondeo. Accordingly, for modelling realistic effects on the fuel consumption with PHEM (Rexeis et al., 2005) a Ford Mondeo Ghia with a 16V, Euro 5 petrol engine was assumed. As in study 1, the simulator records data at 60 Hz, which is inferred from the driver’s inputs, the vehicle movement and position, as well as data related to other vehicles on the simulated roads.

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**Figure 34: The University of Leeds Driving Simulator (University of Leeds, 2013)**

The benefits of driving simulator experiments are listed in section 4.3.1. A simulator, for example, provides the highly controlled environment necessary to measure behaviour changes, some of which can be low in magnitude, with a consistent set of scenarios (Boyle and Lee, 2010). For this reason neither naturalistic driving studies nor FOTs were considered for this research. In addition, the large, motion-based simulator in the University of Leeds provides a very realistic setting.

The road layout for this study consisted of urban and rural road segments forming a single stretch for a 30-minute drive. The road was setup with one lane in each direction and was suitable for scenarios involving traffic lights, a sharp bend and interactions with other vehicles. These interactions include a car-following scenario, in which the lead car is programmed to drive with an oscillating speed, as well as a car crossing the road in front of the participant vehicle. The crossing-car event was triggered with a simulated real-time measure for TTC.

### 5.3.2 Apparatus

The experiment was conducted with the University of Leeds Driving Simulator, described in section 5.3.1. A voice recorder was placed into the vehicle to record the responses to the workload task. The text messages were sent as SMS to UK phone numbers provided by the participants with the internet service BulkSMS.

### 5.3.3 Text message interventions and instructions

The interventions for 3 of the 4 groups in this study were based on text messages, which were sent to the mobile phones of the participants for a period of two weeks. The messages served as primes for the drivers to drive eco-friendly and safely, and to provide eco-driving advice, respective of the experimental group. The messages related to eco-driving were supposed to effect an activation of eco-driving mental models, and therefore create similar behaviour changes as the direct experimental instructions in study 1. A list of the text messages are displayed in Table 19.

**Table 19: Text messages and instructions**

| General eco-driving primes (for the Eco-general texts group) |
|---|
| *1: "The Dutch city of Helmond saves 15% of fuel using intelligent traffic lights that change to keep traffic moving. Would you prefer such traffic lights in your area? Text yes or no"*<br>*2: "Reducing carbon emissions in the transport sector has been challenging. Since 1990 only a reduction of 1.7% has been achieved. Would you support stronger legal restrictions for car manufacturers to achieve larger reductions? Text yes or no"*<br>*3: "Driving in urban conditions can be inefficient, particularly for diesel vehicles. Do you avoid driving on urban roads where possible? Text yes or no"*<br>*4: "Satellite navigation systems can suggest fuel-efficient routes. Would you try such an eco-route? Text yes or no"*<br>*5: "Vehicle emissions can increase local air pollution levels. Do you find there is too much traffic in your area? Text yes or no"* |
| Behavioural eco-driving advice (for the Eco-behaviour texts group) |
| *1: "Increasing your distance to the car in front, so you pass the same landmark after 3 seconds, can help you maintaining a steady speed and save fuel. Is this advice helpful? Text yes or no"*<br>*2: "Use engine braking while you approach curves and junctions and avoid slamming on your brakes. Are you practising driving like this? Text yes or no"*<br>*3: "For fuel efficient driving you may accelerate up to speed swiftly, but not aggressively. Have you tried this? Text yes or no"*<br>*4: "Eco-driving is not always slow driving. It is often wiser to get up to an efficient speed and keep steady. Would you try this? Text yes or no"*<br>*5: "Gently accelerate before a hill and step off the gas pedal before reaching the top. Coast downhill to save fuel. Have you given this a chance? Text yes or no"* |

| General safety primes (for the Safety-general texts group) |
|---|
| *1: "In the UK the injury rate of cyclists and pedestrians is high compared with other European countries. Do/would you feel safe walking or cycling? Text yes or no"*<br><br>*2: "Imagine your car communicates with the road and other vehicles to increase safety, particularly at junctions. Would you worry about your privacy? Text yes or no"*<br><br>*3: "Cars will soon be able to take over control in case of a sudden obstacle, and automatically steer around it. Would feel safer with this feature? Text yes or no"*<br><br>*4: "Several cities in the UK consider organizing buses and cyclists in dedicated lanes, separate from cars, designed to increase the safety of all road users. Would you support (more) segregated infrastructure in your area? Text yes or no"*<br><br>*5: "Young drivers are particularly prone to accidents. Do you support an increase in the minimum age for driver's licenses to increase road safety? Text yes or no"* |
| Filler messages (all three groups that received texts) |
| *1: "From 2007 to 2011, the number of cars purchased by people aged 18 to 34 fell almost 30%. Are cars too expensive for young people? Text yes or no"*<br><br>*2: "Partly automated cars need to constantly monitor the driver to ensure they are able to take over control at any time. Would you feel uneasy? Text yes or no"*<br><br>*3: "'Range anxiety' is the term used to describe the concern about the remaining battery charge in electric vehicles. Do you think there are enough charging stations for electric vehicles in your area? Text yes or no"*<br><br>*4: "Predicting traffic flows is a large research field in the UK. Would you say football games have a strong influence on the amount of traffic? Text yes or no"* |

| Experimental eco-driving instruction (for the Experimenter instruction group) |
|---|
| Instead of receiving text messages, the participants were instructed to eco-drive by the experimenter. The experimental instructions involved the following:<br><br>• They were given in person by the experimenter<br>• They were given before driving, when the participant was seated in the simulator<br>• They were formulated in a direct way (“Drive fuel-efficiently”) |

Text messages for particular groups were alternated with transport-related filler messages in order to make their purpose less obvious. A sample schedule for one participant from the Eco-general texts group is displayed in Table 20.

**Table 20: Sample schedule for text messages**

| **Mo 16 April (session 1)** | **Tu 17 April** | **Th 19 April** | **Sa 21 April** | **Mo 23 April** |
|---|---|---|---|---|
| 8pm: eco 1 | 10am: filler 1 | 10am: eco 2 | 10am: filler 2 | 10am: eco 3 |
| **We 25 April** | **Fr 27 April** | **Sa 28 April** | **Su 29 April** | **Mo 30 April (session 2)** |
| 10am: filler 3 | 10am: eco 4 | 10am: reminder | 10am: filler 4 | 8am eco 5 |

In past studies, mostly from the fields of disease prevention and health management, text messages have been used to induce behaviour change. Phillips et al. (2014) argued that text messages can provide education, clear misconceptions and serve as a ‘cue to action’, for example for requesting a vaccination at the next medical appointment. Text messages are an attractive tool, as they are available, relatively cost-effective, used widely and rely on easy technology (Cole-Lewis and Kershaw, 2010). Receivers tend to check their mobile phones several times a day and read their messages accordingly (Gibbs, 2012). In a study by Hofstetter et al. (2013) the targeted Latino population was generally comfortable with receiving health-related text messages at nearly any time of the day. Hence, it could be expected that the participants in study 2 would receive the text messages and read them within a few hours, and that the messages would not be perceived as too intrusive.

In past research text message campaigns were able to change behaviour significantly (Cole-Lewis and Kershaw, 2010). For example, Stockwell et al. (2012) conducted a study in a poor US neighbourhood, in which an intervention group received text messages besides the usual communication based on telephone calls and letters. Five weekly messages resulted in a 3.7% higher vaccination rate. Durations of such interventions ranged from several months (Cole-Lewis and Kershaw, 2010) to three weeks (Stockwell et al., 2013). In comparison, most priming studies included only one session where the cue was provided, such as reading an article or watching a video clip (Iyengar and Kinder, 1987, Josephson, 1987).

The content of text messages is important as well. People who find the messages most useful tend to display the strongest effects (Stockwell et al., 2013). In addition, text messages should clear misconceptions (Stockwell et al., 2012), and, accordingly, be able to improve eco-driving mental models. Receivers generally tend to appreciate short and informal messages (Gold et al., 2010). Hence, the messages were limited to the maximum length of an SMS, which is 160 characters, where possible. An element of interaction ,such as the possibility to reply to a message, can benefit the intervention (Fjeldsoe et al., 2009). For this reason, and in order to assure that the text messages were read, the messages included simple questions the participants needed to answer. There is some disagreement about the recency of messages. A review of 29 studies involving appointment reminders found no difference between reminders sent one week before and a day before a medical appointment (Hasvold and Wootton, 2011). In contrast, in priming studies a recency effect has been found (Higgins, 1989). It was decided to send the text messages regularly and, the last one, close to the second session, in the early morning of the same day.

Generally, it is suggested to underpin text message interventions with a theoretical basis in order to reduce uncertainty (Abraham and Michie, 2008, Cole-Lewis and Kershaw, 2010). The mental model theory is able to provide a particularly meaningful basis. It provides the justification for primes, meant to bring eco-driving mental models into the participants’ minds, and for advice for the improvement of mental models.

Finally, it was expected that text messages are an intervention that is simple to set up. In order to ensure a smooth handling of the messages during the experiment, the online service BulkSMS was used. The service allowed sending messages larger than 160 characters, where needed, scheduling as well as receiving replies from participants. Participants were expected to provide their own mobile phones with UK numbers, which was verified in the confirmation email sent during the booking process for the study.

### 5.3.4 Design

A three-way (2x4x2) mixed design was employed with Drive as within-subjects factor (2 levels – ‘Drive 1’ and ‘Drive 2’). For the analysis of the coherence scenario, which took place twice during each drive, the within-subjects factor was changed to Task with 4 levels (Drive 1 no TQT, Drive 1 TQT, Drive 2 no TQT, Drive 2 TQT). The between-subjects factor was Intervention (4 levels), Eco-general texts, Eco-behaviour texts, Safety-general texts and Experimenter instruction, as shown in Table 21. The Safety-general texts group was added as a comparison to the Eco-general texts group, so the effects of the general, non-advisory primes could be compared between these two topics. The Eco-behaviour texts group was created to facilitate a comparison between general primes and behavioural advice, designed to improve eco-driving mental models. Instead of receiving text messages, the Experimenter instruction group was asked by the experimenter to drive fuel-efficiently. No further explanations, for example what ‘fuel-efficient’ means, were provided with the instructions. This study did not involve a control group due to resource limitations, and because study 1 offers detailed measures of the behavioural effects of an activation of eco-driving mental models. The baseline measures were taken into account with Drive. The within-subjects factor Drive refers to the experimental Drives in the driving simulator. The levels consisted of Drive 1 and Drive 2. For Drive 1 the participants were asked to drive ‘normally’, as they would every day, so these drives could provide data to measure people’s usual driving behaviour as well as to evaluate practice or boredom effects by comparing it with Drive 2. The participants were asked to drive normally in Drive 2 as well, except for those in the Experimenter instruction group, who were instructed to drive fuel-efficiently.

**Table 21: Design of experiment**

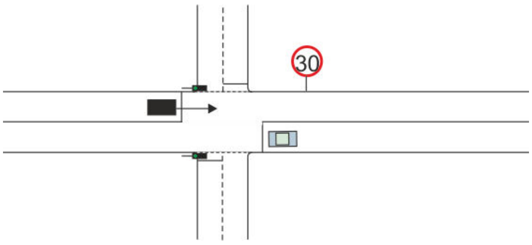
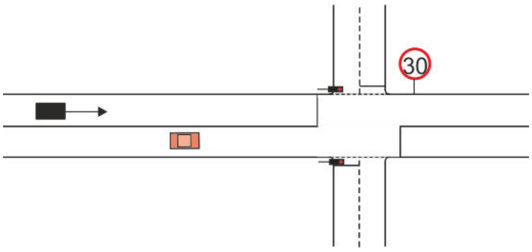
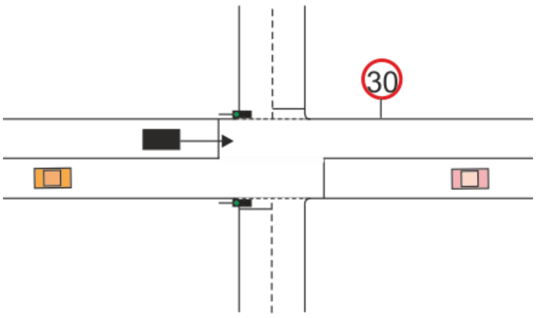
| | Eco-general texts (n = 15) | Eco-behaviour texts (n = 13) | Safety-general texts (n = 15) | Experimenter instruction (n = 15) |
|---|---|---|---|---|
| Drive 1 | "Drive normally." | "Drive normally." | "Drive normally." | "Drive normally." |
| Inter-vention | General eco-driving primes | Behavioural eco-driving advice | General safe driving primes | Experimental instructions |
| Drive 2 | "Drive normally." | "Drive normally." | "Drive normally." | "Drive fuel-efficiently." |

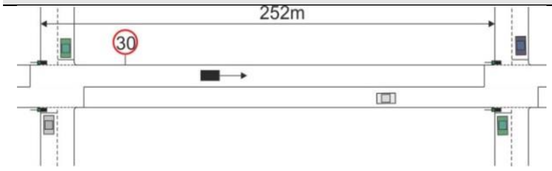
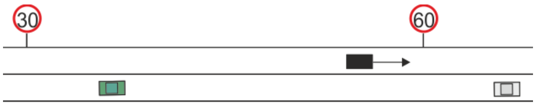
### 5.3.5 Driving scenarios

The experimental road was about 18 km long, and provided for a drive of about 30 minutes. The road of one lane in each direction, leading the participant through urban and rural sections. There was no traffic in the participant's lane, except for the coherence and crossing car scenarios. The posted speed limits were 30 mph (48 km/h), 40 mph (64 km/h) and 60 mph (97 km/h). The speed limit in the cruising scenario was changed from 40 mph in study 1 to 30 mph in the present road layout, because the single drive per experimental session allowed space for more diversity and lower speeds. In addition, the 30 mph speed limit is commonly applied in residential areas in the UK (UK Government, 2015b).

Ten scenarios were developed, which allowed testing a wide range of behaviours. Five scenarios were designed to primarily provide the possibility for eco-driving, and 5 for safe driving. For the former, safety-critical situations were prevented with the absence of surrounding vehicles in the participants' trajectory. In addition, the traffic lights involved provided sufficient time to stop. These scenarios are described in Table 22 and were applicable to study behaviours such as accelerating, cruising and decelerating, as well as speed choice. The scenarios involving traffic lights were also relevant for anticipatory actions during the approach.  The two-junction scenario was changed from study 1, because approaching a red traffic light from standing caused some participants to drive excessively slowly. Hence, it was designed as a 'catch' scenario in the present experiment with the traffic lights at the second junction remaining green. This design still allowed testing for anticipatory behaviours such as slow approaches. Most scenarios occurred once, but there were two occasions of each of the speed-change up as well as the long-range braking scenario. The coherence scenario was added in this study to research car-following behaviour with continuous measures, and a workload task as described in the following section. The scenario was placed both at the beginning and the end of the Drive.

Table 22: Scenarios primarily relevant for eco-driving

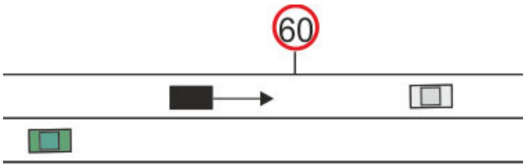
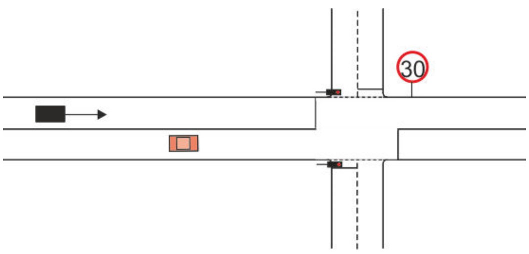
| Road layout | Scenario description |
|---|---|
| Acceleration<br><br> | The participant was stationary at a red traffic light that then switched to green. They then accelerated to the speed limit.<br>Data capture commenced when the traffic light turned green and ended approximately 350m later.<br>This scenario was primarily designed to measure acceleration behaviour, including mean and variation of acceleration, as well as the maximum throttle angle. |
| Long-range braking<br><br> | The long-range 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.<br>Hence, deceleration behaviours could be measured, including the smoothness and locations when stopping actions were initiated. |
| Green lights<br><br> | The green lights scenario involved a junction with traffic lights that remained green throughout. The scenario was designed to measure anticipatory behaviour and as a 'catch' scenario to prevent participants from preparing for red lights at junctions. |
| Two-junction | The two-junction scenario was designed as a catch scenario. It began when the traffic lights at one junction turned green and the traffic |

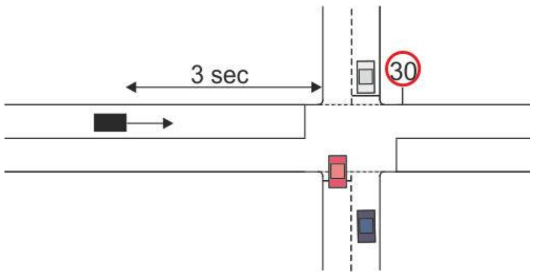
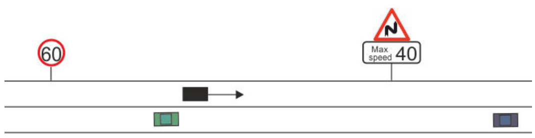
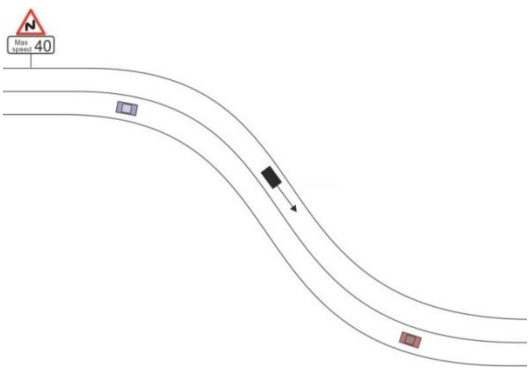
| Road layout | Scenario description |
|---|---|
|  | lights of another junction, 252m further down the road, remained green.<br><br>Similar to the green lights scenario the two-junction scenario measured anticipation, but also acceleration behaviour. |
| Speech change up<br> | The participants drove on a straight road with a speed limit of 30 mph (48 km/h) and then into a 60 mph (97 km/h) zone, marked by a sign.<br><br>This scenario was designed to study acceleration when higher speeds, potentially higher than efficient, were involved. |
| Cruising<br> | The cruising scenario consisted of road sections with slight curves, 250m long. This scenario occurred several times in both the urban and rural sections with a speed limit of 30 mph. Cruising involved free flow driving with no traffic lights present. Hence, it was relevant for speed choice and variation. The scenario had the secondary purpose to create space between the scenarios involving junctions. |

Five scenarios relevant for safe driving were created, as listed in Table 23. They were designed to create a conflict between safe and eco-driving. If drivers attempted to keep a constant speed, these scenarios would have made it unsafe to do so. The scenarios involving traffic lights required strong braking or the option to cross an amber traffic light. Those involving other cars and a speed limit decrease followed by a sharp bend may result in short safety-margins. Events in the scenarios were based on specified values for

TTC, which meant that these scenarios still created such conflicts, even when drivers approached them with lower speeds.

Table 23: Scenarios with conflicts between eco- and safe driving

| Road layout | Scenario description |
|---|---|
| Coherence   | The coherence 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 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). In this study no instructions, e.g. regarding following distance were given. The scenario was 3 km long and lasted 100 seconds. It was relevant for measuring car-following performance, with and without a workload task. |
| Short-notice braking and amber dilemma   | The braking scenario involved a junction, where the drivers could bring the vehicle to a stop at a red traffic light or drive through. The traffic lights were timed in three different ways. In the short-notice braking scenario and amber dilemma they turned red when driver's TTC with them was 3.5 and 2.5 seconds, respectively. The traffic lights in the amber catch scenario remained green. The scenario ended when the traffic lights turned green or when the junction was crossed. These |

| Road layout | Scenario description |
|---|---|
| | scenarios were important for the decision whether to cross the junction, and for braking behaviours. |
| Crossing car   | The crossing car scenario began when the TTC of the host vehicle with the stop line of the junction was 3 seconds. Then a car that stood in a side street crossed the road in front of the participant. Within just over 2 seconds it accelerated to 30 mph before clearing the junction. The crossing car either provoked strong braking reactions or the riskier option of keeping a constant speed. |
| Speed change down   | The scenario began with a speed limit of 60 mph and the participant drove towards a section with an advisory speed limit of 40 mph. This scenario was relevant for potentially early, anticipatory deceleration actions, and adherence to speed limits. |
| Sharp curve   | The sharp curve scenario was taking place on a single carriageway with no traffic in the participant’s lane. The participant approached the scenario on a straight road with a speed limit of 60 mph. The sharp curve (100 m radius, 72 m length per curve) was preceded by the speed change down scenario. A bend to the right (50%) was followed by a bend to the left (50%). |

| Road layout | Scenario description |
|---|---|
| | The sharp curve scenario offset the goal of keeping a constant speed against navigating the curve with a safer, lower speed. |

Figure 35 shows the sequence of the scenarios, which were separated with cruising sections. The scenarios involving safety conflicts were mixed with the scenarios primarily relevant for eco-driving. All participants were provided with the same road layout in both sessions.

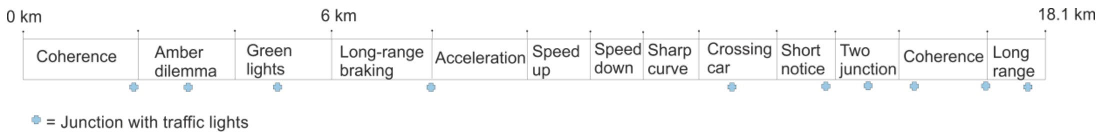



Figure 35: The urban and rural road section with acceleration, braking and cruising scenarios

### 5.3.6 Workload task

Assuming that some drivers would activate and use eco-driving mental models following the interventions, it was tested how they responded, e.g. whether they would revert to their usual driving behaviour, as they were performing a moderate workload task. For this research the selection of the workload task was crucial to ensure that the drivers were engaged in typical, natural activities and thoughts. The reason is that a more abstract task, for example involving arithmetic operations during driving, could cause untypical mental models to be activated. For example, a task based on a set of arrows or other symbols projected into the driver's field of view does not usually occur in everyday driving. Such a task can therefore cause the driver to engage in abstract problem-solving activities, which potentially interfere with the driving task in an unusual way. Similar issues could occur if the task had been competitive enough to trigger the participants' ambition to win (Venables and Fairclough, 2009).

Therefore, it was decided that the drivers were presented with a modified version of the Twenty Questions Test (TQT, Kafer and Hunter, 1997, Mosher and Hornsby, 1966). The TQT is based on a common children's game and has been used in research, particularly in the fields of children's development and education (Denney, 1973, Denney and Connors, 1974, Mosher and Hornsby, 1966) as well as impaired cognitive functioning (Kafer and Hunter, 1997, Klouda and Cooper, 1990, Laine and Butters, 1982). The task requires cognitive resources for problem solving, planning and the working memory (Horrey et al., 2009). It has first been used as a secondary workload task for drivers by Horrey et al. (2009). They valued its natural conversational style, 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). Merat et al. (2012) used this task in a driving simulator study to research the effects of a nonvisual secondary task, which is similar to the use of modern sound-based in-vehicle systems. However, the original version of the task is competitive, as the participants are expected to attempt a good performance by finding as many correct answers as possible (Kafer and Hunter, 1997, Mosher and Hornsby, 1966). Accordingly, people tend to cognitively engage in the TQT, which can make it demanding, frustrating and pressurising as a secondary task for drivers (Horrey et al., 2009).

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 9 small cards with for words, the ‘answers’. 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, and is usually applied by adults with normal cognitive functioning (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’. Some questions were ambiguous to avoid having a task that is too simple. For example, one question for the word ‘apple’ was: “Is it commonly used in cakes?” On the other hand, the participants were instructed not to think too much about a question to avoid excessive variation between the participants and questions. Feedback on the answers was not provided to avoid influencing the participants’ motivation and effort (cf. Venables and Fairclough, 2009). The task was given during the coherence scenario, because it provides several measures relevant to safe and potentially eco-friendly car-following performance.

### 5.3.7 Questionnaires

Because the text messages mostly addressed one of the barriers, ingrained driving habits, the study was supplemented with questionnaires about other reasons for a lack of activation such as the drivers' attitudes towards green behaviours as well as their knowledge of eco-driving. The attitudes questionnaire consisted of 45 questions with answers on a 5-point Likert scale. It was based on a green attitudes questionnaire developed for the ecoDriver project, but to date neither standardised nor validated. It was particularly interesting what was important to drivers, in relation to driving, and what they think when they are driving. Hence, the questionnaire was extended with topics related to safety, comfort as well as fun and innovation. Table 24 lists examples of the groups of questions. Two questions specifically asked drivers to rank these topics with regards to what they think about during driving and what they find important.

**Table 24: Excerpts from the attitude questionnaire**

| |
|---|
| Questions related to eco-driving and green behaviours |
| "*Most drivers think it is a good idea to drive with the conservation of the environment in mind*"<br>"*I buy certain products specifically because they are better for the environment than other products*" |
| Questions related to safe driving and safe behaviours |
| "*It is important to me that I drive as safely as possible*"<br>"*I buy certain products specifically because they are safer than other products*" |
| Questions related to comfort in driving and other behaviours |
| "*Drivers generally value driving comfort*"<br>"*I buy certain products because they increase my comfort*" |
| Questions related to fun and innovation in driving and other behaviours |
| "*I am happy to pay more for a car that has good information and entertainment systems*"<br>"*I consider myself fit and active*" |

Because the study mostly relied on subtle approaches involving text message primes and the detailed measurement of resulting behaviour changes, it was decided to ask the participants direct questions at the end of the second session. Hence, another questionnaire, designed specifically for this study, was administered following the debriefing. It consisted of three open questions, "*What do you know about how to drive fuel-efficiently?*", "*What would help you to drive fuel-efficiently?*" and "*What would be reasons for you to drive fuel-efficiently?*" These questions were intended to confirm earlier findings that drivers know how to eco-drive, as well as to gather suggestions for making them use their knowledge.

### 5.3.8 Dependent variables

The data recorded in this study included objective, behavioural measures as well as data collected with questionnaires. Speed and x- and y-position of the vehicle on the roadway were used to model the fuel consumption. Objective measures were recorded for entire road layouts, except for the start section, as well as for the distinct scenarios taking place within each drive, which are relevant for each of the measures of interest. Mean and standard deviation values for speed, acceleration and deceleration data were extracted. For the accelerator pedal angle and brake pedal pressure, maximum values were also identified. The measures used from the coherence scenario included headway, coherence, phase shift and modulus. The coherence is the squared correlation between the speed of the front and the participant car, the phase shift is the delay of reactions to the speed fluctuations of the lead car, and the modulus is an amplification factor indicating whether the participant is over- or underreacting (Brookhuis et al., 1994)[8]. The questionnaires included closed questions about attitudes towards green driving behaviours, but also about other driving styles, and topics such as automation, comfort and safety. The questionnaire at the end of the second session consisted of three open questions regarding one's knowledge about and ideas for support for eco-driving, as well as one's motivations to do so. The replies to the text messages, 'yes' and 'no', were recorded as well. The engagement with the TQT was ensured by recording the participants' answers. Because the task did not focus on performance,

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[8] The MATLAB code for calculating the coherence, phase shift and modulus was provided by Michael Daly.

and because several questions were ambiguous, the actual replies to the text messages and the TQT were not analysed.

### 5.3.9 Hypotheses

*Hypotheses for eco-driving-relevant scenarios*

Roskos-Ewoldsen et al. (2002) argued that repeated priming over a period of time can increase the activation of the targeted mental models. Likewise, prompts were expected to lead to automated behaviours being overruled (Steg et al., 2012). Transferring these ideas to this study, it was expected that general eco-driving primes increase the activation of the eco-driving mental models, similar to the direct instructions in the previous study in the present thesis. Hence, participants who received general eco-themed messages were hypothesised to change their behaviour and lower their fuel consumption.

It was expected that behavioural advice causes a refinement of eco-driving mental models and stronger behavioural changes compared to the general primes. When drivers use their eco-driving mental models, a lack of practise and misconceptions can prevent them from reaching their full potential of fuel savings. One common misconception is the belief that low speeds are necessary, as shown in previous research (Harvey et al., 2013, van der Voort et al., 2001, Waters and Laker, 1980) and the first study in the present thesis. Furthermore, it is not necessary to accelerate as slowly as some drivers do when eco-driving (Beusen et al., 2009, Birrell et al., 2010, Evans, 1979).

The members of the Safety-general texts group were hypothesised to change their behaviour in some regards and improve their fuel consumption slightly. The reason is that several safe and eco-driving practises overlap (Young et al., 2011). Safety-themed messages can lead people to adhere to the speed limits (Cristea et al., 2012), gently slow down at red traffic lights (cf. Summala, 2007) and leave longer headways (Boer et al., 2005, Cristea et al., 2012). Usually, these safety margins can serve as margins for eco-driving, too, for example to avoid stepping on the brake.

The Experimenter instruction group was expected to display the strongest behaviour changes, due to the directly prompted activation of eco-driving mental models. For example, Hasvold and Wootton (2011) showed that phone calls are more effective than text messages in reminding patients of appointments.

*Hypotheses for safety-relevant scenarios*

In safety-relevant scenarios the participants had to trade-off safety and eco-driving. Summala (1988) defined safety margins as the spatial or temporal distance of a driver to a hazard. Drivers tend to control these safety margins as their measure of risk. Time headway, for example, is one important safety margin (Goodrich and Boer, 2003).

During eco-driving drivers were expected to aim for the maintenance of a constant speed. They may keep a longer mean headway during car-following (Birrell et al., 2014, Boer et al., 2005), but tolerate when the headway temporally becomes very short (Mensing et al., 2013), e.g. when a car is cutting in the front, to avoid braking. Drivers could also be tempted to cross a junction with amber traffic lights to keep their speed constant (Andrieu and Pierre, 2012, Delhomme et al., 2013, cited in Haworth and Symmons, 2001, Nairn and Partners et al., 1994), when stopping would be safer. A speed limit decrease can have implications for eco-driving as well, as drivers who activate their eco-driving mental models may coast rather than step on the brake pedal and begin to do so early on (Andrieu and Pierre, 2012, Birrell et al., 2014, Delhomme et al., 2013, Evans, 1979). However, they may be tempted to postpone using the brake pedal and compromise safety by driving too fast when passing the traffic sign.

Driving through a sharp curve can present another trade-off between safety and fuel-efficiency, as, in order to improve the latter, drivers attempt to keep their speed constant and avoid pedal braking. However, drivers tend to associate eco-driving with low speeds (Birrell and Young, 2011, Evans, 1979, Harvey et al., 2013, van der Voort et al., 2001, Waters and Laker, 1980), which could be measured during the approach and navigation of the curve. Hence, it was expected that eco-driving leads to a slower approach to the curve and then a more constant speed compared to the Safety-general group.

Safety primes were hypothesised to lead to increased driving safety such as a stronger adherence to the speed limits (Cristea et al., 2012). In some cases safe driving behaviour is different from eco-driving, for example when stronger speed adjustments can help maintaining safety margins (Brookhuis et al., 1994, Ward et al., 2003) or when stopping at amber or red traffic lights is safer than driving through a junction (cf. Summala, 2007).

*Hypotheses for the coherence scenario and workload task*

It was predicted that during the first coherence scenario in Drive 1, without TQT, the participants would display a relatively accurate car-following performance. An activation of eco-driving mental models in Drive 2 can cause larger headways in order to attain milder reactions (Boer et al., 2005), and lower speeds (Birrell et al., 2010). Hence, in the first coherence scenario in Drive 2 car-following was expected to be compromised.

The workload task, performed during the second coherence scenario, which occurred towards the end of both Drives, had the potential to have two types of effects. It has been found that higher workload can cause lower coherence, a higher phase delay and a lower modulus (Ward et al., 2003). For the second session, in particular, it was expected that effects caused by Intervention diminished during the workload task, as drivers reverted to old habits (cf. Rasmussen, 1979). In that case, previously displayed eco-driving behaviours would not be resumed in the long-range braking scenario following the task.

*Summary of main hypotheses*

- When drivers receive text messages with general eco-driving primes they are expected to increase eco-driving behaviours such as lower speeds as well as the variation of speed, acceleration and deceleration
- When drivers receive text messages with behavioural eco-driving advice they are hypothesised to increase eco-driving behaviours, but apply higher speeds and stronger acceleration
- When drivers receive text messages with general safety primes, they are expected to increase anticipatory eco-driving behaviours such as coasting, adherence to speed limits and longer headways, but prioritise safety in safety-critical scenarios by braking sooner, e.g. at higher speeds as well as distances to junctions and hazards, and stronger

- Experimental instructions to drive ‘fuel-efficiently’ are hypothesised result in the strongest increase in eco-driving behaviours including lower speeds as well as the variation of speed, acceleration and deceleration
- In scenarios relevant for safe driving, eco-driving interventions are expected to increase the prioritisation of eco-driving and therefore to maintain a constant speed, also in safety-critical situations, and therefore apply the brake less strongly and closer to the junction, traffic sign or hazard, and lower the mean and variation of deceleration as well as do not lower their speed as much as in ‘normal’ driving
- A workload task as well as eco-driving interventions are expected to compromise car-following behaviour, measured in a coherence scenario with coherence, phase shift and modulus as well as headway
- After the workload task behaviours resulting from interventions are not expected to resume

### 5.3.10 Participants

Participants were recruited utilising the driving simulator as well as the database of the Institute for Psychological Sciences in the University of Leeds, both including a diverse range of participants, as indicated in Table 25. The base consisted of 58 drivers, gender balanced. Every participant drove at least 1000 miles per year and held a full EU license for at least two years. As a gesture of appreciation all participants were given £20.

**Table 25: Participant demographic information**

| | Male | | | Female | | |
|---|---|---|---|---|---|---|
| | Age (years) | Annual mileage (miles) | Driving experience (years) | Age (years) | Annual mileage (miles) | Driving experience (years) |
| Mean | 32.0 | 8614 | 11.6 | 38.4 | 8045 | 17.4 |
| Sd. | 11.3 | 4565 | 9.6 | 11.4 | 4766 | 10.6 |
| Max. | 63 | 20000 | 40 | 61 | 25000 | 38 |
| Min. | 21 | 1000 | 3 | 22 | 4000 | 2 |

### 5.3.11 Procedure

During recruitment the participants were told that the study was about ‘driving styles’, without mentioning the eco-driving focus, to prevent the participants preparing for the study. When the appointments were confirmed, the participants were randomly assigned to an Intervention and an email was sent to them. Those in the texts groups were told that the study involved regular text messages on their mobile phones for two weeks, at least every 48 hours. The email also informed the participants of their right to withdraw from the study at any point in time. 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 practise drive to become familiar with the driving simulator and the TQT. The scenarios involving junctions and other vehicles in the participants’ trajectory were not included in the practise drive to prevent the drivers from expecting them. For the experimental Drives, each participant was asked to drive through a combined urban and rural section normally, as they would every day. They were told that they would encounter junctions with traffic lights and one sharp bend, and that they were expected to handle those as they normally would. The coherence scenario was explained to the drivers, who were then instructed to follow the lead car as long as it is in front of them on the main road. The participants were told that the simulated car is equipped with a conventional petrol engine. The Drive lasted around 30 minutes. Subsequently, the participants were given questionnaires enquiring about their attitudes towards green and other driving behaviours as well as demographic information.

After the session the intervention took place according to the assigned Intervention. For a period of 2 weeks a text message was sent to each participant, except for the Experimenter instruction group, at least every 2 days. At the end of the period the participants were scheduled for a second session in the driving simulator. The second session began with an experimental drive, for 30 minutes. For this drive the participants were asked to drive normally, except for the Experimenter instruction group, which was asked to drive fuel-efficiently. The coherence scenario and the questions task were explained as in the first session. After the drive the participants filled in the same attitudes questionnaire. Subsequently, a debriefing took place and the participants had the opportunity to ask questions about the study. To finalise the session, another questionnaire was given to the participants, with the open questions “What do you know about how to drive fuel-efficiently?”, “What would help you to drive fuel-efficiently?” and “What would be reasons for you to drive fuel-efficiently?”

During the experimental drives in the first and second session, the drivers were presented with the TQT, which is described in detail in section 5.3.6, for the duration of the second occurrence of the coherence scenario. The participants had been given a set of ‘answers’ on a card, which they took with them into the simulator. When the front car of the second coherence scenario was placed in front of the participant, the task began with instructions by the experimenter. The task was performed as a conversation between the participant and the researcher via the hands-free communications system in the vehicle. The experimenter asked 15 pre-formulated questions about each word. The participant was instructed to reply to each question with either ‘yes’, ‘no’ or ‘I don’t know’. They were instructed to ask the experimenter to repeat the question, if they wished to do so. Once the experimenter ‘guessed’ the word, the participant was asked to move on to the next answer on their list.

### 5.3.12 Analysis

The raw data collected by the driving simulator was processed in Matlab to extract the dependent variables, for the whole drives and separately for each scenario. For the behavioural measures a mixed methods ANOVA was performed, with the within-subjects factor Drive (2 levels: Drive 1 and Drive 2), and the between-subjects factors Gender (2 levels) and Intervention (4 levels). Instead of 2 within-subjects levels the coherence scenario involved 4 Task levels (Drive 1 no TQT, Drive 1 TQT, Drive 2 no TQT, Drive 2 TQT). In order to assure that significant effects were not due to differences between the Intervention groups in Drive 1, a separate one-way ANOVA was conducted with data from Drive 1 only. Drive*Intervention interaction effects were further explored using two-tailed t-tests. Due to a strong literary foundation for the hypotheses as well as the findings of study 1, the t-tests were one-tailed when comparing Drive 1 and Drive 2 for the Experimenter instruction group. When assumptions of parametric testing were violated, non-parametric methods were used with Wilcoxon on within-subjects factors, the Mann-Whitney U-test on Gender, and the Kruskal-Wallis test on

Intervention. In the case of multiple tests, the results were Bonferroni corrected. Statistical significance was accepted at $p < 0.05$.

Because the questionnaire items were ordinal, they were analysed with the Wilcoxon sign-rank test for within-subjects differences and with the Kruskal-Wallis test for between-subjects effects in Drive 2. Besides analysing the items separately, the differences between Drive 1 and Drive 2 scores were calculated and then grouped into the categories ‘eco’, ‘safety’, ‘comfort’ and ‘fun and innovation’ with the latter incorporating items related to innovations, information and entertainment systems as well as driving enjoyment. For a more detailed analysis, the ‘eco’ items were grouped into the categories ‘self’ (“*It is important to me that I save as much fuel as possible while driving*”), ‘others’ (“*Drivers generally drive with the environment in mind*”) and ‘non-driving’ (“*I wash laundry in cold water rather than warm or hot water specifically to save energy*”). The summed-up scores were then compared between the Intervention groups with independent-samples t-tests. Gender differences were tested with Drive 1 responses using the Mann-Whitney U-test.

## 5.4 Results for scenarios relevant for eco-driving

### 5.4.1 Fuel consumption and travel time effects

There were no significant main effects of Drive, Intervention and Gender for mean fuel consumption either for the entire drive or for the cruising scenario. For the total time spent in a drive no significant effect was found. However, for the time spent in the cruising scenario a Drive*Intervention interaction effect could be identified [$F(3, 50) = 3.828$, $p = .015$, $\eta^2 = .187$], as displayed in Figure 36. Especially for Experimenter instruction group this time increased by 27 seconds to 15:06 minutes, and a t-test prove this difference to be significant [$t(14) = -2.688$, $p = .036$, $r = .583$].

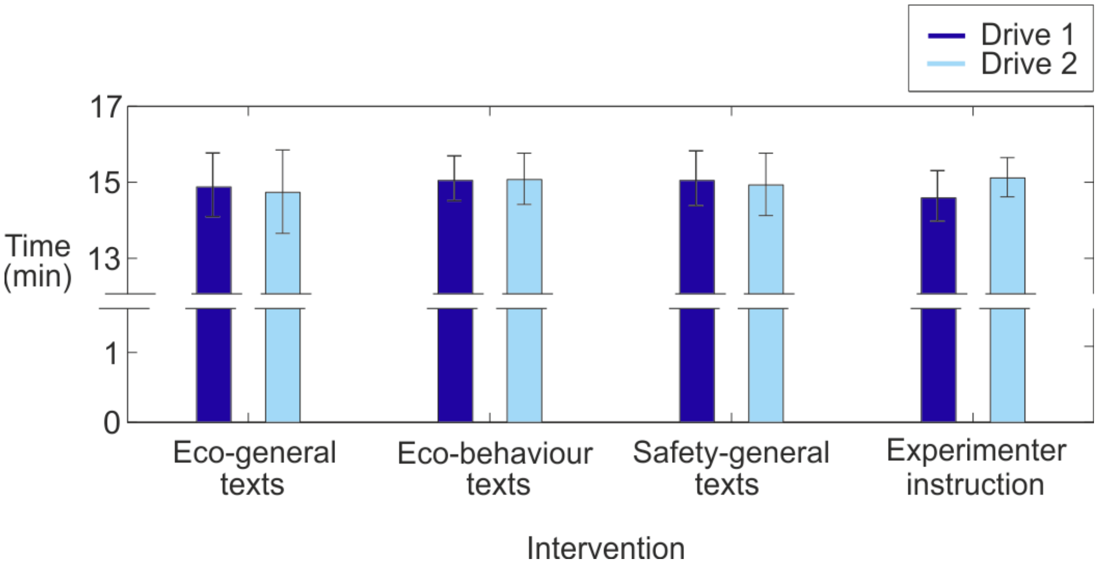


**Figure 36: Drive*Intervention interaction effects for the time spent in the cruising scenario**

**Table 26: Drive 1 to Drive 2 changes for the total drives and cruising sections**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Fuel consumption total (g/s) | 0.002 | 0.003 | -0.001 | -0.001 |
| Fuel consumption cruising scenario (g/s) | -0.008 | -0.013 | -0.024 | -0.022 |
| Time total (sec) | -41s | -1s | 13s | 32s |
| Time cruising scenario (sec)* | -7s | 2s | -7s | 27s |

* p < .05

** p < .01

*** p < .001

### 5.4.2 Acceleration scenario

Figure 37 shows the speed profiles in the acceleration scenario for the group instructed to eco-drive, compared to the group receiving eco-driving prime messages.

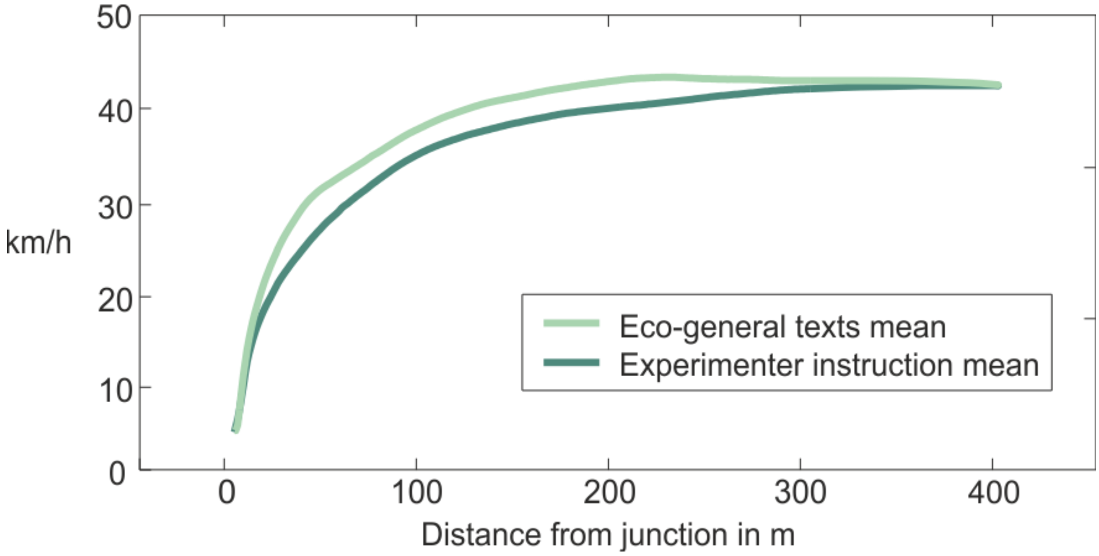


**Figure 37: Speed profile in the acceleration scenario**

In this scenario several effects could be attributed to the interventions. For mean acceleration a Drive*Intervention interaction effect was found [$F(3, 50) = 3.049$, $p = .037$, $\eta^2 = .155$] with the Experimenter instruction group accelerating 19% less harshly in Drive 2 [$t(14) = 3.343$, $p = .010$, $r = .666$], Figure 38. In order to analyse the mean acceleration in isolation an ANCOVA was conducted with the mean cruising speed in Drive 2 as covariate. The result showed that the cruising speed affected the speed, and the Drive*Intervention became non-significant ($p = .054$).

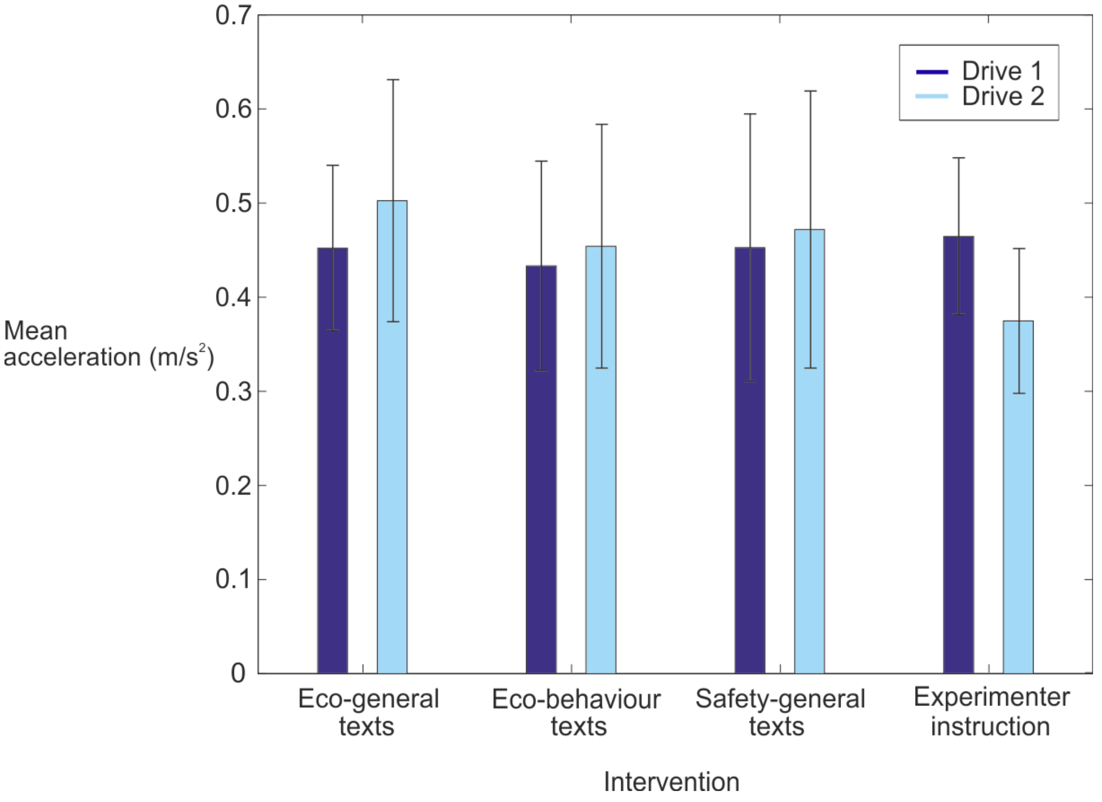


**Figure 38: Drive*Intervention interaction effect for mean acceleration in the acceleration scenario**

The Experimenter instruction group also accelerated 30% more smooth in the acceleration scenario, indicated by another Drive*Intervention interaction effect [F(3, 50) = 3.396, p = .025, $\eta^2$ = .169] and supported by a t-test [t(14) = 3.772, p = .004, r = .710], as depicted in Figure 39.

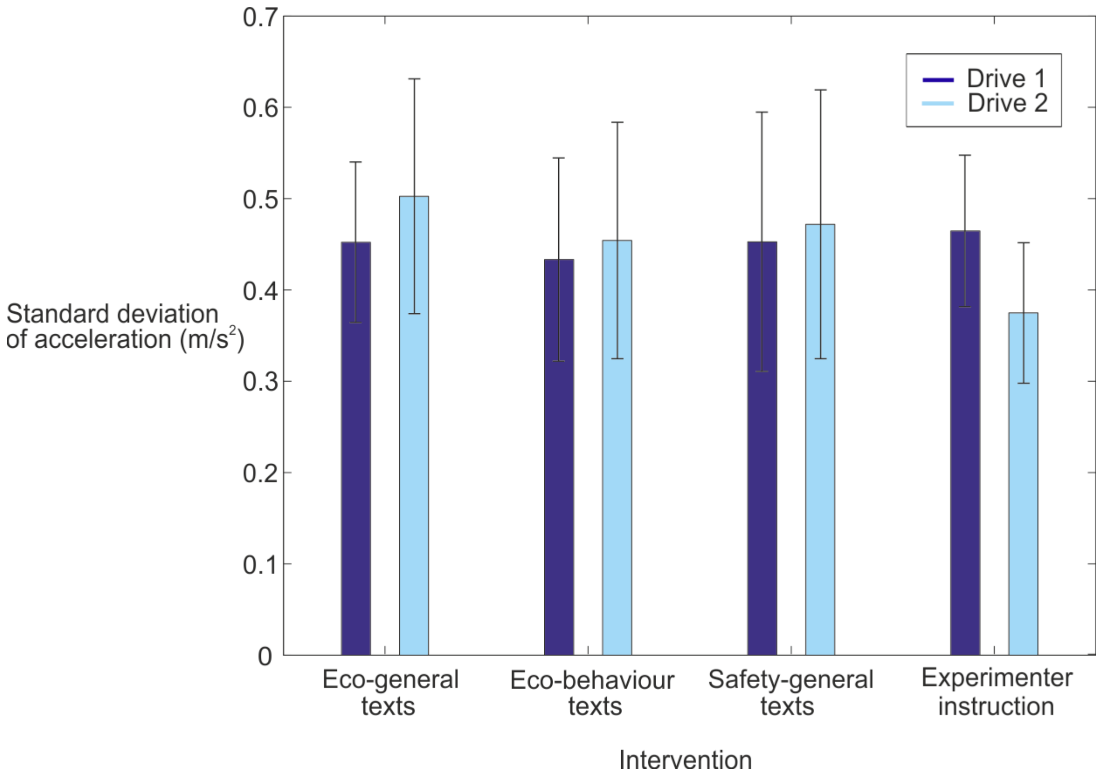


**Figure 39: Drive*Intervention interaction effect for the standard deviation of acceleration in the acceleration scenario**

**Table 27: Drive 1 to Drive 2 changes for the acceleration scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean acceleration ($m/s^2$)* | 0.05 | 0.02 | 0.02 | -0.09 |
| Time with accelerator pedal angle above 10° (s) | -1.20 | 3.60 | 4.30 | 5.90 |
| Sd. of acceleration ($m/s^2$)** | 0.07 | -0.01 | 0.03 | -0.14 |
| Max. accelerator pedal angle (°) | 5.00 | 0.40 | 5.70 | -9.20 |
| Time over speed limit (s)* | 1.90 | 0.00 | 2.40 | -1.50 |

* p < .05
** p < .01
*** p < .001

In addition, in Drive 2 males spent almost 3 more seconds, or about 22% more time, above the speed limit, while females 2 seconds less in the acceleration scenario. This resulted in a significant Drive*Gender interaction effect [$F(1, 50) = 4.567$, $p = .038$, $\eta^2 = .084$], drawn in Figure 40.

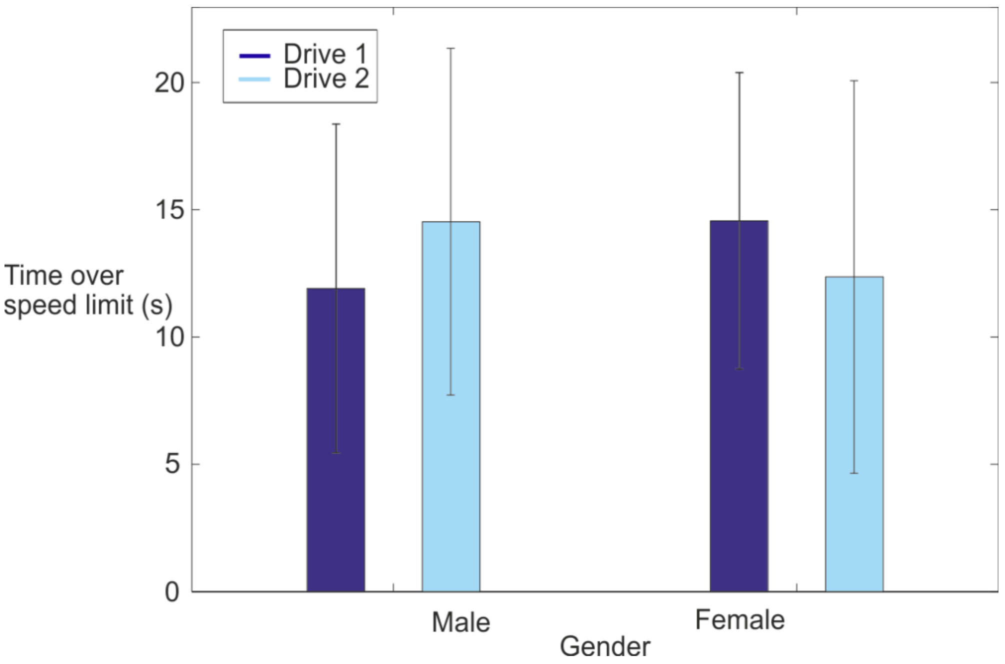


**Figure 40: Drive*Gender interaction effect for the time spent above the speed limit in the acceleration scenario**

### 5.4.3 Long-range braking scenario

The first occurrence of the long-range braking scenario was placed exactly half-way along the road layout. The speed profiles in Figure 41 illustrate the performance in this scenario for the Experimenter instruction and the Eco-general texts groups.

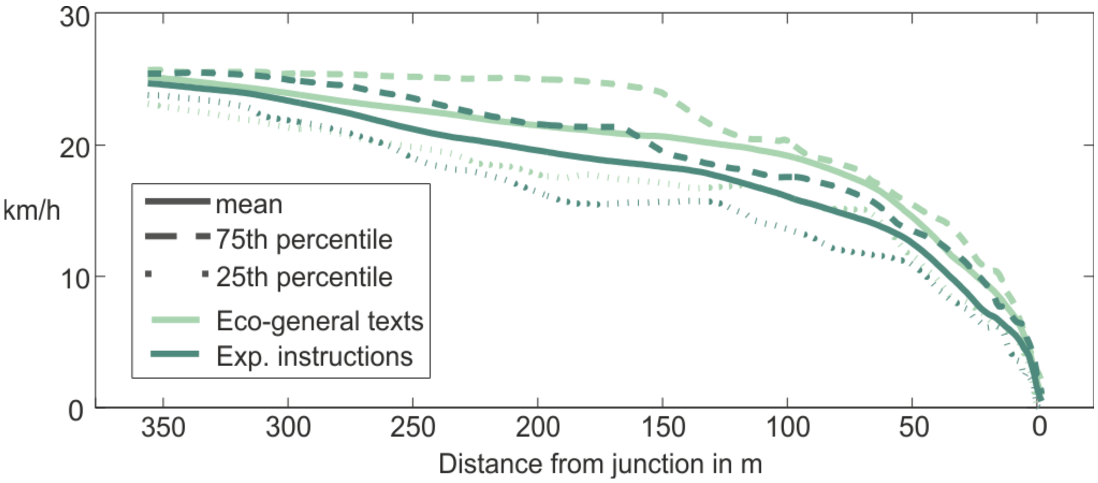


**Figure 41: Speed profile for the Eco-general and the Experimenter instruction groups in Drive 2 in the long-range braking scenario**

The analysis of the mean speed in the long-range braking scenario produced several results. For all groups except the group instructed by the experimenter mean speed increased in Drive 2 [$F(1,50) = 4.354$, $p = .042$, $\eta^2 = .080$] with no significant effects emerging for any Intervention group in t-tests. However, a Drive*Intervention interaction effect $F(3,50) = 3.302$, $p = .028$, $\eta^2 = .165$ supports this change in mean speed. Differences between the groups in Drive 1, as Figure 42 suggests, were not significant. Hence, the effect can be attributed to Intervention.

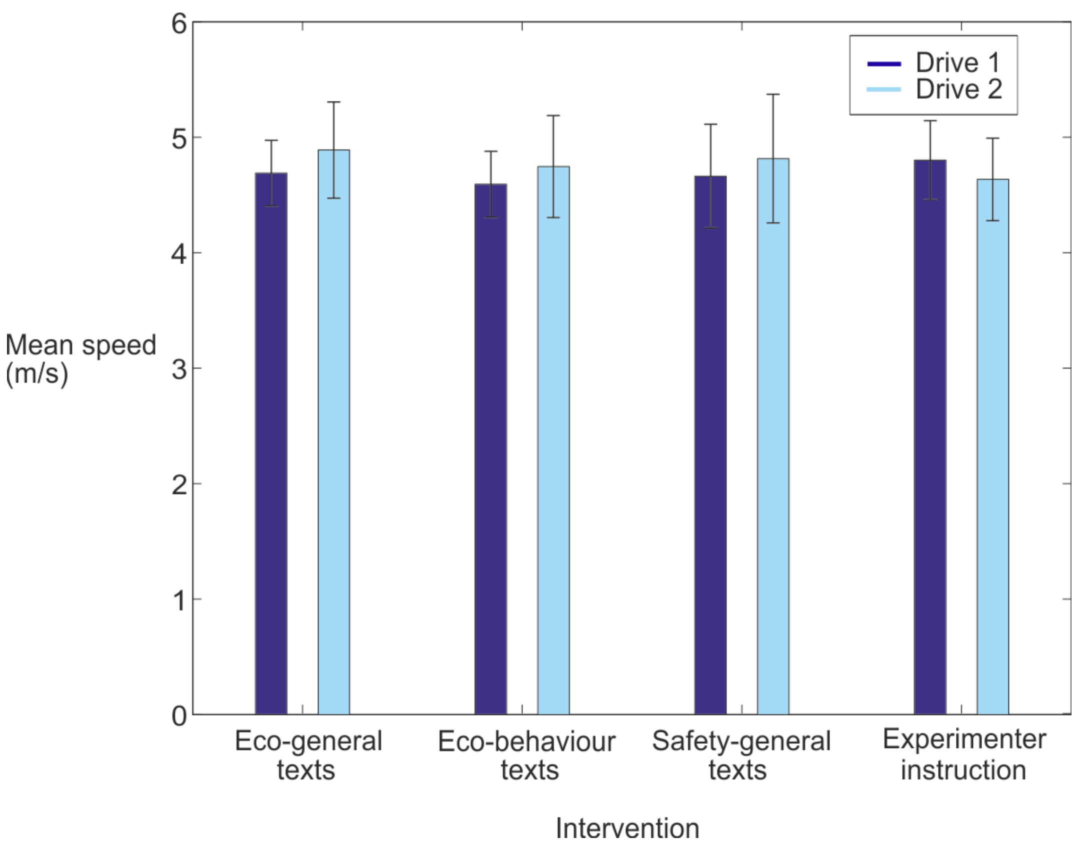


**Figure 42: Drive*Intervention interaction effect for mean speed in the long-range braking scenario**

A main effect for Drive indicated that drivers in all groups lifted their foot off the accelerator on average 29 m closer to the junction in Drive 2 [$F(1, 50) = 8.052$, $p = .007$, $\eta^2 = .139$], Figure 43.

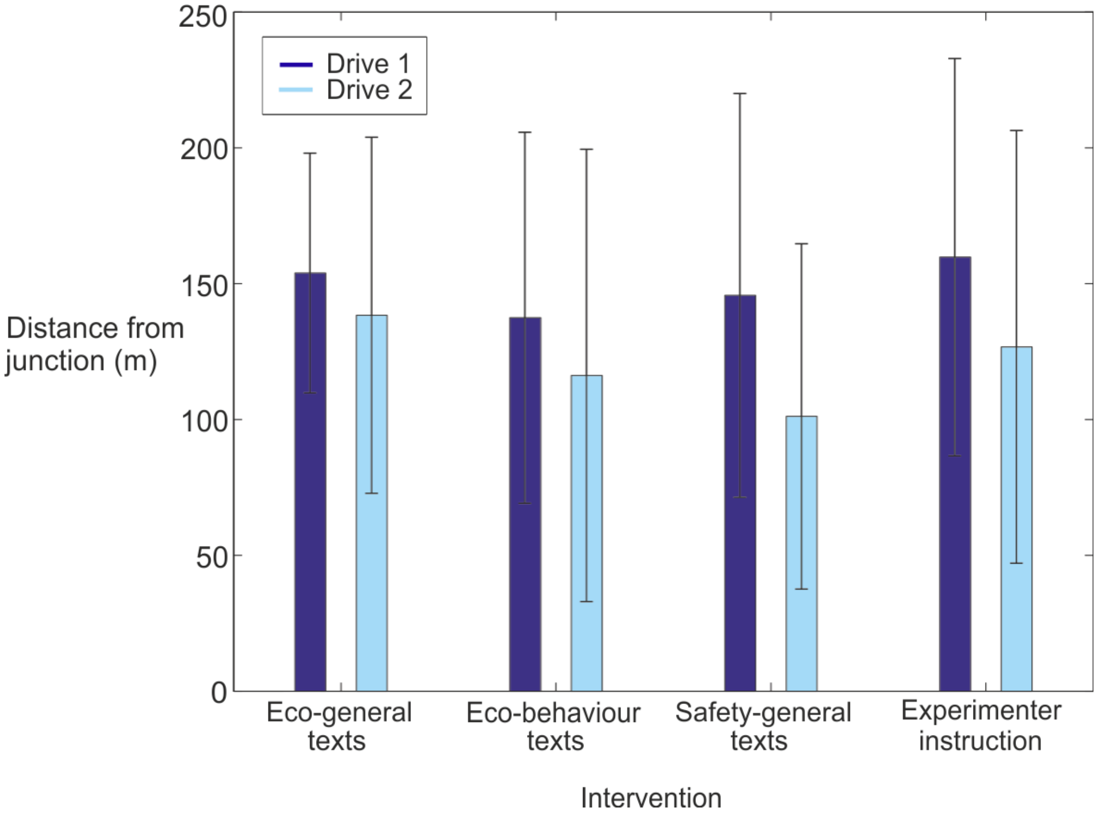


**Figure 43: Drive effect for location when foot off gas pedal in the long-range braking scenario**

**Table 28: Drive 1 to Drive 2 changes for the long-range braking scenario 1**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets)* | 0.22 (0.5) | 0.16 (0.3) | 0.15 (0.4) | -0.17 (-0.3) |
| Mean deceleration ($m/s^2$)* | -0.05 | 0.02 | 0.00 | 0.04 |
| Sd. of deceleration ($m/s^2$) | 0.01 | 0.03 | 0.04 | -0.01 |
| Max. brake pressure (N) | 1.9 | 20.1 | 6.4 | 5.1 |
| Location when foot off gas pedal (m)** | -16 | -21 | -45 | -33 |
| Location when foot on brake pedal (m) | -11 | -56 | -24 | -6 |
| Time coasting (s) | -1.98 | -0.08 | -1.94 | 1.93 |

* $p < .05$
** $p < .01$
*** $p < .001$

There was a Intervention*Gender interaction effect in the long-range braking scenario with females driving slower in the Eco-general and Safety-general texts groups (each by 6%), but faster than males in the Eco-behaviour (8%) and Experimenter instruction group [4%, $F(1,50) = 4.876$, $p = .005$, $\eta^2 = .226$]. However, the effect was already significant in Drive 1 [$F(3,50) = 3.319$, $p = .027$, $\eta^2 = .166$], as Figure 44 suggests, which means that the former interaction effect cannot be attributed to the interventions.

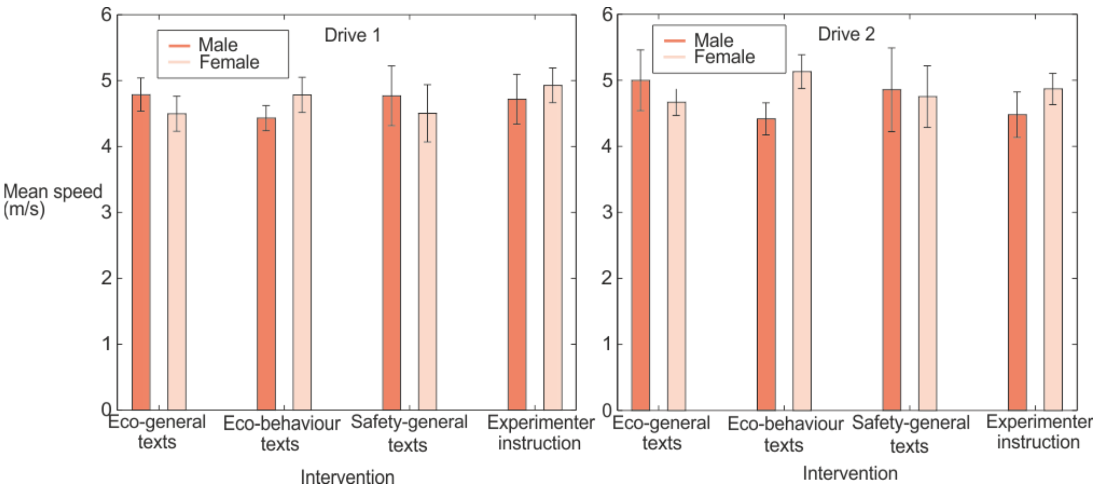


**Figure 44: Intervention*Gender interaction effect for mean speed in the long-range braking scenario**

For mean deceleration there was a significant Intervention*Gender interaction effect [$F(3, 50) = 3.221$, $p = .030$, $\eta^2 = .162$], as illustrated in Figure 45, with females decelerating 27% stronger than males in the Eco-behaviour texts group, and males 31% stronger than females in the Safety-general texts group. However, because an ANOVA conducted solely with the Drive 1 values of the long-range braking scenario concluded with an even stronger, significant Intervention*Gender interaction effect [$F(3, 50) = 3.748$, $p = .017$, $\eta^2 = .184$], Figure 45, these results were treated with caution when drawing conclusions.

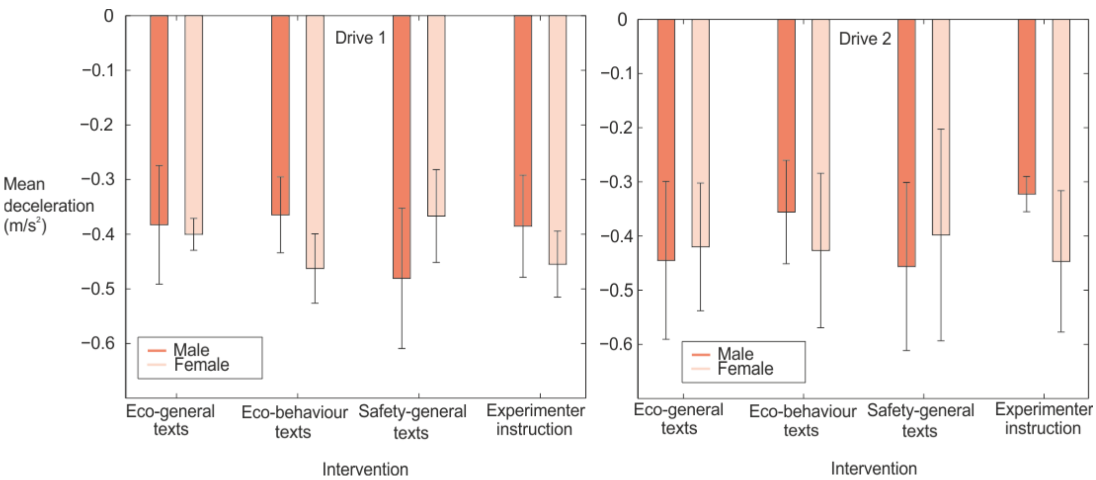


**Figure 45: Intervention*Gender interaction effect for mean deceleration in the long-range braking scenario**

### 5.4.4 Green lights scenario

There were no main effects in the scenario involving a junction with green traffic lights.

**Table 29: Drive 1 to Drive 2 changes for the green lights scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets) | 1.0 (2) | 0.2 (1) | 0.4 (1) | -0.3 (-1) |
| Mean deceleration ($m/s^2$) | 0.027 | 0.071 | -0.013 | 0.044 |
| Max. deceleration ($m/s^2$) | 0.012 | 0.141 | -0.007 | 0.110 |
| Sd. of deceleration ($m/s^2$) | -0.005 | -0.038 | 0.014 | -0.025 |
| Min speed (m/s) (mph in brackets) | 1.4 (3) | 0.5 (2) | 0.3 (1) | -0.1 (-1) |

* $p < .05$

** $p < .01$

*** $p < .001$

### 5.4.5 Two-junction scenario

This scenario involved traffic lights at one junction turning from red to green and the traffic lights of another junction, 252m further down the road, remaining green. No main effects for the factors Intervention and Drive were found.

**Table 30: Drive 1 to Drive 2 changes for the two-junction scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean acceleration ($m/s^2$) | 0.016 | 0.035 | 0.108 | -0.051 |
| Time with accelerator pedal angle above 10° (s) | 0.1 | 1.9 | 1.8 | 2.6 |
| Sd. of acceleration ($m/s^2$) | 0.039 | 0.032 | 0.107 | -0.091 |
| Max. accelerator pedal angle (°)* | 0.50 | 4.30 | 9.20 | 1.80 |
| Time over speed limit (s)* | 3.67 | 1.98 | -0.79 | 1.33 |

* p < .05

** p < .01

*** p < .001

The analysis resulted in two Gender effects for the two-junction scenario. A Kruskal-Wallis test flagged up that males pressed the accelerator pedal 39% more than females at the maximum following the interventions [$\chi^2(1) = 5.168$, $p = .023$, $\varphi = .299$], as depicted in Figure 46.

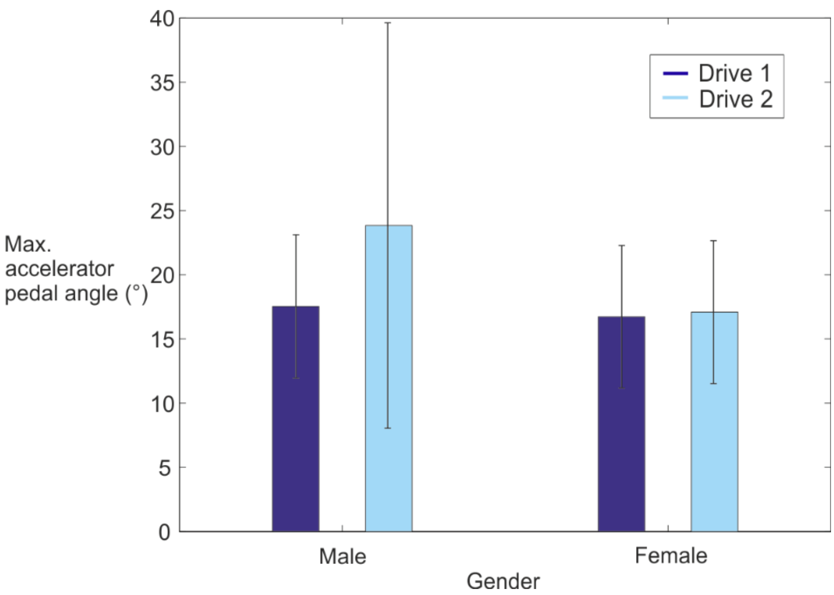


**Figure 46: Gender effect for the maximum accelerator pedal angle in the two-junction scenario**

The other Gender effect in the two-junction scenario [$F(1, 50) = 5.385$, $p = .024$, $\eta^2 = .097$] indicated that males speeded longer, by 2.8 seconds in Drive 1, and also increased this time by 1.3 seconds in Drive 2, as shown in Figure 47. A Kruskal-Wallis test confirmed the Gender effect for Drive 1 [$\chi^2(1) = 3.921$, $p = .048$, $\varphi = .260$].

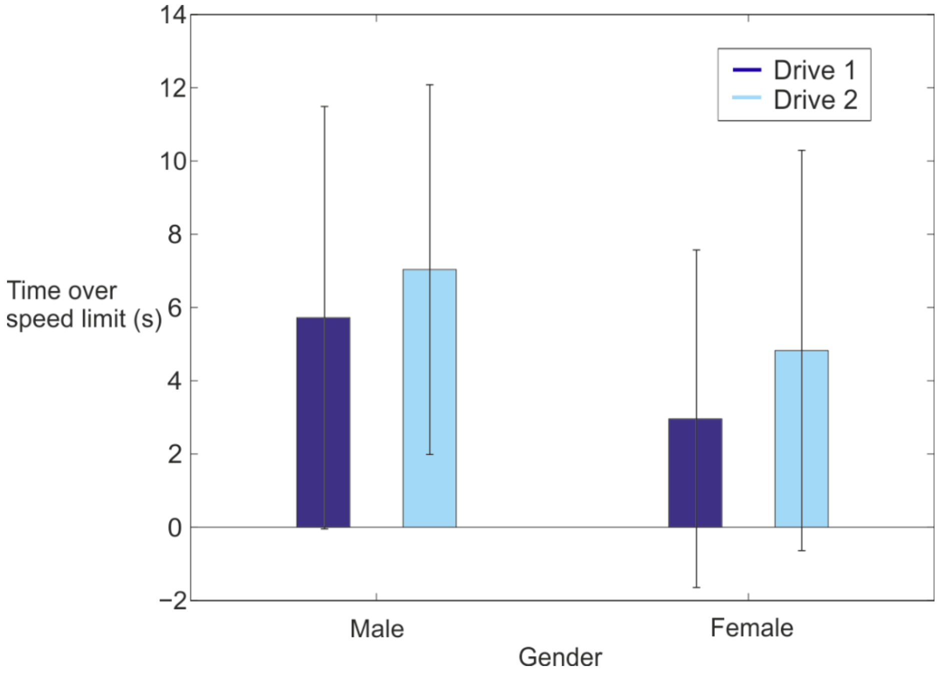


**Figure 47: Gender effect for the time spent above the speed limit in the two-junction scenario**

### 5.4.6 Speed change up scenario

In this scenario the speed limit changed from 30 mph (48 km/h) to 60 mph (97 km/h). Figure 48 shows the speed profiles for the Eco-general texts and Experimenter instruction groups.

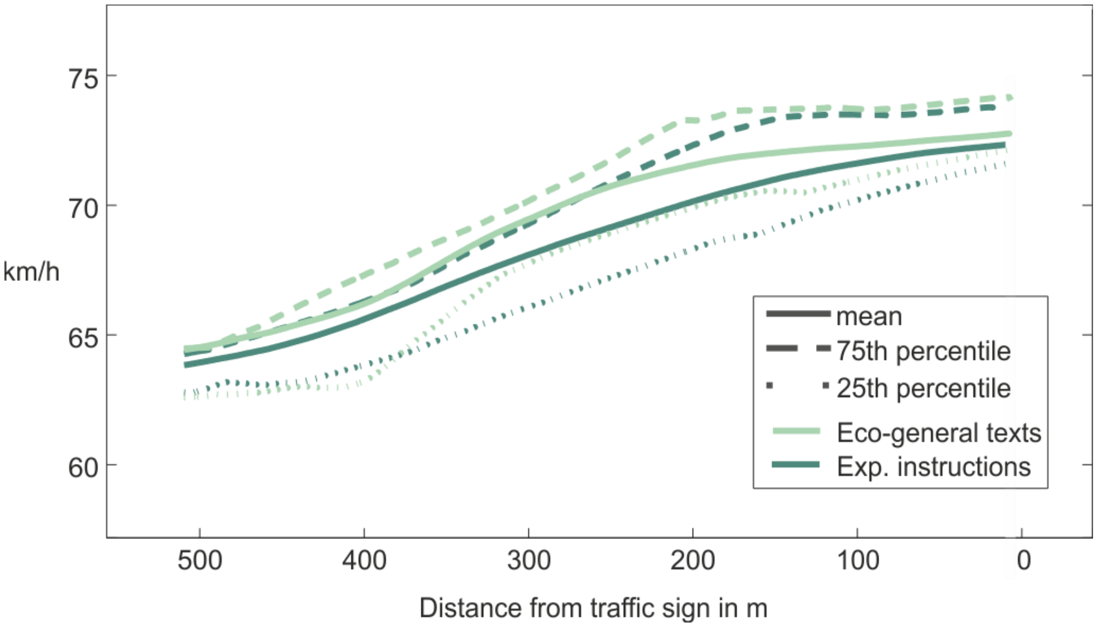


**Figure 48: Speed profile for the Eco-general and the Experimenter instruction groups in Drive 2 in the speed change up scenario**

For mean speed there was a Drive*Intervention interaction effect [F(3, 50) = 3.378, p = .025, $\eta^2$ = .169] in the speed change up scenario, with both the Eco-general and Safety-general texts groups raising their mean speed, each on average by about 2.3 mph, in Drive 2, Figure 49. T-tests confirmed that the Experimenter instruction group lowered their mean speed by 6% [t(14) = 3.036, p = .005, r = .630]. The effect was supported by the fact that differences between the Intervention groups in Drive 1 were not significant.

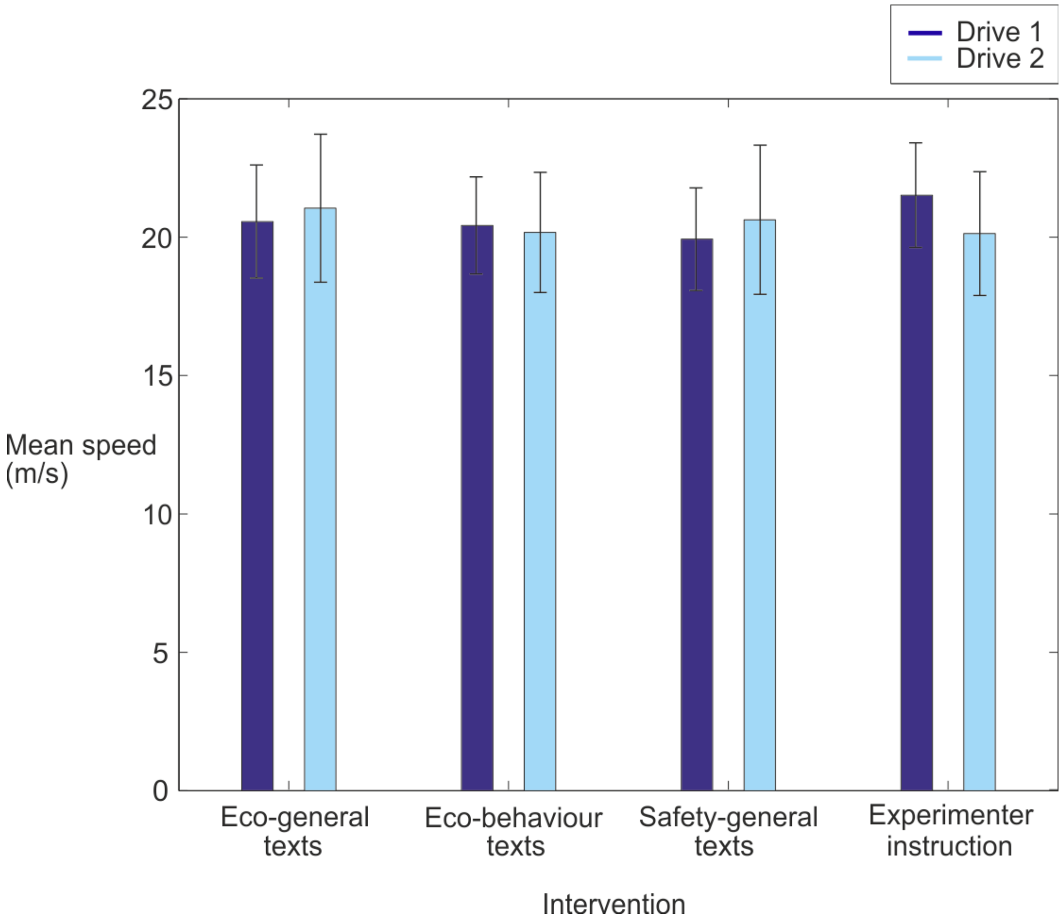


**Figure 49: Drive*Intervention interaction effect for mean speed in the speed change up scenario**

There was no main effect for mean acceleration in this scenario. For the standard deviation of speed there was a main effect for Drive [F(1,50) = 9.815, p = .003, $\eta^2$ = .164]. T-tests showed that the speed following the interventions was steadier in both the Eco-general [17%, t(14) = 2.897, p = .048, r = .612] and the Experimenter instruction groups [19%, t(14) = 3.085, p = .016, r = .636]. Although Figure 50 suggests relatively large differences between the Intervention groups in Drive 1, these were not significant.

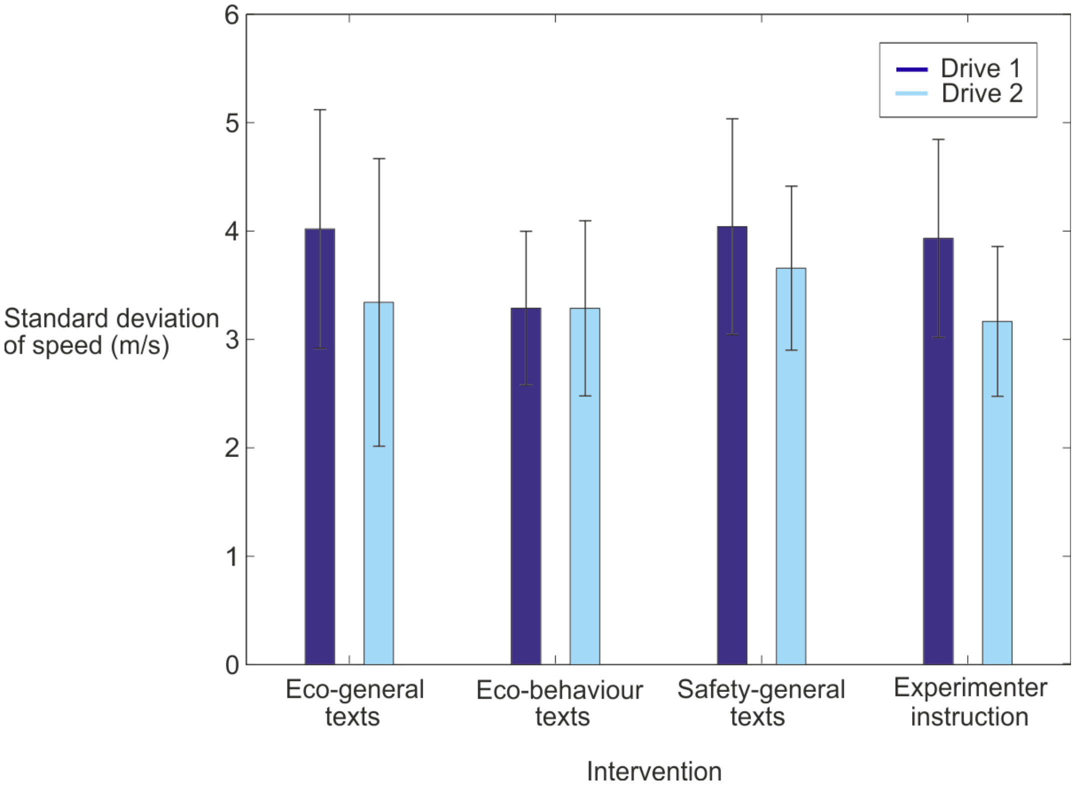


**Figure 50: Drive effect for the standard deviation of speed in the speed change up scenario**

For the variation of acceleration in the speed change up scenario there were significant effects for Drive [$F(1,50) = 6.246$, $p = .016$, $\eta^2 = .111$] and for the interaction Drive*Intervention [$F(3,50) = 5.460$, $p = .003$, $\eta^2 = .247$]. Because the measure for the Eco-behaviour and Safety-general texts groups in Drive 2 were not normally distributed, a Kruskal-Wallis test was performed, which confirmed a Intervention effect in Drive 2 [$\chi^2(3) = 9.546$, $p = .023$, $\varphi = .406$]. A t-test showed that for the Experimenter instruction group the measure was significantly lowered, by 51%, in Drive 2 [$t(14) = 4.910$, $p < .001$, $r = .795$]. This difference is well visible in Figure 51.

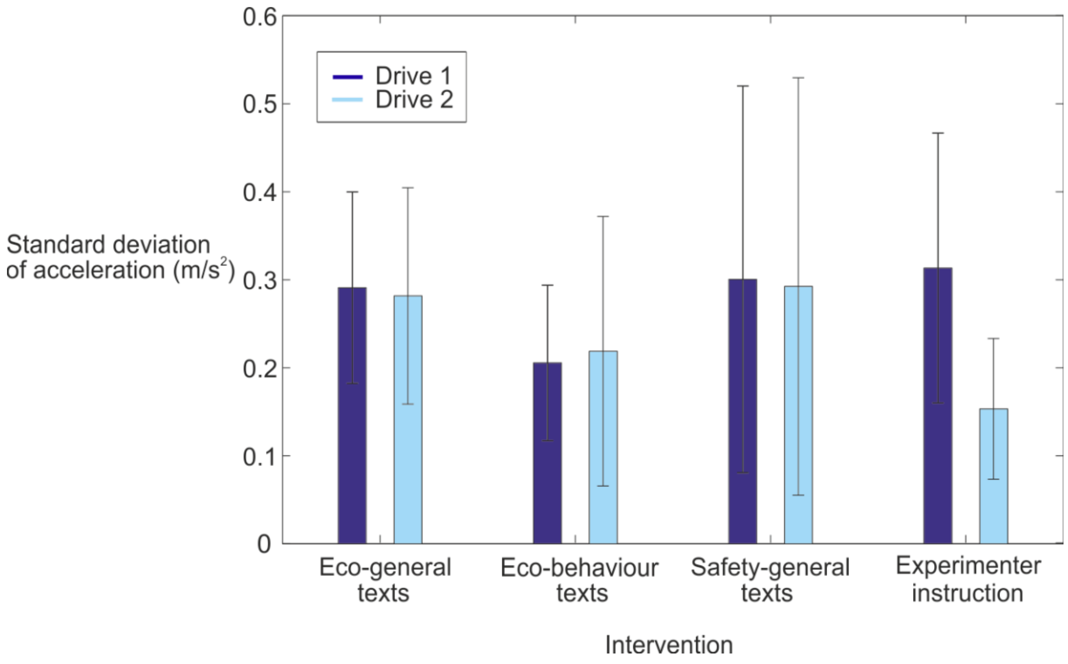


**Figure 51: Drive*Intervention interaction effect for the standard deviation of acceleration in the speed change up scenario**

The analysis of the maximum speed did not result in main effects attributable to Intervention in this scenario.

**Table 31: Drive 1 to Drive 2 changes for the speed change up scenario, from 30 to 60 mph**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets)** | 0.4 (1) | -0.2 (-1) | 0.7 (1) | -1.4 (3) |
| Speed at traffic sign (m/s) (mph in brackets)* | 0.9 (2) | -0.1 (0) | 1.3 (3) | -1.0 (-2) |
| Max. speed (m/s) (mph in brackets)* | -0.5 (-1) | -0.3 (-1) | 0.4 (1) | -1.8 (-4) |
| Sd. of speed (m/s) (mph in brackets)** | -0.68 (-1.5) | 0.00 (0.0) | -0.38 (-0.8) | -0.76 (-1.7) |
| Mean acceleration ($m/s^2$)* | -0.060 | 0.012 | -0.006 | -0.096 |
| Sd. of acceleration ($m/s^2$)** | -0.009 | 0.013 | -0.009 | -0.16 |
| Max. accelerator pedal angle (°) | 2.3 | 4.6 | 3.8 | -2.9 |
| Time over speed limit (s) | -0.92 | 0.04 | 0.12 | -0.75 |

* $p < .05$

** $p < .01$

*** $p < .001$

A Drive*Gender interaction effect for the speed change up scenario indicates that the speed when passing the traffic sign increased for males by 5% and decreased for females by 4% in the second session [$F(1,50) = 5.467$, $p = .023$, $\eta^2 = .099$].

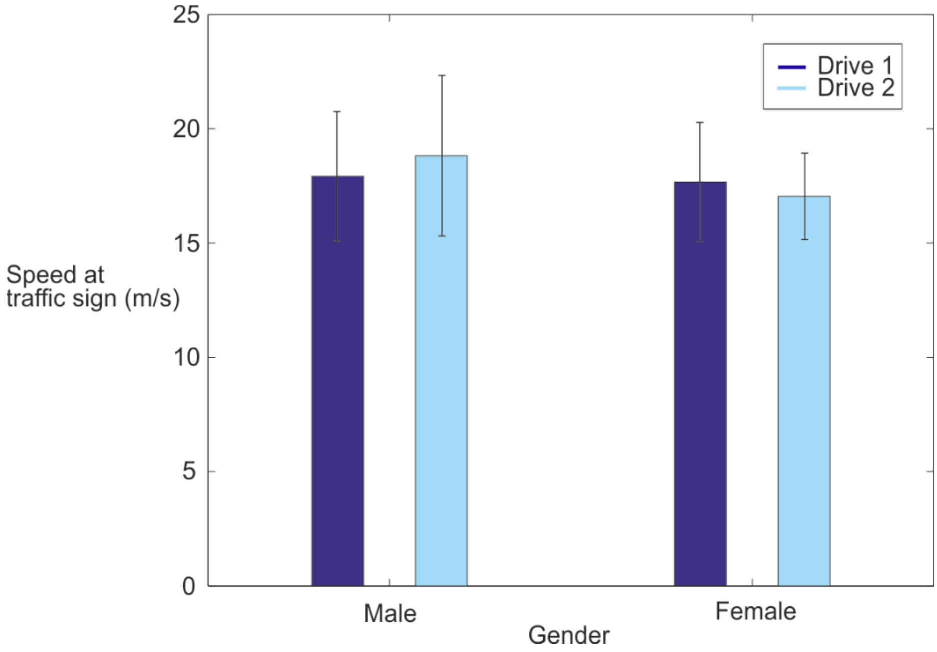


**Figure 52: Drive*Gender interaction effect for the speed at traffic sign in the speed change up scenario**

### 5.4.7 Cruising scenario

For the mean speed in the cruising scenario there was a Drive*Intervention interaction effect [$F(3,50) = 3.655$, $p = .018$, $\eta^2 = .180$] with the largest average reduction, 1mph, for the Experimenter instruction group, Figure 53. A t-test confirmed this reduction to be significant [$t(14) = 2.671$, $p = .036$, $r = .581$]. The mean speed before the intervention was not significantly different to other Intervention groups.

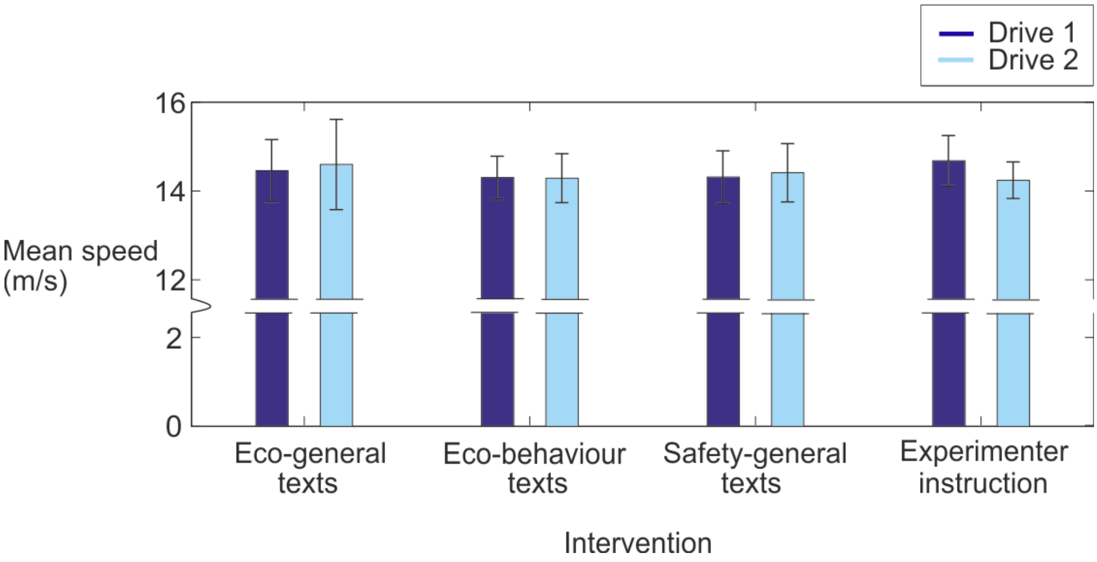


**Figure 53: Drive*Intervention interaction effect for mean speed in the cruising scenario**

The analysis of the mean acceleration during the cruising scenario resulted in a main effect for Drive [$F(1,50) = 15.237$, $p < .001$, $\eta^2 = .234$]. Although all groups lowered their acceleration rate, from 4% for the Eco-general texts group to 14% for the Eco-behaviour texts group, as shown in Figure 54, t-tests did not find any of these reductions to be significant ($p = .092$ for Eco-behaviour).

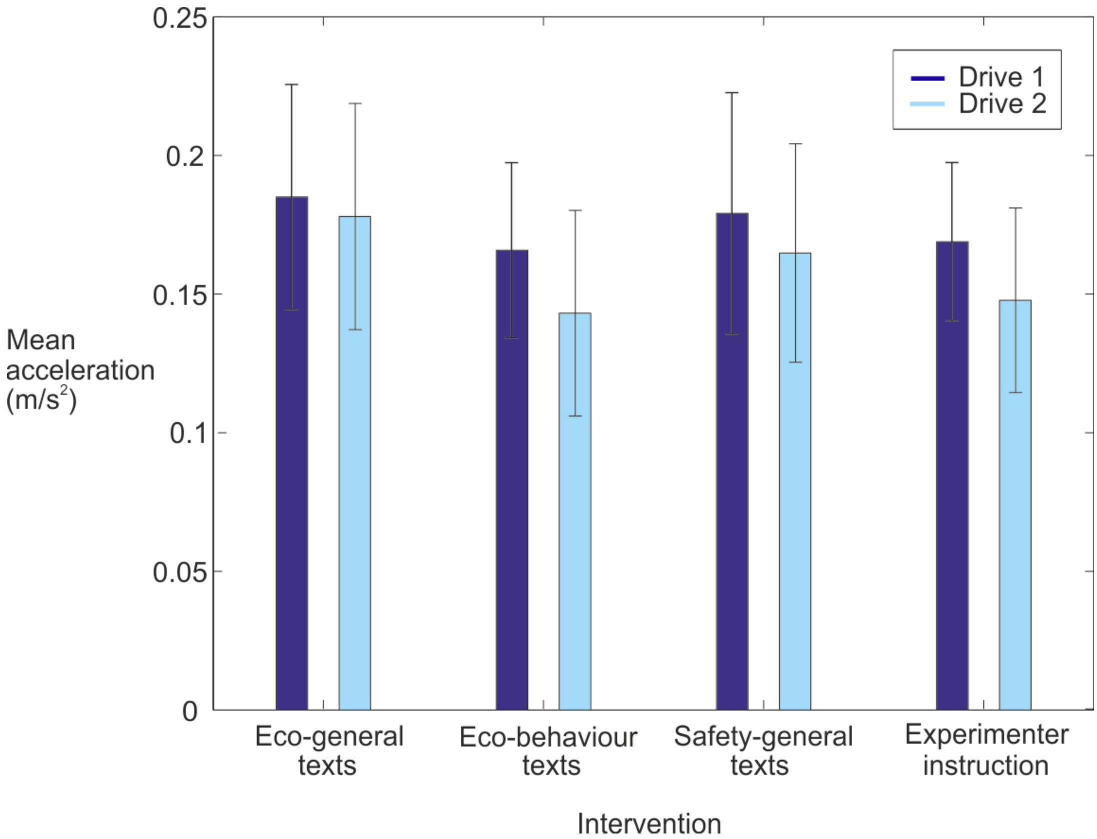


**Figure 54: Drive effect for mean acceleration in the cruising scenario**

The analysis of the variation of acceleration resulted in several significant effects, for Drive [$F(1,50) = 4.758$, $p = .034$, $\eta^2 = .087$] and for the interaction between Drive*Intervention [$F(3,50) = 3.404$, $p = .025$, $\eta^2 = .170$]. In the cruising scenario the acceleration was smoothened by 20% on average between the Drive 1 and 2 for the Experimenter instruction group, Figure 55, confirmed by a t-test [$t(14) = 2.835$, $p = .026$, $r = .604$].

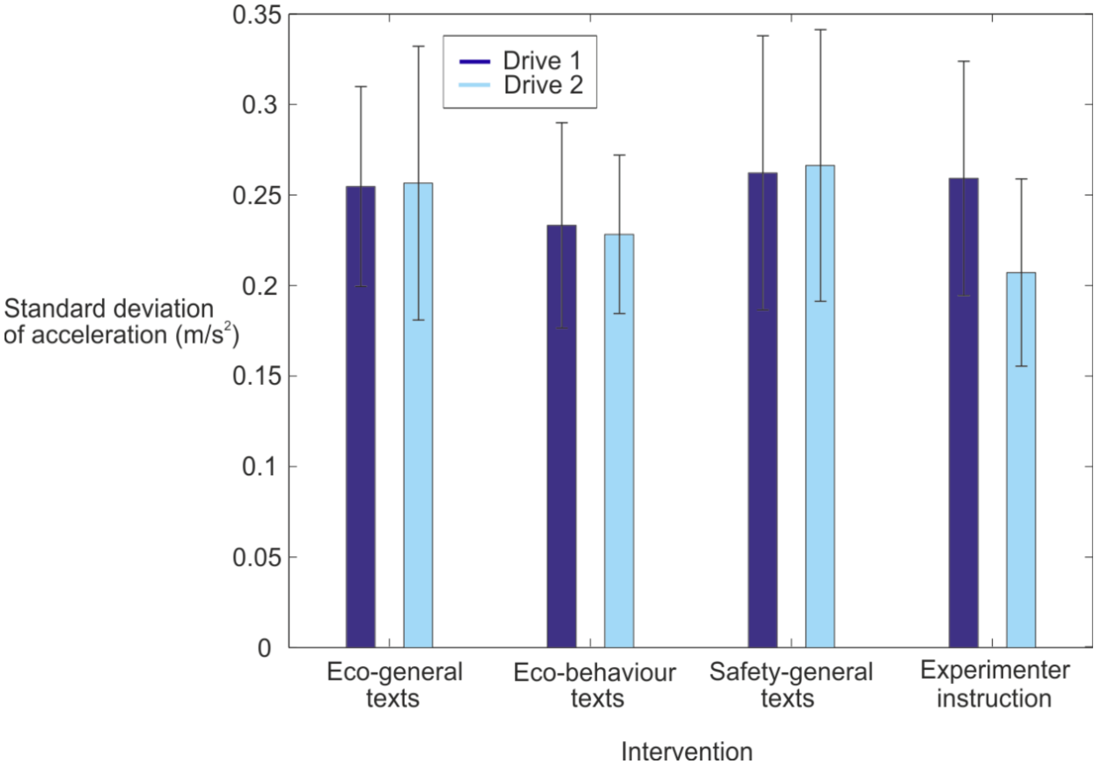


**Figure 55: Drive*Intervention interaction effect for standard deviation of acceleration in the cruising scenario**

For the smoothness of deceleration a main effect for Drive was found [$F(1,50) = 7.235$, $p = .010$, $\eta^2 = .126$]. As Figure 56 illustrates, the participants decelerated steadier in Drive 2 in the cruising scenario, on average in each, and most substantially by 25% in the Experimenter instruction group. Yet, comparisons for the Intervention groups did not confirm any reduction to be significant ($p = .214$ for Experimenter instruction).

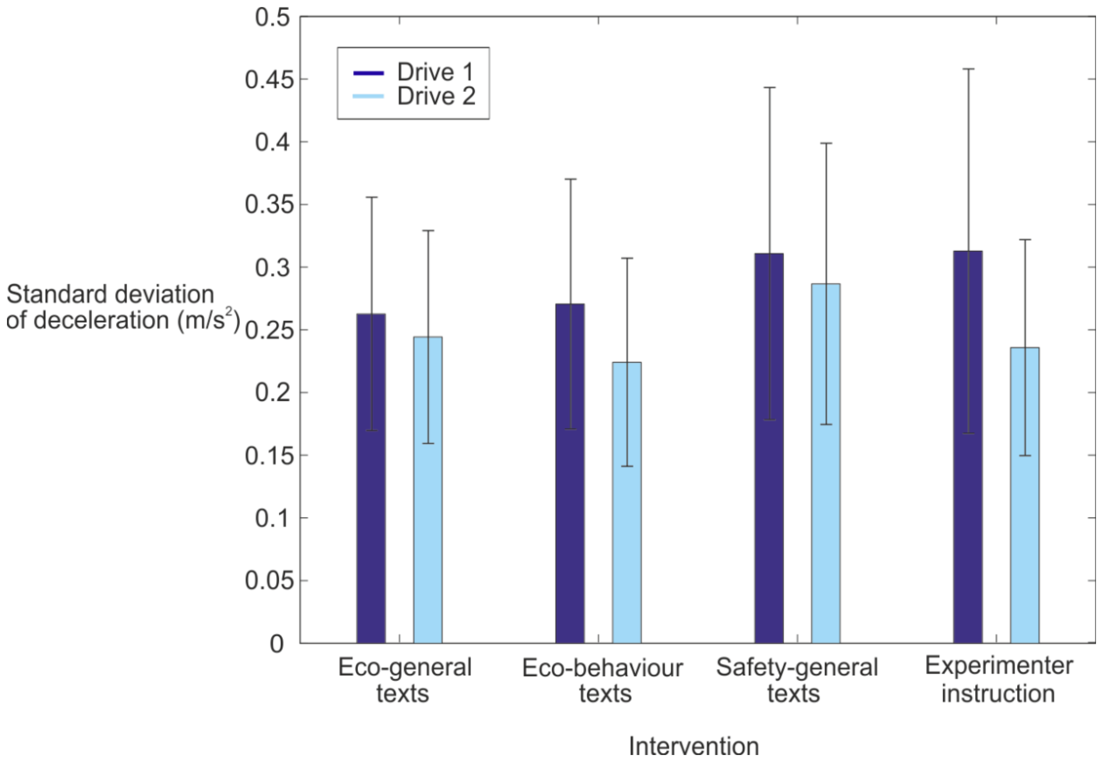


**Figure 56: Drive effect for standard deviation of deceleration in the cruising scenario**

**Table 32: Drive 1 to Drive 2 changes for the cruising scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets)* | 0.1 (1) | 0.0 (0) | 0.1 (0) | -0.5 (-1) |
| Standard deviation of speed (m/s) (mph in brackets) | 0.04 (0.1) | -0.08 (-0.1) | -0.05 (-0.2) | -0.04 (-0.1) |
| Mean acceleration (m/s$^2$)*** | -0.007 | -0.023 | -0.014 | -0.021 |
| Sd. of acceleration (m/s$^2$)* | 0.002 | -0.005 | 0.004 | -0.052 |
| Sd. of deceleration (m/s$^2$)* | -0.019 | -0.047 | -0.024 | -0.077 |
| Time over speed limit (s)* | 8 | -14 | 15 | -50 |

* $p < .05$

** $p < .01$

*** $p < .001$

A Drive*Gender interaction effect for the cruising scenario was due to females reducing their standard deviation of acceleration on average by 14% in Drive 2 [$F(1,50) = 6.532$, $p = .014$, $\eta^2 = .116$], as shown in Figure 57.

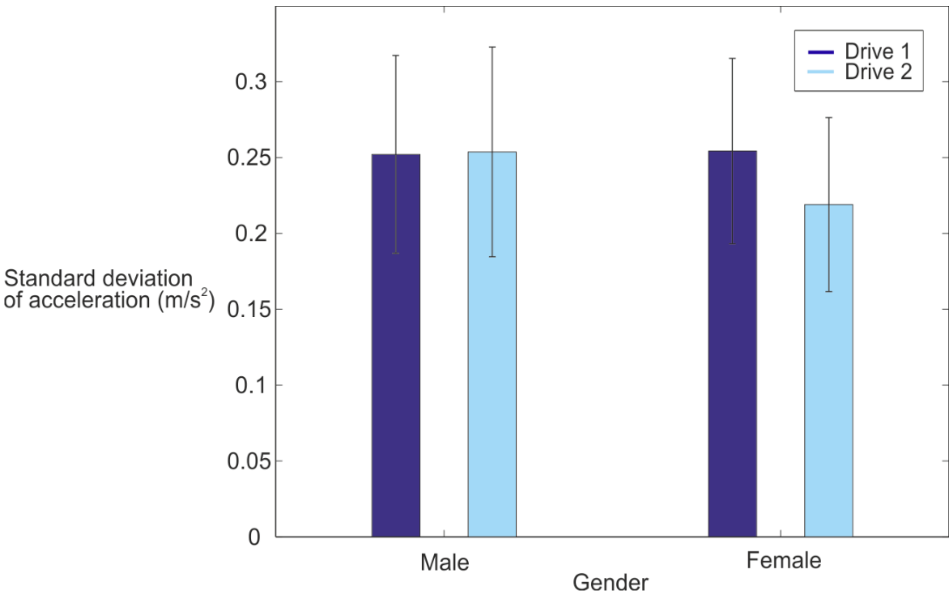


**Figure 57: Drive*Gender interaction effect for standard deviation of acceleration in the cruising scenario**

A Intervention*Gender interaction effect [$F(3,50) = 3.228$, $p = .030$, $\eta^2 = .162$] occurred in the cruising scenario. However, an interaction effect for Drive 1 alone [$F(3,50) = 2.939$, $p = .042$, $\eta^2 = .150$] clarified that already then females accelerated more erratically in the Experimenter instruction group, but more smoothly in the Eco-general texts group, as opposed to males, Figure 58.

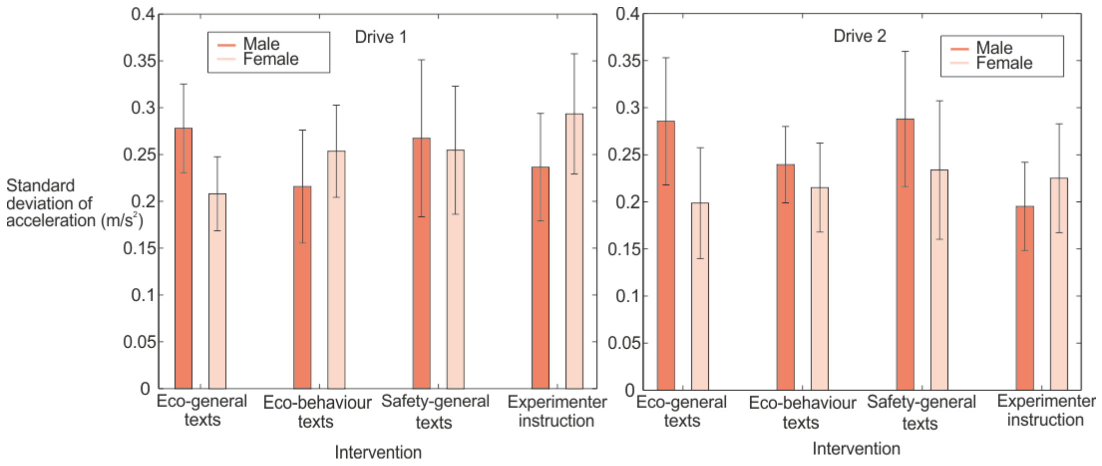


**Figure 58: Intervention*Gender interaction effect for standard deviation of acceleration in the cruising scenario**

A Intervention*Gender interaction effect for the variation of deceleration for the cruising scenario pinpointed large differences [$F(3,50) = 3.082$, $p = .036$, $\eta^2 = .156$]. These were, however, already apparent when considering Drive 1 alone [$F(3,50) = 4.019$, $p = .012$, $\eta^2 = .194$], as indicated in Figure 59.

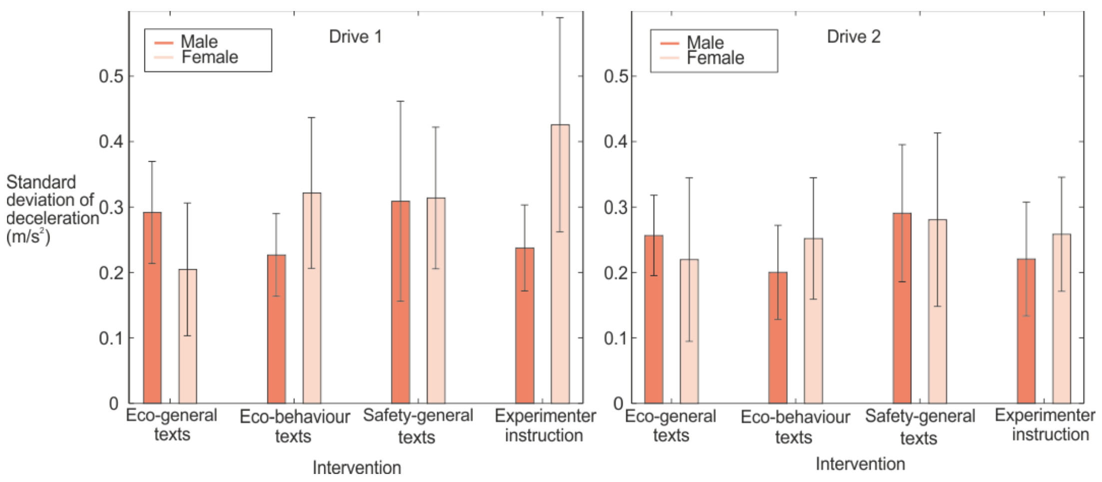


**Figure 59: Intervention*Gender interaction effect for standard deviation of deceleration in the cruising scenario**

A Drive*Gender interaction shows that females reduced the time they spent above the speed limit during cruising in Drive 2 by 45 seconds [$F(1,50) = 4.432$, $p = .040$, $\eta^2 = .081$], and males increased it by 13 seconds, Figure 60.

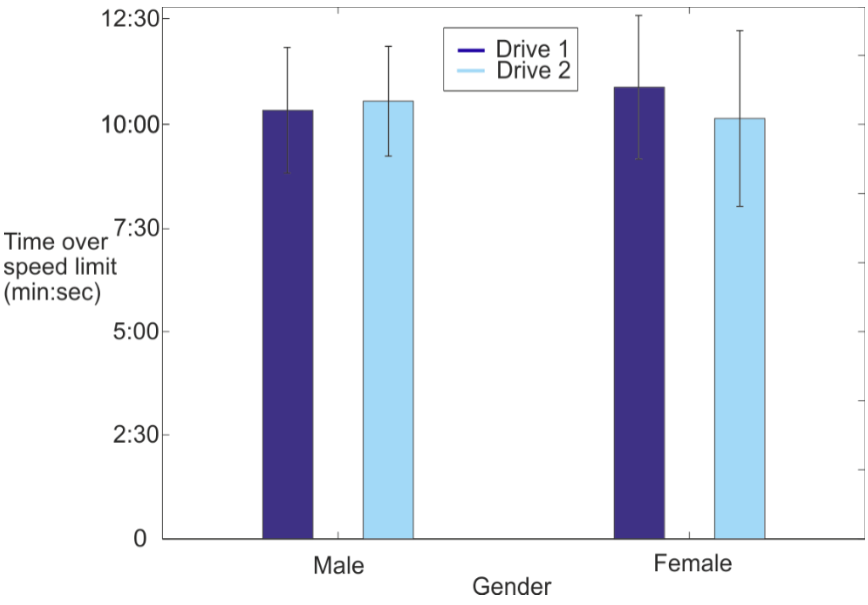


**Figure 60: Drive*Gender interaction effect for time over speed limit in the cruising scenario**

## 5.5 Results for scenarios relevant for safe driving

### 5.5.1 Short notice braking scenario

In the short-notice braking scenario traffic lights at a junction turned red when the drivers' TTC with them was 3.5 seconds. For the maximum brake pedal pressure in the short notice braking scenario there was no significant effect for the factor Intervention.

**Table 33: Drive 1 to Drive 2 changes for the short notice braking scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Driving through (count) | -1 | 0 | -1 | 1 |
| Mean speed excl. those driven through (m/s) (mph in brackets) | 0.12 (0.2) | -0.02 (0.0) | 0.13 (0.3) | 0.38 (0.9) |
| Max. brake pressure excl. those driven through (N)* | 34 | 11 | -1 | -19 |

* p < .05

** p < .01

*** p < .001

A Drive*Gender interaction effect was found for those who stopped at the short notice braking scenario [$F(1,42) = 4.686$, $p = .036$, $\eta^2 = .100$], with males putting their foot down 26% more in Drive 2, while females reduced the maximum brake pedal pressure by 16%, Figure 61.

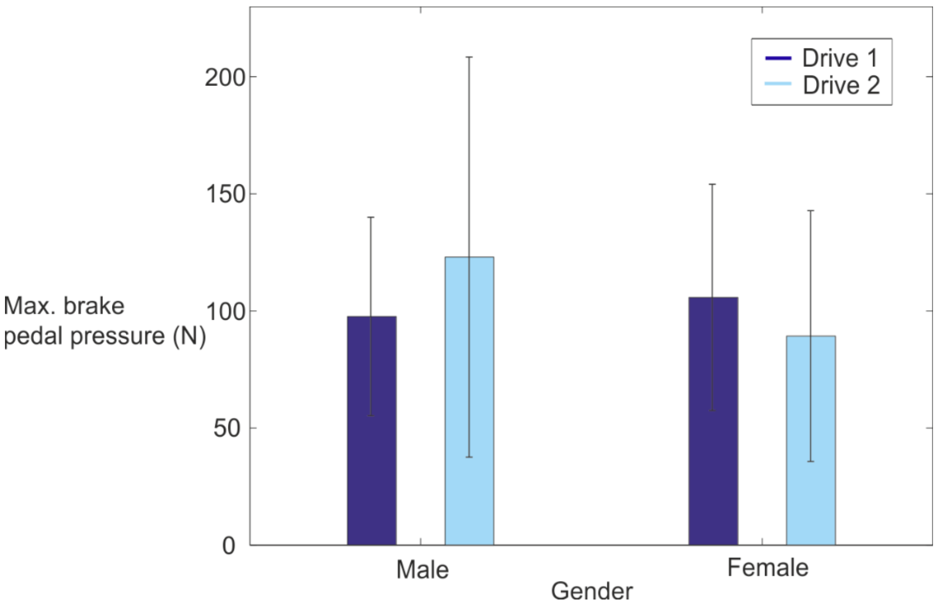


**Figure 61: Drive*Gender interaction effect for maximum brake pedal pressure in the short notice braking scenario**

### 5.5.2 Amber dilemma scenario

In the amber dilemma scenario the traffic lights at a junction turned red at a TTC of 2.5 seconds. There was no main effect for mean speed.

**Table 34: Drive 1 to Drive 2 changes for the amber dilemma scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Driving through (count) | -1 | -1 | 1 | -2 |
| Mean speed for those driven through (m/s) (mph in brackets)* | 0.7 (1) | -0.9 (-2) | -0.2 (-1) | -1.0 (-2) |
| Mean speed for those stopped (m/s) (mph in brackets) | -0.2 (0) | -0.1 (0) | -0.1 (0) | -0.5 (-1.0) |

* p < .05

** p < .01

*** p < .001

### 5.5.3 Crossing car scenario

The crossing car scenario involved a car crossing the road in front of the participant. In Figure 62 the speed profiles for the Experimenter instruction and the Eco-general texts group are depicted.

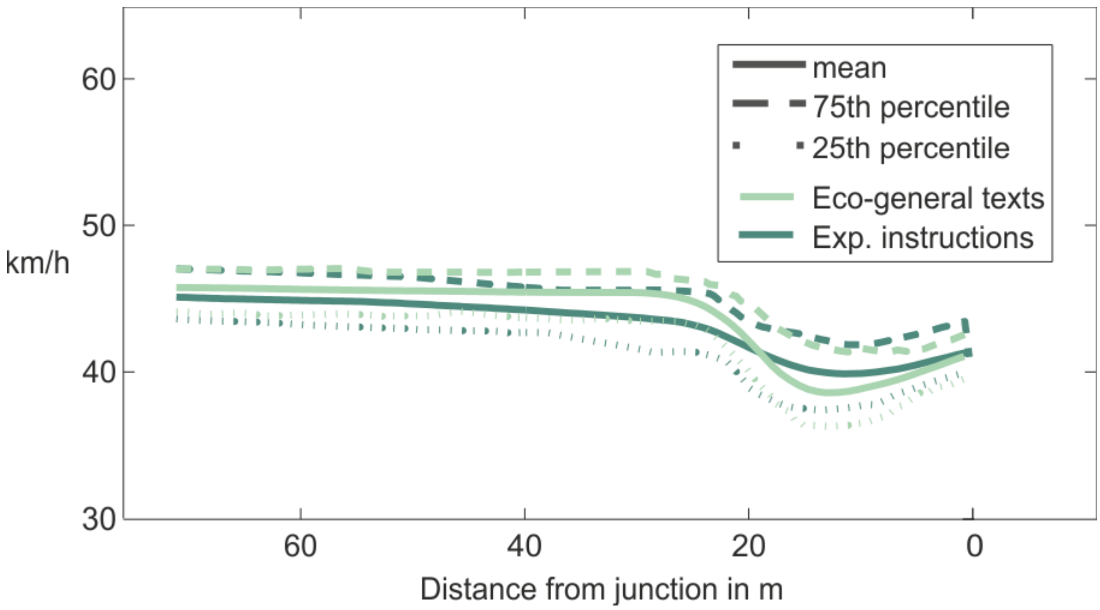


**Figure 62: Speed profile for the Eco-general and the Experimenter instruction groups in Drive 2 in the crossing car scenario**

A main effect for Drive indicates that the mean deceleration in the crossing car scenario was reduced [F(1,50) = 5.923, p = .019, $\eta^2$ = .106], with 38% particularly for the Safety-general texts group and with 23% for the Experimenter instruction group. Although Figure 63 suggests relatively high differences before the intervention, the Drive 1 measures was not significantly different between the Intervention groups. Comparisons between Drive 1 and Drive 2 only support a reduction for the Experimenter instruction group [t(14) = -2.566, p = .044, r = .566] (p = .312 for Safety-general texts).

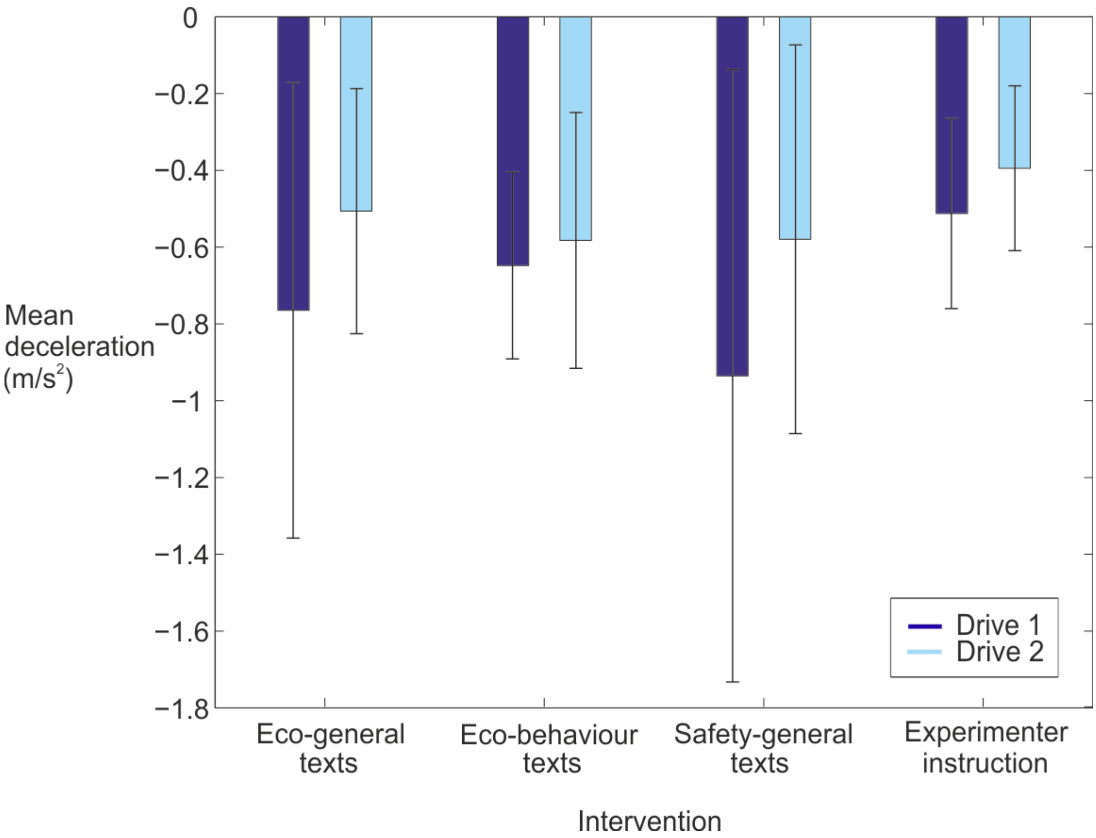


**Figure 63: Drive effect for mean deceleration in the crossing car scenario**

A Drive effect for the variation of deceleration in the crossing car scenario indicated a reduction for the second session [$F(1,50) = 10.243$, $p = .002$, $\eta^2 = .170$], visible in Figure 64. When Drive1 and Drive 2 values were compared for each group, a Wilcoxon signed-rank test confirmed that the difference of 32% for the Eco-general texts group was significant [$Z(15) = -2.499$, $p = .048$, $-.645$]. In addition, the Experimenter instruction group decelerated significantly more smoothly, by 42% [$t(14) = 2.938$, $p = .022$, $r = .785$].

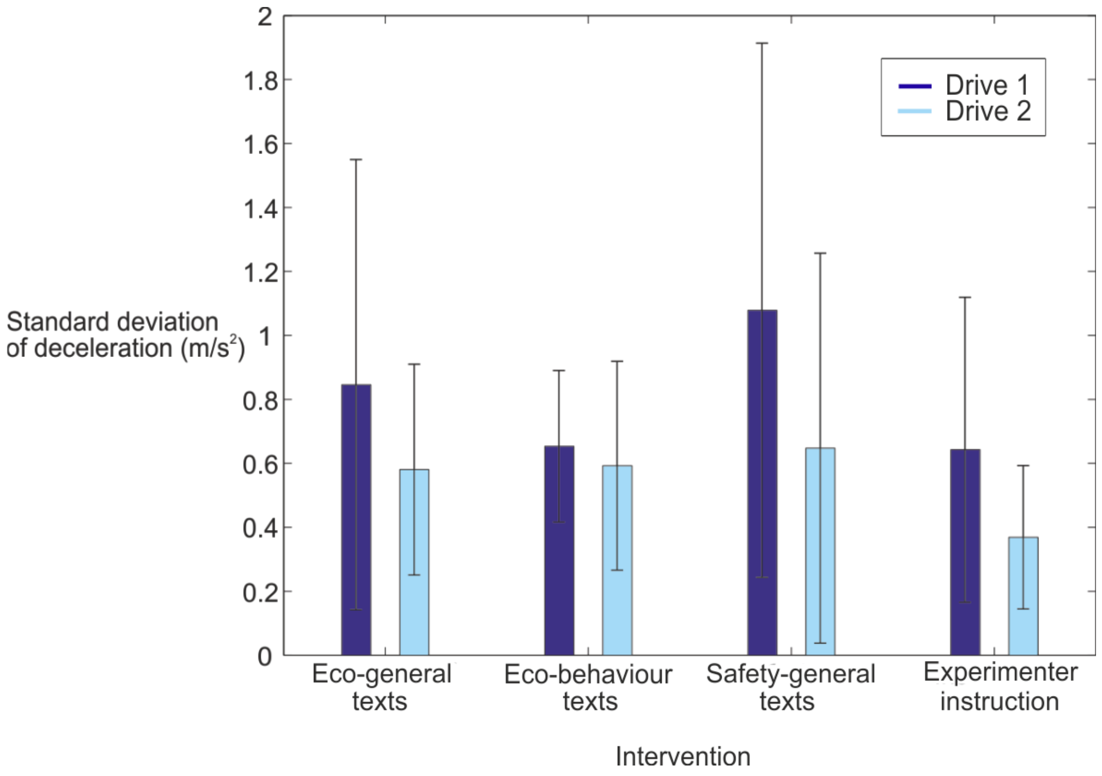


**Figure 64: Drive effect for the standard deviation of deceleration in the crossing car scenario**

The maximum brake pedal pressure was lowered in the crossing car scenario during Drive 2, as illustrated in Figure 65, supported by a main effect [$F(1,50) = 4.775$, $p = .034$, $\eta^2 = .087$]. Wilcoxon signed-rank tests confirmed significant reductions for the Eco-general [50%, $Z(15) = -2.499$, $p = .048$, $r = -.645$] and Safety-general [44%, $Z(15) = -2.668$, $p = .032$, $r = -.689$] texts groups.

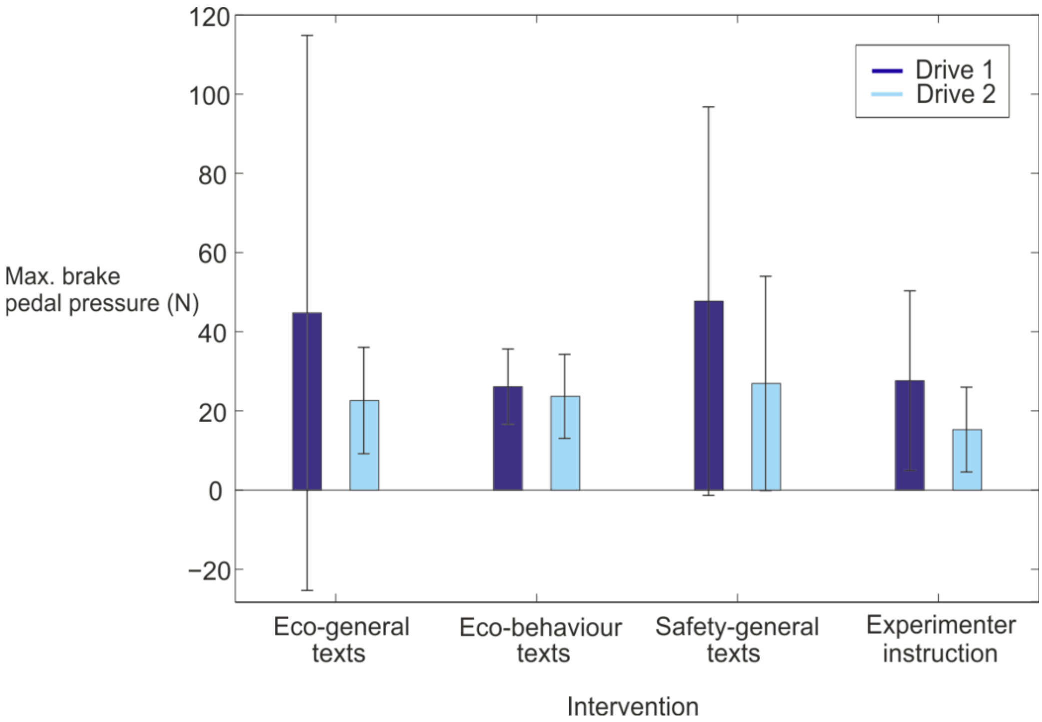


**Figure 65: Drive effect for maximum brake pedal pressure in the crossing car scenario**

**Table 35: Drive 1 to Drive 2 changes for the crossing car scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets) | 0.3 (1) | 0.1 (0) | -0.9 (-2) | -0.1 (0) |
| Mean deceleration ($m/s^2$)* | 0.258 | -0.114 | 0.356 | 0.118 |
| Sd. of deceleration ($m/s^2$)** | -0.27 | -0.06 | -0.43 | -0.27 |
| Max. brake pressure (N)* | -22.2 | -2.4 | -20.8 | -12.3 |
| Location when foot off gas pedal (m) | -4 | -8 | 1 | -1 |

* p < .05

** p < .01

*** p < .001

### 5.5.4 Speed change down scenario

In a scenario involving a decrease in the speed limit, 31 participants did not coast during Drive 1. Hence, a statistical analysis of the time spent coasting was not conducted. It could be observed, however, that the number of people not coasting increased in each Intervention group in Drive 2. Nevertheless, the mean speed was lowered in Drive 2 [$F(1,50) = 13.874$, $p < .001$, $\eta^2 = .217$], with t-test showing significant reductions for the Safety-general texts [$t(14) = 2.934$, $p = .044$, $r = .617$] and Experimenter instruction groups [$t(14) = 3.156$, $p = .014$, $r = .645$], each by about 2 mph, visible in Figure 66.

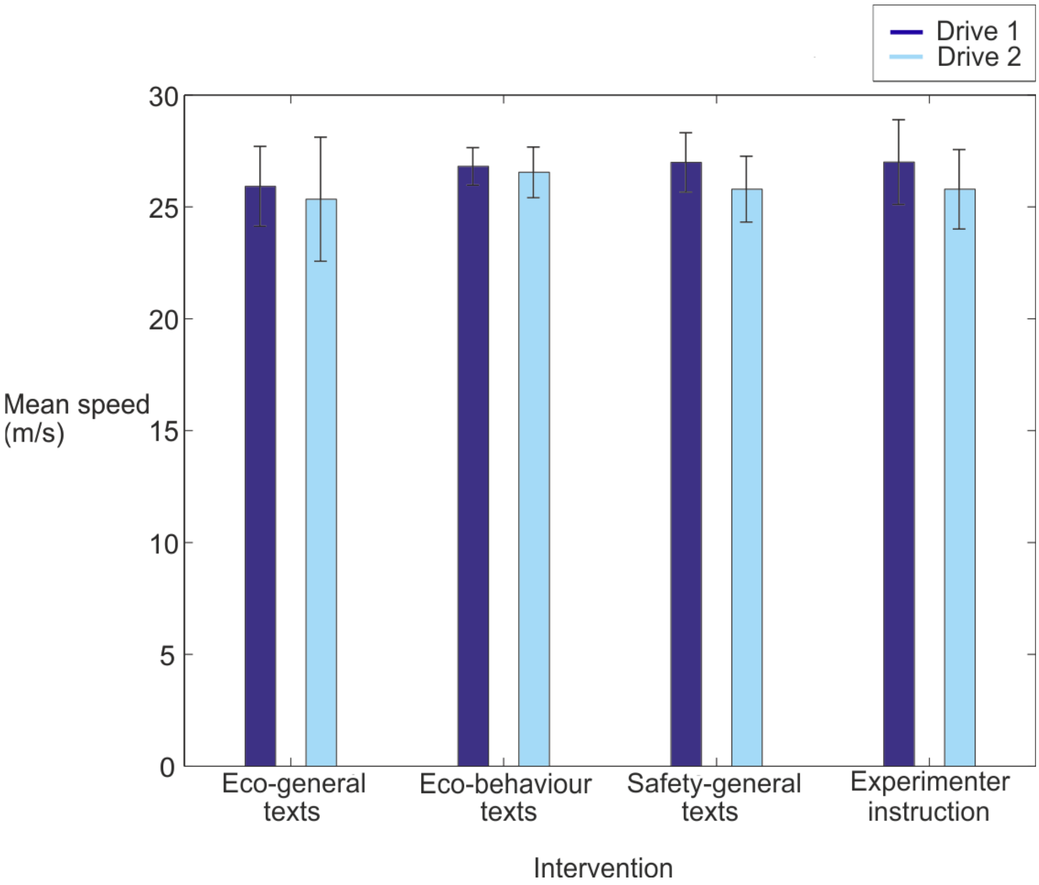


**Figure 66: Drive effect for mean speed in the speed change down scenario**

On average all groups drove past the traffic sign, which showed the lower speed limit, slower in Drive 2, supported by a main effect for Drive [$F(1,50) = 15.493$, $p < .001$, $\eta^2 = .237$]. T- and Wilcoxon signed-rank tests revealed significant reductions for the Safety-general texts [$t(14) = 3.338$, $p = .020$, $r = .666$] and the Experimenter instruction groups [$Z(15) = -2.897$, $p = .008$, $r = -$

.748], each by 4 mph. A Intervention effect [$F(3,50) = 3.150$, $p = .033$, $\eta^2 = .159$] occurred, with pairwise comparisons showing a significant difference between the Eco-general and Eco-behaviour texts group ($p = .028$), with the latter being 4 mph faster before and after the intervention. There was an effect for Intervention in Drive 1 only [$F(3,57) = 3.129$, $p = .033$, $\eta^2 = .148$], but post-hoc tests did not confirm this to be significant, Figure 67.

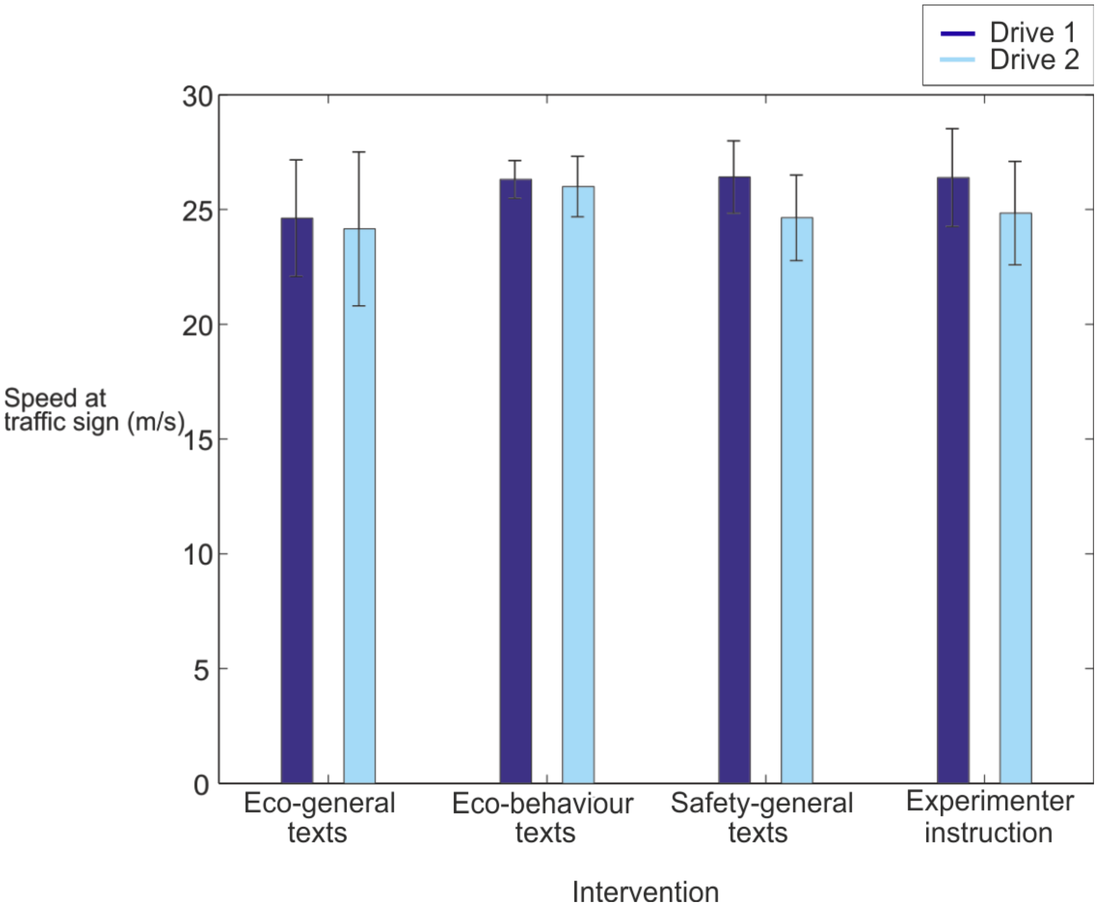


**Figure 67: Drive effect for the speed at traffic sign in the speed change down scenario**

For mean deceleration in the speed change down scenario there was a main effect for Drive [$F(1,50) = 4.357$, $p = .042$, $\eta^2 = .080$]. T-tests confirmed a significantly stronger deceleration in Drive 2 for the Experimenter instruction group [$t(14) = 2.764$, $p = .030$, $r = .594$], with an increase of 47%. A Intervention effect could be identified as well [$F(3,50) = 3.271$, $p = .029$, $\eta^2 = .164$]. Pairwise comparisons clarified that the absolute value was higher for the Eco-general than for the Eco-behaviour texts group, by 58 % in Drive 2 (p = .033). An ANOVA with the Drive 1 values did not find a significant difference before the intervention (p = .089).

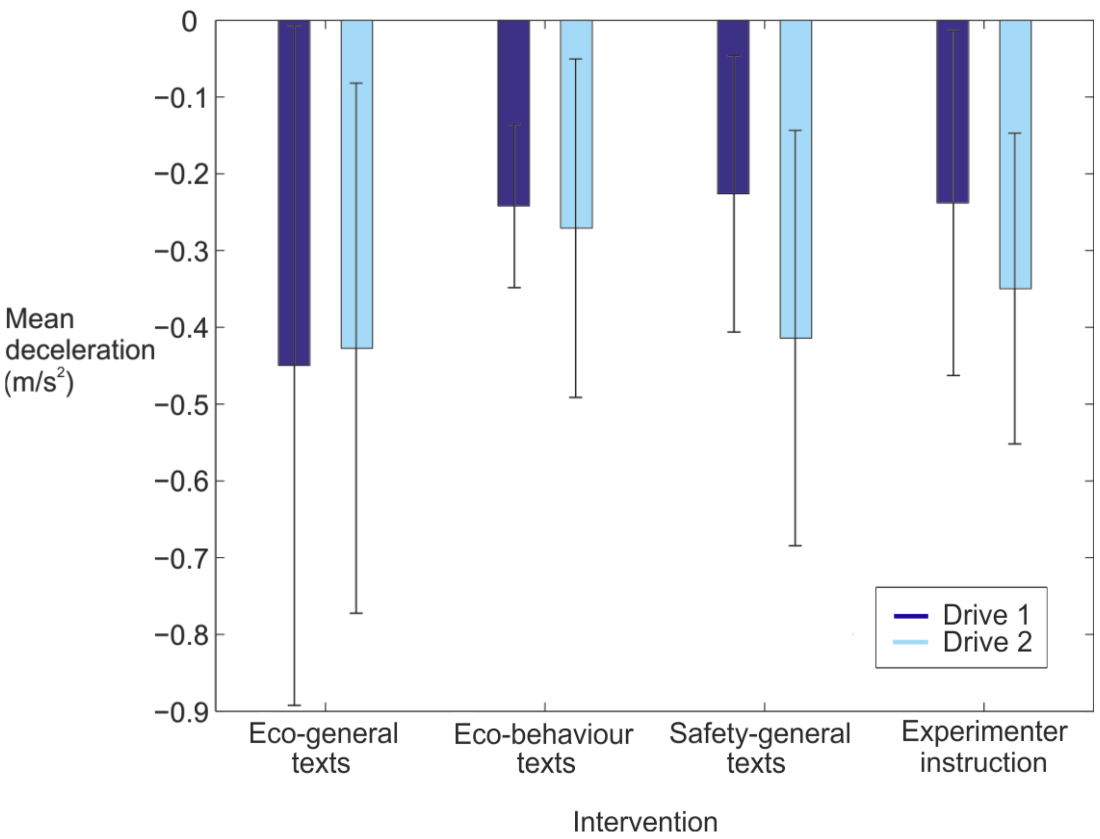


**Figure 68: Drive effect for mean deceleration in the speed change down scenario**

There were several effects for the smoothness of deceleration in the speed change down scenario. A Intervention effect was found [F(3,50) = 6.049, p = .001, $\eta^2$ = .266] with pairwise comparisons revealing that the Eco-general texts group drove more erratically than the other Intervention groups [Eco-behaviour: p =.003, Safe: p = .009, Instruction: p = .011)], but the Intervention effect was already significant in Drive 1 [F(3,54) = 3.617, p = .019, $\eta^2$ = .167], as visualised in Figure 69. A Drive*Intervention interaction effect showed that, on average, the Eco-general texts group then reduced their standard deviation of deceleration in the second Drive, contrary to the others [F(3,50) = 3.011, p = .039, $\eta^2$ = .153]. However, a Wilcoxon signed-rank test did not confirm the significance of this reduction (p = .560).

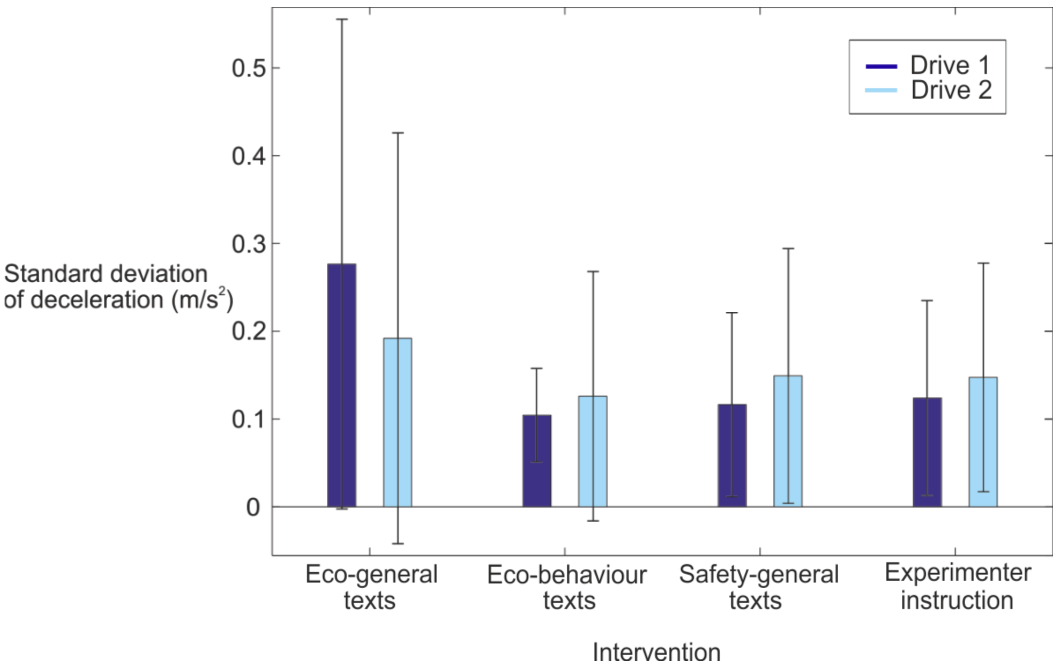


**Figure 69: Drive*Intervention interaction effect for the standard deviation of deceleration in the speed change down scenario**

**Table 36: Drive 1 to Drive 2 changes for the speed change down scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets)*** | -0.6 (-1) | -0.3 (-1) | -1.2 (-2) | -0.9 (-2) |
| Speed at traffic sign (m/s) (mph in brackets)*** | -0.4 (-1) | -0.3 (-1) | -1.8 (-4) | -1.6 (-4) |
| Mean deceleration ($m/s^2$)* | 0.023 | -0.029 | -0.188 | -0.111 |
| Sd. of deceleration ($m/s^2$)** | -0.084 | 0.022 | 0.033 | 0.023 |
| Time over speed limit (s) | 0.06 | 0.24 | -0.49 | -0.67 |

* $p < .05$

** $p < .01$

*** $p < .001$

An Intervention*Gender interaction effect [$F(3,50) = 3.107$, $p = .035$, $\eta^2 = .157$] revealed that the strong deceleration in the Eco-general texts group in the speed change down scenario was performed by females. This interaction effect, however, was present in Drive 1 [$F(3,50) = 3.407$, $p = .025$, $\eta^2 = .170$], as shown in Figure 70. This effect could be attributed to two outliers, who decelerated excessively strongly in both Drives.

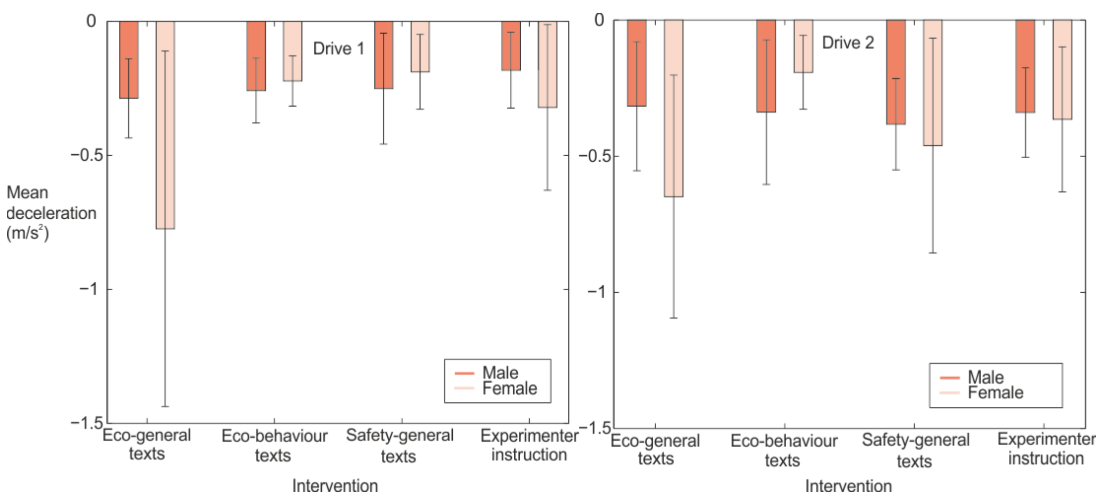


**Figure 70: Intervention*Gender interaction effect for mean deceleration in the speed change down scenario**

A Gender effect in the speed change down scenario, shown in Figure 71, indicated that females decelerated more erratically than males [$F(1,50) = 6.694$, $p = .013$, $\eta^2 = .118$], by 78 % in the Drive 1 and then only by 37 % in Drive 2.

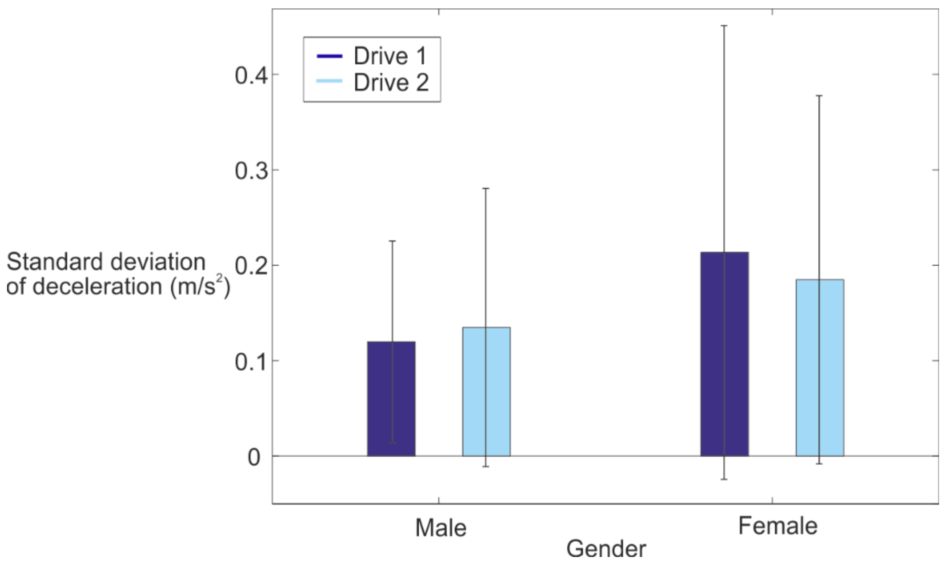


**Figure 71: Gender effect for the standard deviation of deceleration in the speed change down scenario**

An Intervention*Gender interaction pinpoints the erratic deceleration of the females in this scenario to the Eco-general texts group [$F(3,50) = 5.599$, $p = .002$, $\eta^2 = .251$], visible in Figure 72. However, this effect was present in Drive 1 [$F(3,50) = 11.732$, $p < .001$, $\eta^2 = .413$], which denies that the interventions were the cause. A Drive*Intervention*Gender interaction effect also highlighted that females then reduced the standard deviation in their second Drive on average by 13%, as opposed to males [$F(3,50) = 4.201$, $p = .010$, $\eta^2 = .201$].

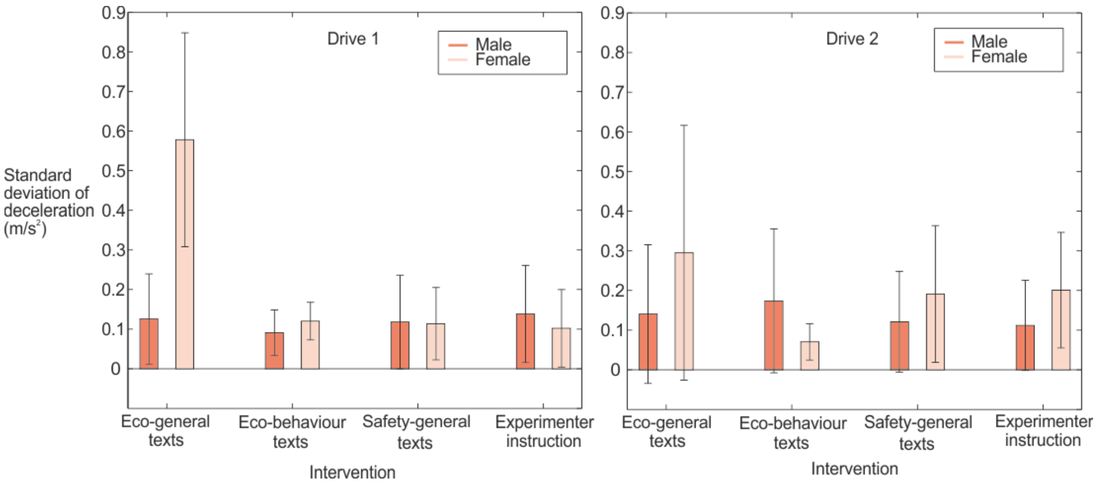


**Figure 72: Intervention*Gender interaction effect for the standard deviation of deceleration in the speed change down scenario**

## 5.5.5 Sharp curve scenario

Figure 73 depicts the speed profiles for the group instructed by the experimenter to drive fuel-efficiently and for the group that received eco-driving prime text messages.

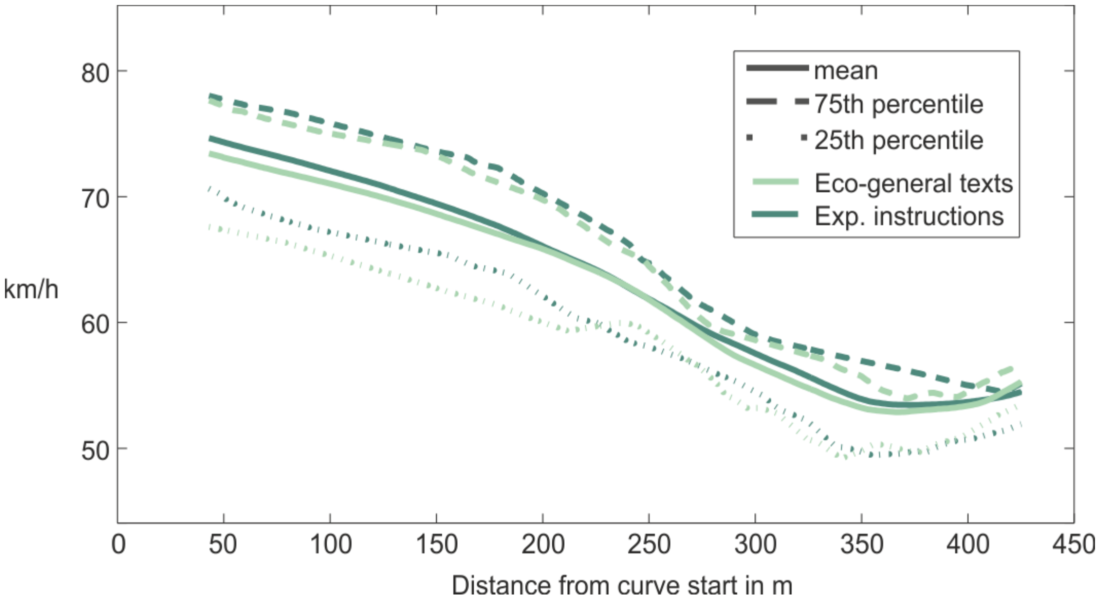


**Figure 73: Speed profile for the Eco-behaviour and the Experimenter instruction groups in Drive 2 in the sharp curve scenario**

For mean deceleration in the sharp curve scenario there was a main effect for Drive [$F(1,50) = 6.085$, $p = .017$, $\eta^2 = .108$], indicating weaker decelerations in Drive 2, as shown in Figure 74. A t-test showed that this was the case, significantly for the Safety-general texts group [$t(14) = -3.362$, $p = .020$, $r = .668$] with a reduction of 18 %. However, there was a Intervention effect during Drive 1 [$F(3,57) = 3.502$, $p = .021$, $r = .163$], in which the Safety-general texts group already decelerated 31% stronger than in the Eco-general texts group ($p = .015$).

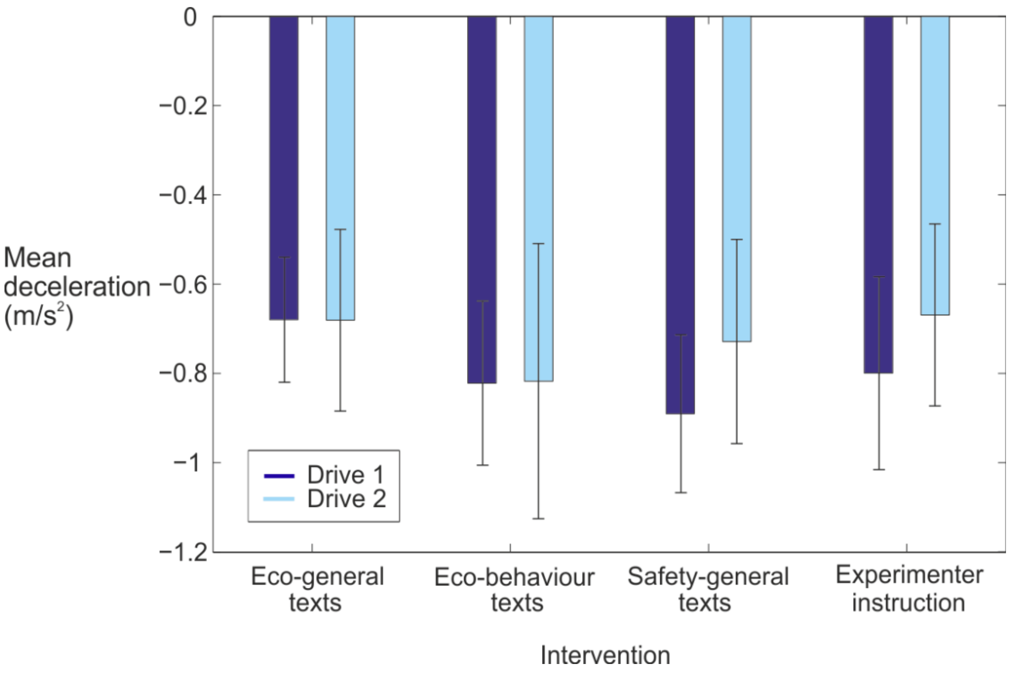


**Figure 74: Drive effect for mean deceleration in the sharp curve scenario**

Analysing the standard deviation of deceleration resulted in a main effect for Drive [$F(1,50) = 18.317$, $p < .001$, $\eta^2 = .268$] with all Intervention groups decelerating more steadily on average in Drive 2 in the sharp curve scenario. This effect is visible in Figure 75, and significant for the Safety-general texts group [$Z(15) = -2.726$, $p = .024$, $r = -.704$], which lowered it by 26 %, and the Experimenter instruction group [$t(14) = 3.420$, $p = .008$, $r = .675$], which achieved a 42% reduction.

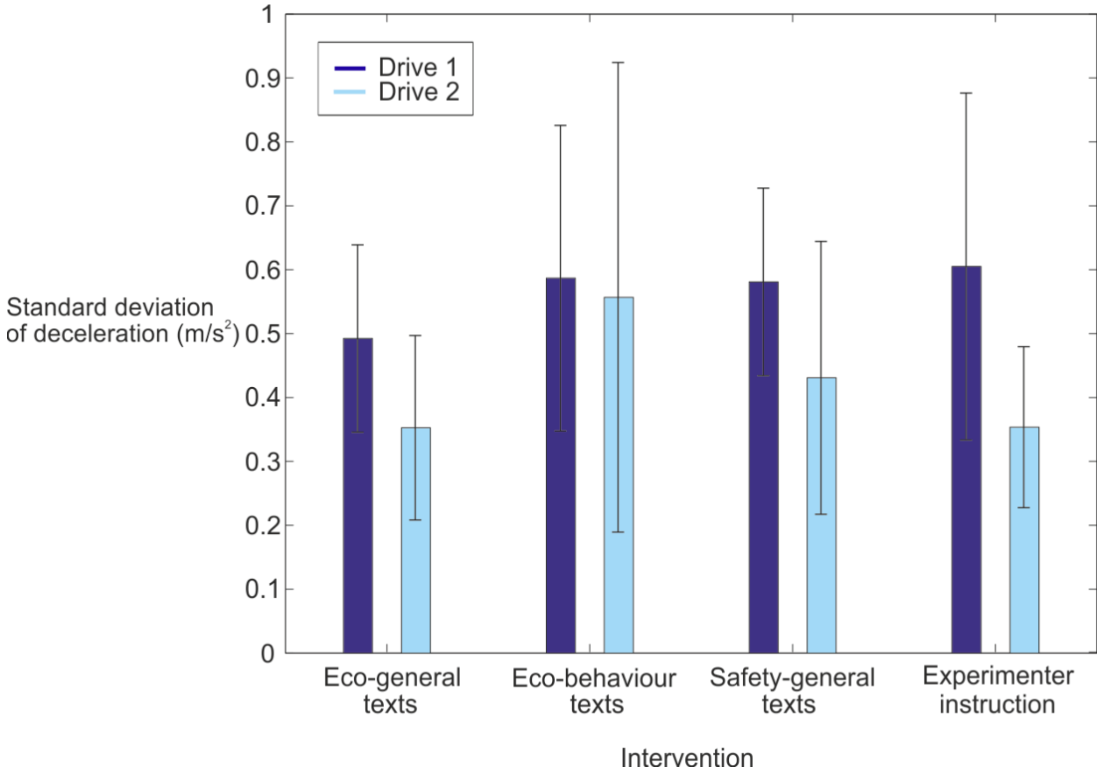


**Figure 75: Drive effect for the standard deviation of deceleration in the sharp curve scenario**

There was a main effect for Drive for the maximum brake pedal pressure in the sharp curve scenario [$F(1,50) = 19.918$, $p < .001$, $\eta^2 = .285$]. T-tests indicated significant reductions between the Drives, by 20% for the Eco-general [$t(14) = 3.467$, $p = .016$, $r = .680$] and by 26 % for the Safety-general texts groups [$Z(15) = -2.840$, $p = .020$, $r = -.733$], illustrated in Figure 76.

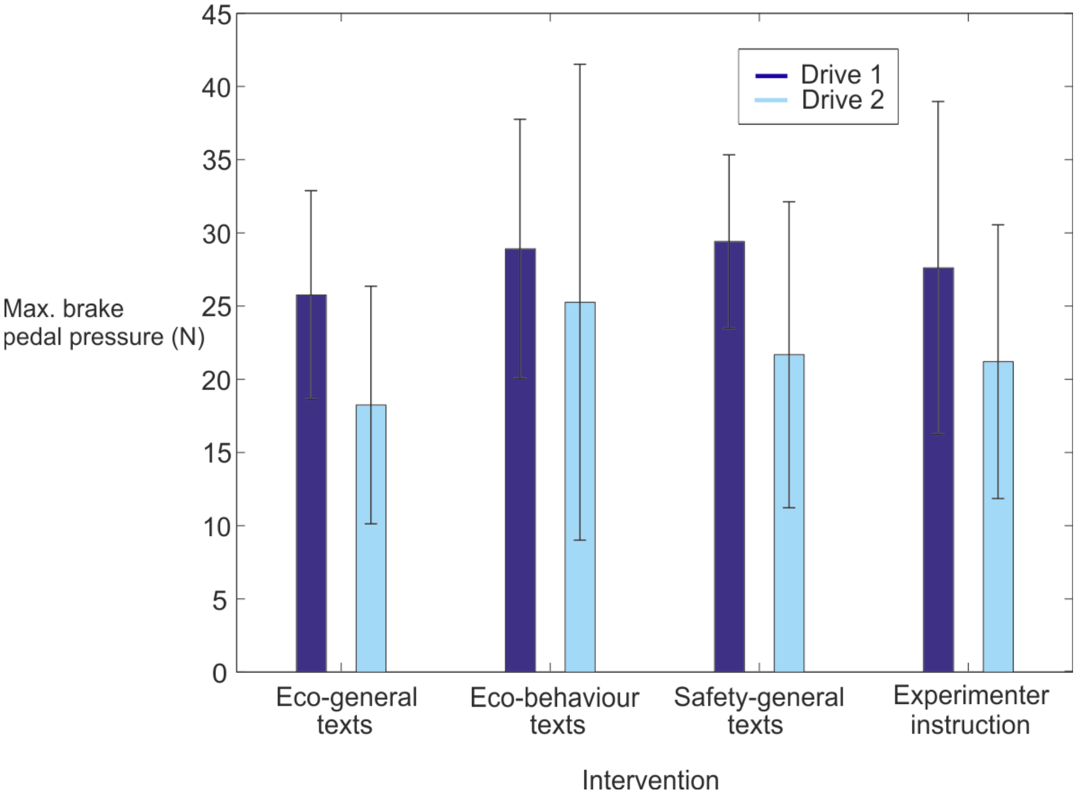


**Figure 76: Drive effect for the maximum brake pedal pressure in the sharp curve scenario**

**Table 37: Drive 1 to Drive 2 changes for the sharp curve scenario**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets)** | 0.0 (0) | 0.7 (2) | 0.0 (0) | -0.4 (-1) |
| Min. speed (m/s) (mph in brackets)* | 0.0 (0) | 0.6 (2) | 0.8 (1) | 0.3 (1) |
| Mean acceleration ($m/s^2$)* | 0.081 | -0.042 | -0.015 | -0.133 |
| Max. accelerator pedal angle (°) | 7.5 | 2.3 | 7.8 | 1.4 |
| Sd. of lateral acceleration ($m/s^2$)** | 0.02 | 0.11 | 0.1 | 0.05 |
| Mean deceleration ($m/s^2$)* | -0.001 | 0.005 | 0.162 | 0.131 |
| Sd. of deceleration ($m/s^2$)*** | -0.139 | -0.030 | -0.150 | -0.251 |
| Max. brake pressure (N)*** | -7.6 | -3.6 | -7.7 | -6.4 |

* $p < .05$

** $p < .01$

*** $p < .001$

A Gender effect for the sharp curve scenario [$F(1,50) = 9.105$, $p = .004$, $\eta^2 = .154$] indicated that males drove faster than females, about 4 mph before and 2 mph after the intervention, as illustrated in Figure 77.

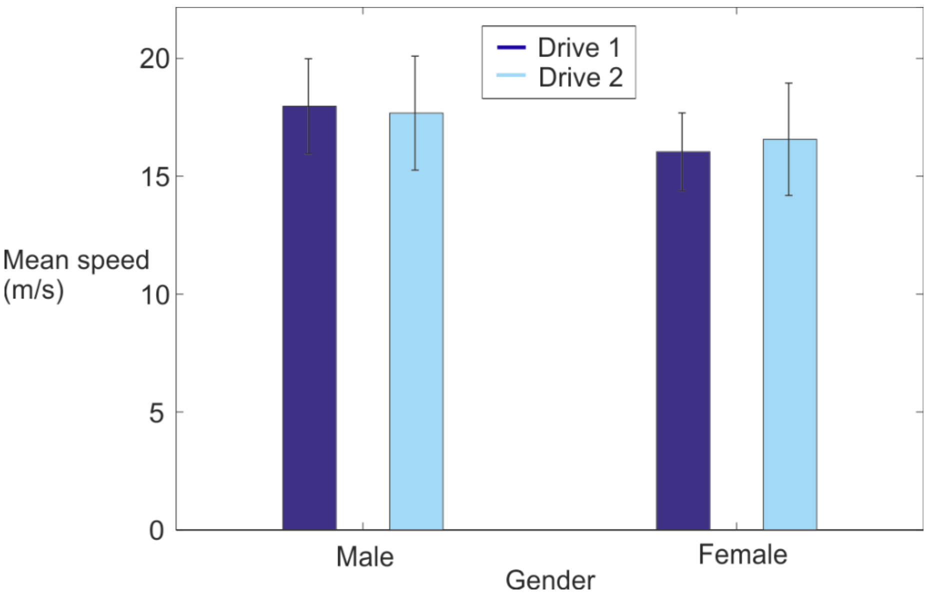


**Figure 77: Gender effect for mean speed in the sharp curve scenario**

In addition, females had a lower minimum speed than males in this scenario [F(1,50) = 7.117, p = .010, $\eta^2$ = .125], by 4 mph in the Drive 1 and 2 mph in Drive 2, Figure 78.

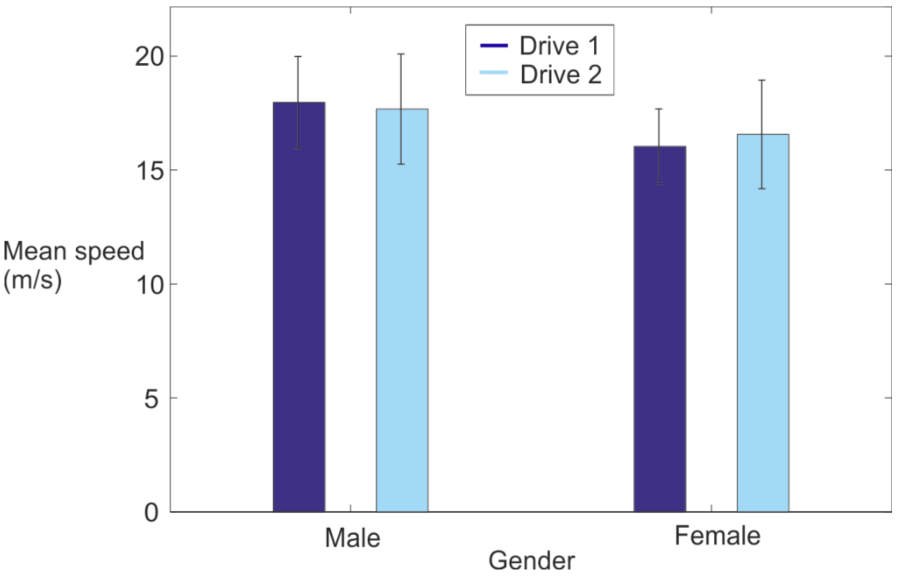


**Figure 78: Gender effect for minimum speed in the sharp curve scenario**

For mean acceleration there was a Drive*Gender interaction [F(1,50) = 5.071, p = .029, $\eta^2$ = .092] with males increasing and females decreasing their acceleration while navigating the sharp curve in Drive 2, by 11 and 27 %, respectively, Figure 79.

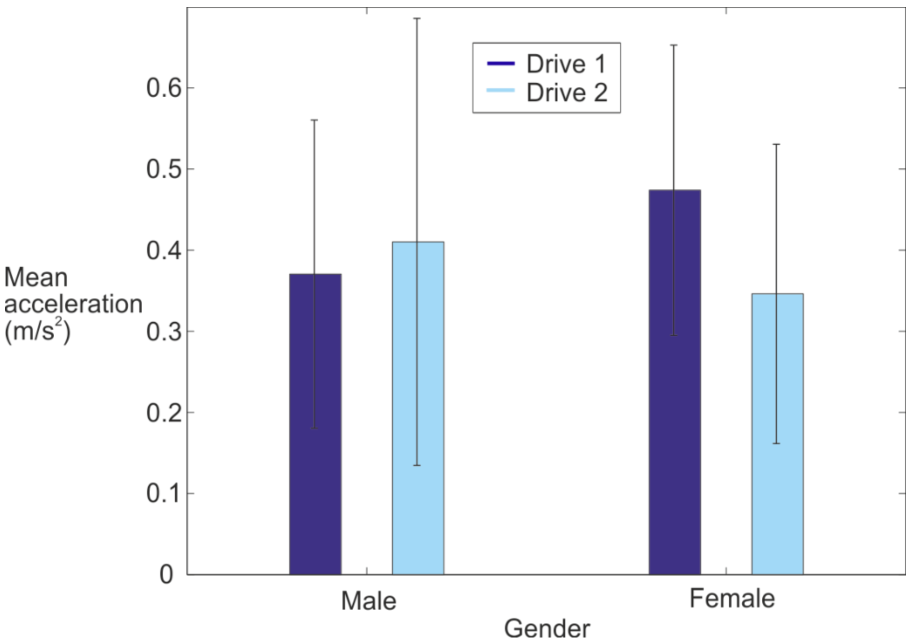


**Figure 79: Drive*Gender interaction effect for mean acceleration in the sharp curve scenario**

A Gender effect indicates a lower variation of lateral acceleration for females [F(1,50) = 8.026, p = .007, $\eta^2$ = .138], 24 % during the first and 15 % in the second session in the sharp curve scenario, Figure 80.

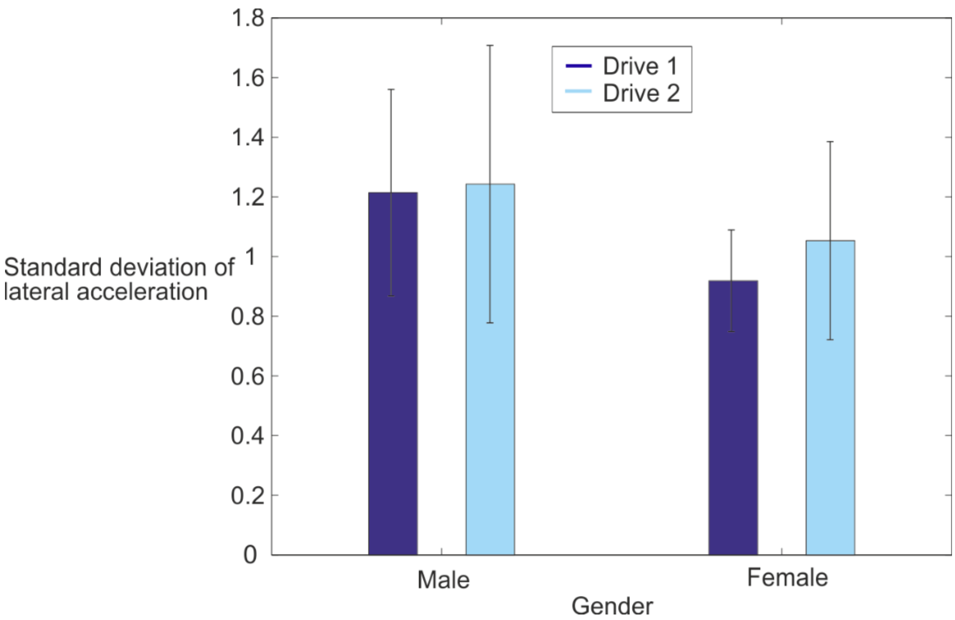


**Figure 80: Gender effect for the standard deviation of lateral acceleration in the sharp curve scenario**

## 5.6 Coherence and workload

The measures relevant in the coherence scenario included the coherence, phase shift and modulus. The coherence is the correlation between the speed of the front and the participant car, the phase shift is the delay of reactions to the speed fluctuations of the lead car, and the modulus is an amplification factor. The analysis of the coherence and phase shift measures did not result in significant main effects for the factors Intervention, Task and Gender for the coherence scenario. The analysis of the modulus, however, flagged up a Task effect [$F(3,150) = 9.929$, $p < .001$, $\eta^2 = .166$]. This effect was due to the values being higher when driving without TQT (Drive 1 no TQT: $p = .001$, $p < .001$, Drive 2 no TQT: $p = .025$, $p = .005$), visible in Figure 81.

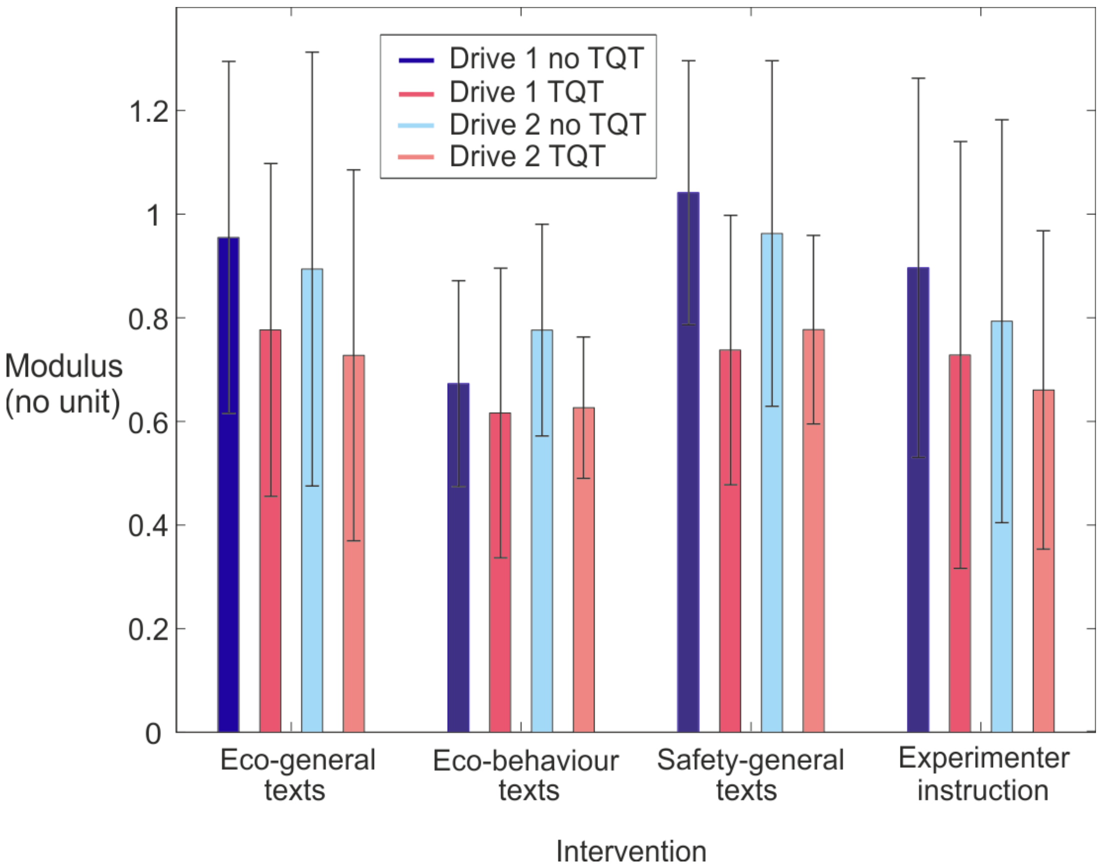


**Figure 81: Task effect for the modulus in the coherence scenario**

For mean speed there was a main effect for Task [$F(1.870,93.511) = 9.593$, $p < .001$, $\eta^2 = .161$]. Post-hoc tests clarified that the participants drove faster during the coherence scenario without the TQT (Drive 1 no TQT: $p = .001$, Drive 2 no TQT: $p = .004$, Drive 1 TQT: $p = .001$, Drive 2 TQT: $p = .004$),

Figure 82. Because the measures for the Eco-behaviour and Experimenter instruction groups were not normally distributed, the Friedman Test was performed, and it confirmed the Task effect [$\chi^2(3) = 29.234$, $p < .001$, $\varphi$ = .710].

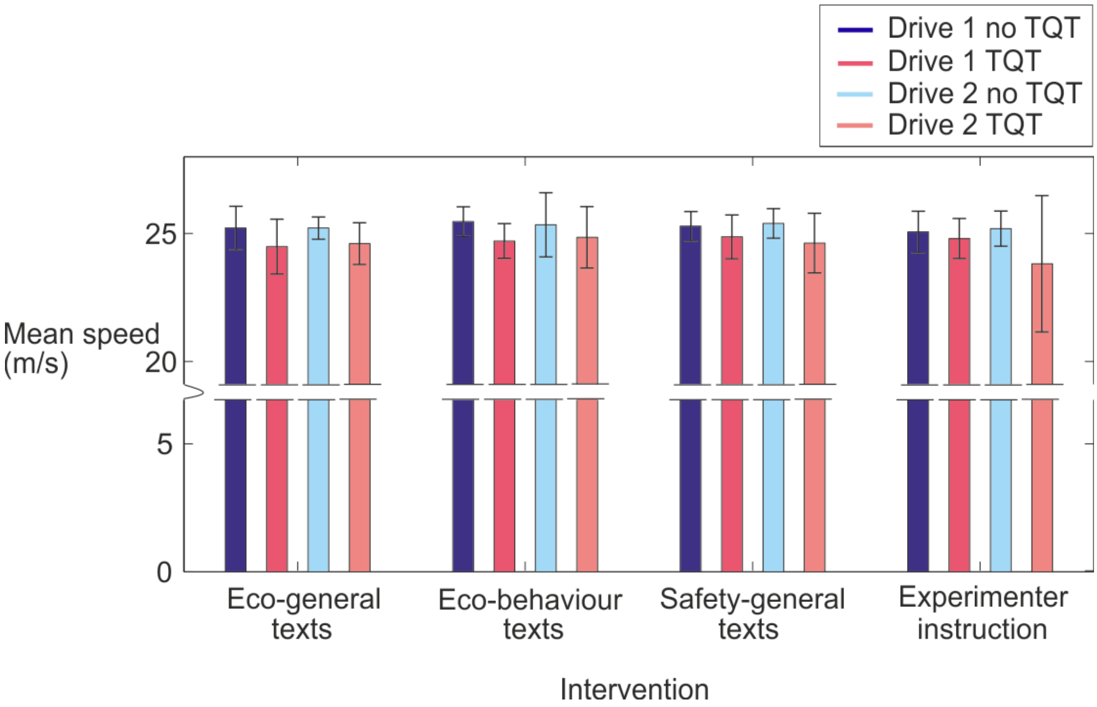


**Figure 82: Task effect for the mean speed in the coherence scenario**

The analysis of the speed variation during the coherence scenario resulted in a Task effect as well [$F(3,150) = 10.561$, $p < .001$, $\eta^2 = .174$]. Post-hoc tests clarified that it was higher in the Drive 1 no TQT condition compared to both conditions with questions task ($p < .001$, $p = .015$), coloured in red in Figure 83. It was also higher in the Drive 2 no TQT compared to the Drive 1 TQT condition ($p < .001$). Due to the distributions of the measures during the Drive 2 TQT condition, a Friedman Test was conducted, which confirmed the significance [$\chi^2(3) = 18.848$, $p < .001$, $\varphi = .570$].

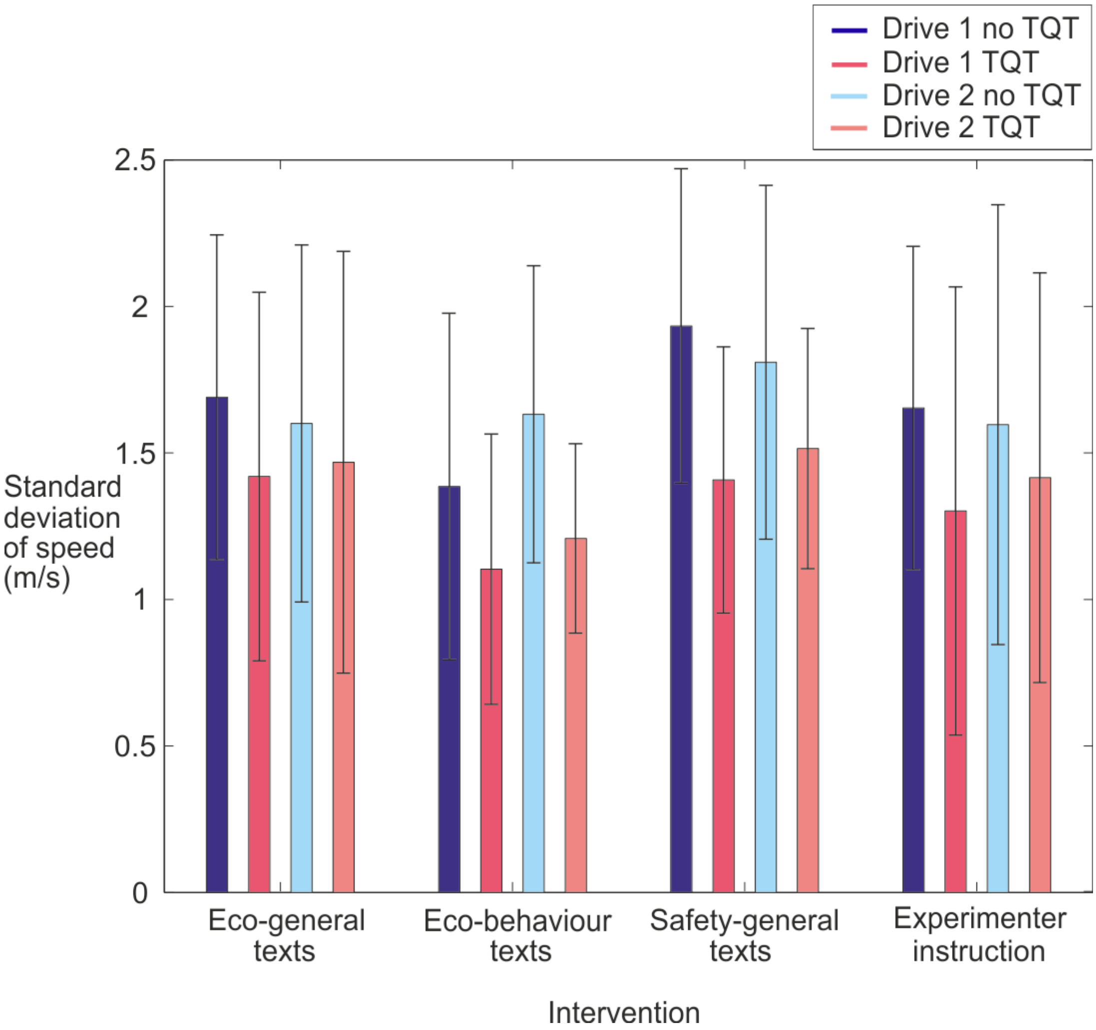


**Figure 83: Task effect for the standard deviation of speed in the coherence scenario**

For the standard deviation of lateral acceleration during the coherence scenario there was a significant effect for Task [$F(2.11,105.5) = 10.427$, $p < .001$, $\eta^2 = .173$], visualised in Figure 84. Post-hoc pairwise comparisons clarified that both conditions without TQT had higher values than the conditions with Task (Drive 1 no TQT: $p < .001$, $p = .015$, Drive 2 no TQT: $p = .001$, $p = .001$). The Friedman test, performed due to the distribution of the Drive 2 TQT values, confirmed the difference [$\chi^2(3) = 32.524$, $p < .001$, $\varphi = .749$].

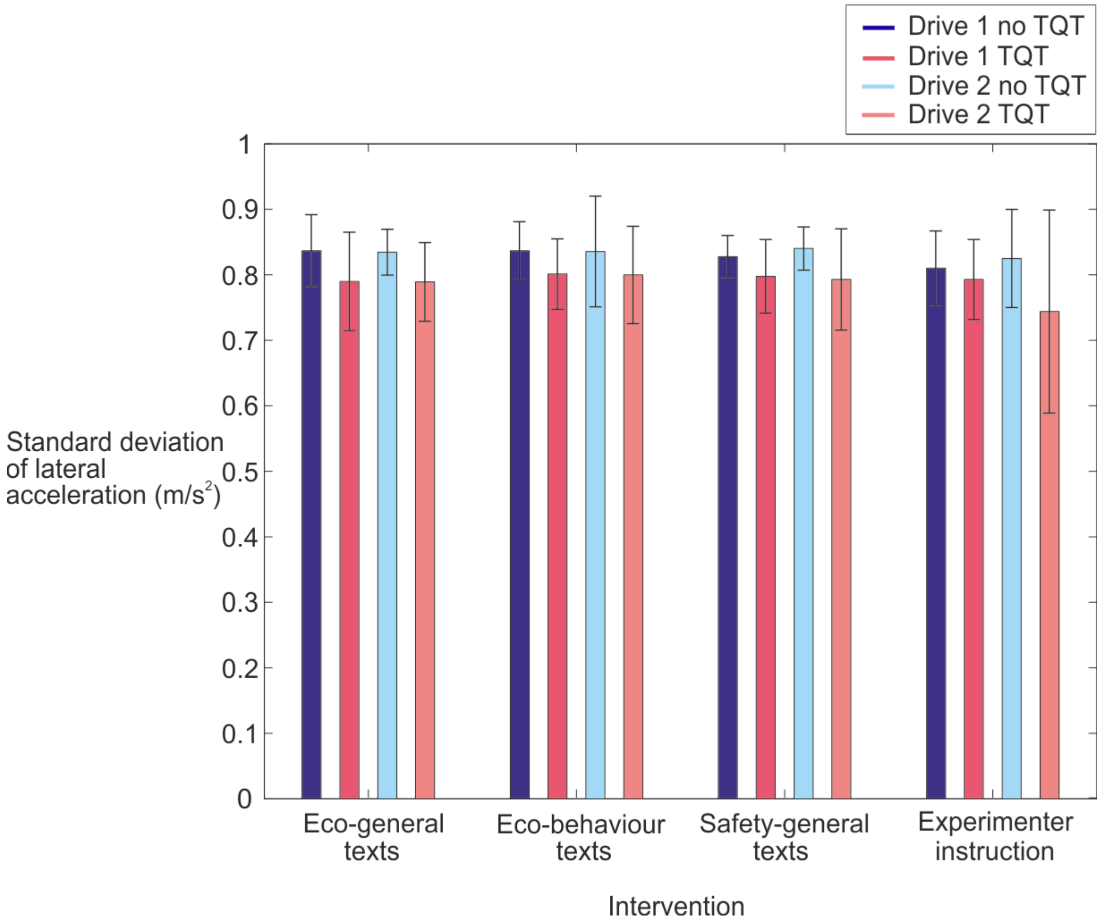


**Figure 84: Task effect for the standard deviation of lateral acceleration in the coherence scenario**

**Table 38: Results for the coherence scenario**

| Variable | | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|---|
| Coherence | Drive 1 no TQT | .263 | .176 | .281 | .327 |
| | Drive 1 TQT | .251 | .199 | .249 | .189 |
| | Drive 2 no TQT | .264 | .216 | .177 | .198 |
| | Drive 2 TQT | .271 | .132 | .172 | .191 |
| Phase shift | Drive 1 no TQT | 3.12 | 4.74 | 7.56 | 5.14 |
| | Drive 1 TQT | 5.32 | 6.67 | 4.52 | 2.90 |
| | Drive 2 no TQT | 4.39 | 5.11 | 6.76 | 4.09 |
| | Drive 2 TQT | 3.42 | 5.89 | 5.98 | 5.08 |
| Modulus*** | Drive 1 no TQT | .96 | .67 | 1.04 | .90 |
| | Drive 1 TQT | .78 | .62 | .74 | .73 |
| | Drive 2 no TQT | .89 | .78 | .96 | .79 |
| | Drive 2 TQT | .73 | .63 | .78 | .66 |
| Mean speed (m/s) (mph in brackets)*** | Drive 1 no TQT | 25.2 (56) | 25.5 (57) | 25.3 (57) | 25.1 (56) |
| | Drive 1 TQT | 24.5 (55) | 24.7 (55) | 24.9 (56) | 24.8 (55) |
| | Drive 2 no TQT | 25.2 (56) | 25.3 (57) | 25.4 (57) | 25.2 (56) |
| | Drive 2 TQT | 24.6 (55) | 24.8 (55) | 24.6 (55) | 23.8 (53) |

| Variable | | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|---|
| Sd. of speed (m/s) (mph in brackets)*** | Drive 1 no TQT | 1.69 (3.8) | 1.39 (3.1) | 1.93 (4.3) | 1.65 (3.7) |
| | Drive 1 TQT | 1.42 (3.2) | 1.10 (2.5) | 1.41 (3.2) | 1.30 (2.9) |
| | Drive 2 no TQT | 1.60 (3.6) | 1.63 (3.6) | 1.81 (4.0) | 1.60 (3.6) |
| | Drive 2 TQT | 1.47 (3.3) | 1.21 (2.7) | 1.52 (3.4) | 1.42 (3.2) |
| Mean headway(s) | Drive 1 no TQT | 6.55 | 6.28 | 5.02 | 5.70 |
| | Drive 1 TQT | 6.72 | 6.94 | 5.96 | 6.19 |
| | Drive 2 no TQT | 4.95 | 7.08 | 4.96 | 6.70 |
| | Drive 2 TQT | 6.25 | 7.32 | 7.52 | 11.2 |
| Mean headway max. 6 seconds (s)* | Drive 1 no TQT | .90 | .97 | .93 | .61 |
| | Drive 1 TQT | .56 | .63 | .74 | .78 |
| | Drive 2 no TQT | .66 | .58 | .85 | .69 |
| | Drive 2 TQT | .67 | .52 | .81 | .78 |
| Min. headway (s) | Drive 1 no TQT | 4.75 | 4.05 | 3.13 | 4.06 |
| | Drive 1 TQT | 4.52 | 5.32 | 4.17 | 4.49 |
| | Drive 2 no TQT | 3.41 | 4.42 | 3.15 | 4.67 |
| | Drive 2 TQT | 4.36 | 4.96 | 5.19 | 6.27 |

| Variable | | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|---|
| Standard deviation of lateral acceleration ($m/s^2$)*** | Drive 1 no TQT | .837 | .837 | .828 | .810 |
| | Drive 1 TQT | .790 | .801 | .798 | .793 |
| | Drive 2 no TQT | .834 | .836 | .840 | .825 |
| | Drive 2 TQT | .789 | .800 | .793 | .744 |

* p < .05

** p < .01

*** p < .001

A Task*Gender interaction effect indicates that females had a lower variation of speed compared to males when performing the TQT in the coherence scenario [F(3,150) = 3.028, p = .031, $\eta^2$ = .057], Figure 85.

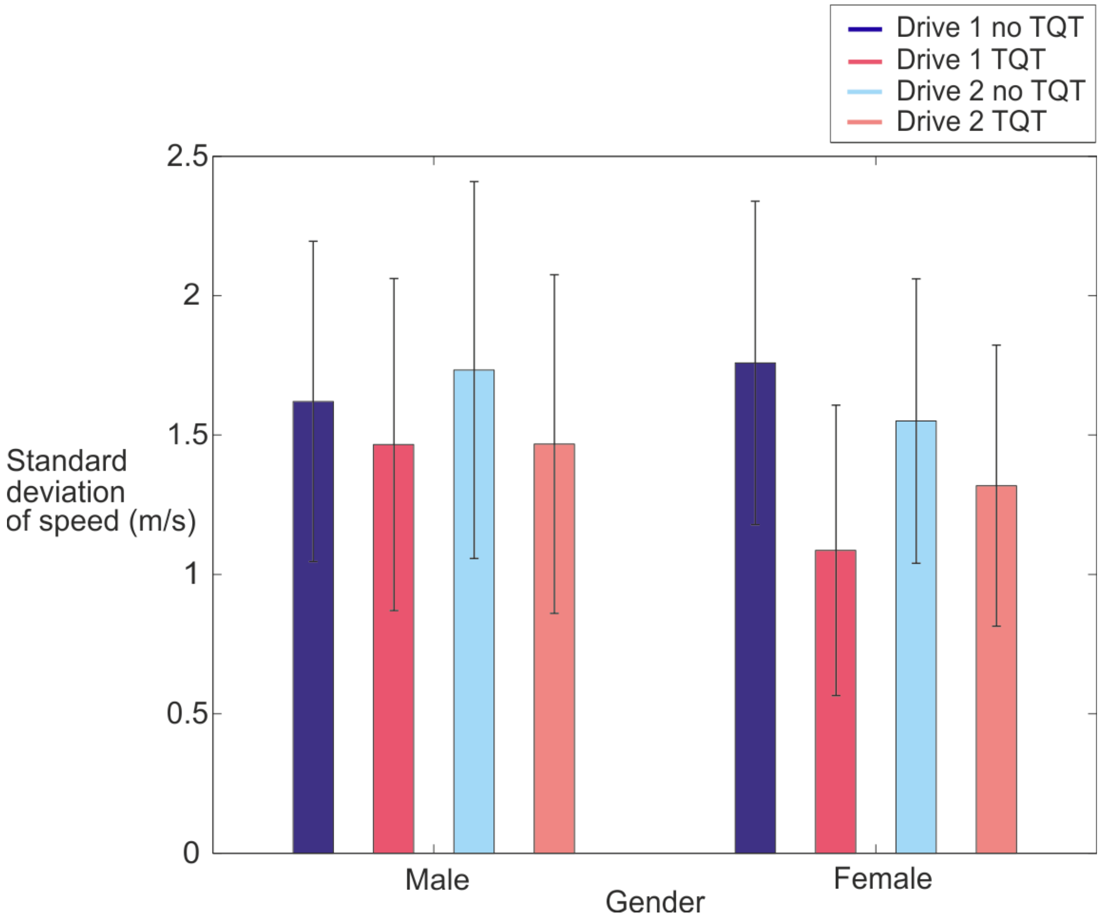


**Figure 85: Task*Gender interaction effect for the standard deviation of speed in the coherence scenario**

When the headway during this scenario was limited to 6 seconds, there was a Task*Gender interaction effect [$F(3,57) = 2.802$, $p = .048$, $\eta^2 = .129$]. Figure 86 suggests that males drove at shorter headways when answering the questions.

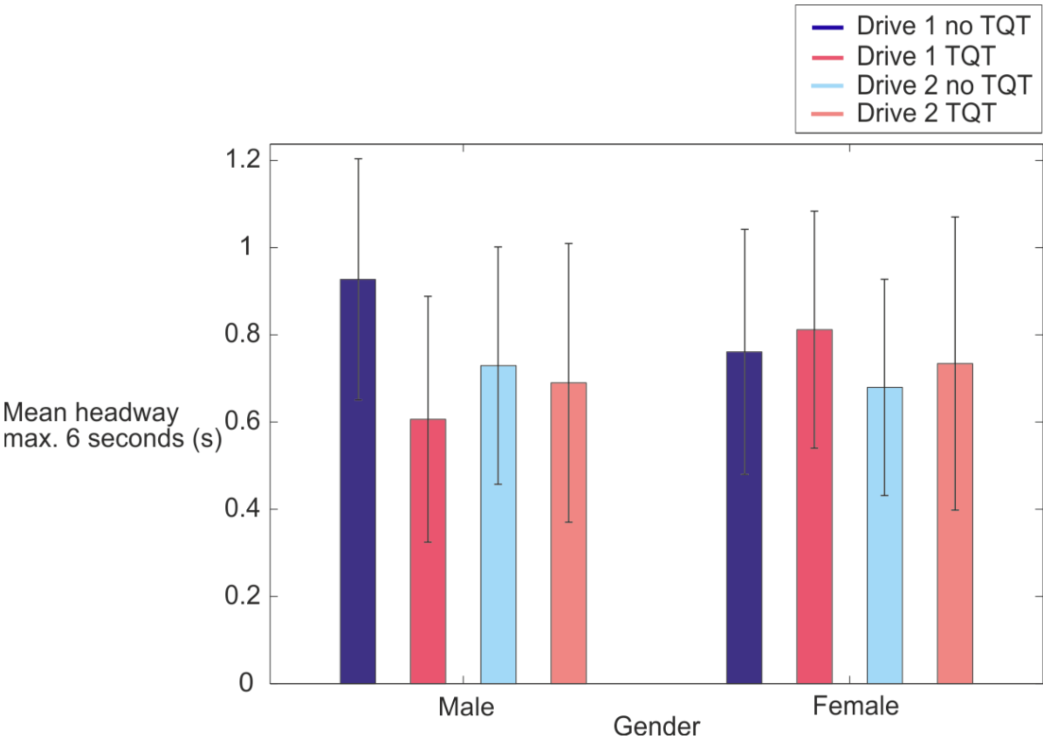


**Figure 86: Task*Gender interaction effect for the mean headway, limited to 6 seconds, in the coherence scenario**

The second long-range braking scenario occurred directly after the second coherence scenario, which involved the TQT. In this scenario no main effects were found, for the factors Intervention, Drive and Gender.

**Table 39: Drive 1 to Drive 2 changes for the long-range braking scenario 2**

| Variable | Eco-general | Eco-behaviour | Safe | Instruction |
|---|---|---|---|---|
| Mean speed (m/s) (mph in brackets) | 0.7 (2) | 0.4 (1) | 0.2 (0) | -0.5 (1) |
| Mean deceleration (m/s$^2$) | -0.031 | -0.031 | -0.047 | -0.002 |
| Sd. of deceleration (m/s$^2$) | 0.006 | 0.011 | -0.003 | -0.017 |
| Max. brake pressure (N) | -1.4 | 0.3 | 3.8 | -3.4 |
| Location when foot off gas pedal (m) | -6 | -13 | -6 | -5 |
| Location when foot on brake pedal (m) | -25 | -19 | 11 | 4 |
| Time coasting (s) | -2.43 | 1 | -0.69 | 0.68 |

* p < .05

** p < .01

*** p < .001

## 5.7 Questionnaires

A comparison of the questionnaire items between the Drive 1 and Drive 2 conditions resulted in significant differences for 5 of the total of 55 questions, Table 40. Regarding questions about eco-driving, both groups that received text messages, with either eco-driving primes or advice, increased the score for the item ‘Drivers generally drive with the conservation of the environment in mind’. Conversely, the group instructed by the experimenter reduced the ranking for ‘environment’ in the questions about what they think about and what they find important during driving. For a more concise analysis, the items were grouped into the categories ‘eco’, ‘safety’, ‘comfort’ and ‘fun and innovation’, as well as ‘self’, ‘others’ and ‘non-driving’. Summing up the scores according to these categories did not result in significant effects.

**Table 40: Questionnaire items† with significant differences between the Drive 1 and Drive 2 sessions**

| Variable | | Eco-general | Eco-behaviour | Safe | Instruction | P (Z) |
|---|---|---|---|---|---|---|
| Drivers generally drive safely* | Drive 1 | 2.60 | 2.77 | 2.73 | 3.14 | .021 (-2.31) |
| | Drive 2 | 3.13 | 2.92 | 3.07 | 3.29 | |
| Drivers generally drive with the conservation of the environment in mind* | Drive 1 | 1.80 | 1.85 | 1.93 | 2.36 | .049 (2.00), .039 (-2.07) |
| | Drive 2 | 2.07 | 2.62 | 2.07 | 2.36 | |
| It is important to me that my driving style is comfortable* | Drive 1 | 4.47 | 4.92 | 4.40 | 4.64 | .034 (-2.12) |
| | Drive 2 | 4.40 | 4.38 | 4.40 | 4.43 | |
| Ranking: When you drive what do you think about? – environment* | Drive 1 | 2.60 | 2.54 | 2.53 | 2.79 | .039 (-2.06) |
| | Drive 2 | 3.27 | 2.85 | 2.93 | 2.00 | |
| Ranking: When you drive what do you find important? – environment* | Drive 1 | 2.67 | 2.46 | 2.33 | 3.21 | .027 (-2.21) |
| | Drive 2 | 2.80 | 2.38 | 2.80 | 2.14 | |

* p < .05

** p < .01

*** p < .001

† Likert scale from 1 (strongly disagree) to 5 (strongly agree)

Significant difference between Drive 1 and Drive 2 conditions

Analysing differences between Intervention groups with the Kruskal-Wallis test did not result in significant effects. However, the Mann-Whitney U-test indicated that for a number of items male and female responses in the Drive 1 session differed significantly. These items are presented in Appendix A. When summing up the scores for categories, only the ‘fun and excitement’ category produced a significant effect, related to Gender [$t(58) = 4.879$, $p < .001$, $r = .539$], with males scoring higher in this category.

The open questionnaires provided some insights into the higher-level knowledge of eco-driving, as well as drivers’ suggestions towards motivating and helping them to eco-drive. Each of the 58 participants was able to write at least one point into the first answer field. Forty-five mentioned the avoidance of potentially harsh accelerations and decelerations (“`gentle acceleration`”), but 3 drivers from the Eco-behaviour texts group reported swift acceleration to an efficient speed, as communicated in one of the advice messages sent to them. Twenty-six commented on an optimal gear and the engine revolutions per minute (rpm), respectively (“`under 2000 revs is efficient`”). Twenty-eight participants would aim for a steadier speed (“`driving at a steady speed`”), 9 of them were in the Eco-behaviour texts group, in line with one advice message. Twenty-four would choose an efficient speed, but none of the participants in the Eco-behaviour texts group referred to the advice that eco-driving is not slow driving. Twelve drivers, 5 of them from the Eco-behaviour texts group, added coasting to their answer. In fact, engine braking and coasting, respectively, were mentioned in two advice messages. Also mentioned were vehicle maintenance, fuel-efficient technologies and environmental factors such as less traffic.

When asked what would help them to drive fuel-efficiently, 32 participants suggested in-vehicle feedback systems, while 18 wished for more information, education or training. Seventeen see potential in innovative technologies. Six drivers, 3 of them from the Experimenter instruction group, would find reminders useful and 5 would consider government programmes and campaigns as helpful. Five also mentioned eco-route guidance systems. Most would be motivated by financial savings (54) and by benefitting the environment (46), but 7 said that safety would be a consideration.

## 5.8 Summary of main results

- When drivers received text messages with general eco-driving primes they did not increase eco-driving behaviours, but displayed more constant speeds and milder decelerations in some situations
- When drivers received text messages with behavioural eco-driving advice they did not increase eco-driving behaviours
- When drivers received text messages with general safety primes they displayed stronger acceleration and deceleration behaviours as well as higher speeds when it was safe to do so, but lower speeds and milder decelerations in safety-critical situations
- Experimental instructions to drive ‘fuel-efficiently’ resulted in several effects on driving behaviour, including lower speeds as well as milder and more smooth accelerations and decelerations
- In scenarios relevant for safe driving, eco-driving interventions did not increase the prioritisation of eco-driving in most cases
- A workload task, but not eco-driving interventions, compromised car-following behaviour
- After the workload task behaviours resulting from interventions did not resume

## 5.9 Discussion

For the current study the activation of eco-driving mental models was attempted using text messages, containing eco-driving primes and advice. In order to compare possible behaviour changes, the experiment also included conditions with primes related to driving safety and instructions delivered verbally by the experimenter. The aim was to find out whether and to what degree these four interventions changed eco- and safe driving behaviour, implying an activation of all or a subset of the relevant mental models. Driving behaviour was measured in a variety of scenarios using a motion-based driving simulator before and after the interventions. In order to test whether safe or eco-driving behaviours were more prevalent during the second Drive, a number of scenarios were designed that required drivers to potentially offset these goals against each other. Assuming that the interventions effect an activation of eco-driving mental models, the question arose whether this activation would be stable in the face of conditions such as unrelated thoughts or stress. Hence, it was attempted to challenge the strength of the activated mental models with a moderate workload task.

### 5.9.1 Effects of text messages on eco-driving

It appears that the Intervention groups receiving eco-driving primes and behavioural advice did not activate their eco-driving mental models in Drive 2. These groups displayed some behavioural changes, but these were not consistent enough to be classified as eco-driving. For example, contrary to expectations, there was a tendency that both groups increased their mean speed in Drive 2 in the long-range braking scenario. However, in line with typical eco-driving behaviours, the Eco-general texts group achieved significantly steadier speeds in the speed change up scenario. It also reduced the variation of deceleration as well as the maximum brake pedal pressure when a car crossed the road in front of them, and the latter measure again in the sharp curve scenario. However, among the wide range of scenarios and measures, these effects do not stand out. For the Eco-behaviour texts group there were no notable significant changes, and often the average measures were more stable between the Drives than for other groups. Hence, the significant results could have occurred due to chance, and it was concluded that none of the text message interventions had the desired effect.

Possible explanations for the absence of an activation of eco-driving mental models include the timing, the delivery mode, and the lack of directness. Firstly, in studies utilising prompts, it has been found that such messages are most effective when provided close to the targeted behavioural decisions (Geller et al., 1971). Studies investigating the effects of training have shown that the timing can have an influence on the magnitude of behaviour change (af Wåhlberg, 2007, Chapman et al., 2002, de Groot et al., 2011). For this study it was assumed that sending the last message at 8am on the day of the second appointment would be sufficiently close. However, the time between the last message and the actual driving session could have provided the participants with sufficient time to attend to other topics. Hence, effects of the eco-driving message could have been faded, once the participants arrived at the simulator. Secondly, it is possible that text messages are less effective than messages delivered by a person. The human brain responds differently to voice (Latinus and Belin, 2011), which enhances the interaction with a message, potentially leading to more trust and increased adherence (Large and Burnett, 2014). Lastly, it may have been insufficient that the messages were not directly prompting drivers to eco-drive. They were intended to make the drivers think about eco-driving and inform them about it, respectively. The advice messages also included instructions about how to implement such behaviours. However, they did not ask drivers to actually change their behaviour, which is more likely to be effective (Sarason and Minard, 1962). In addition, advice messages that are in conflict with existing knowledge can result in distrust (Risto and Martens, 2013). As an alternative explanation, contrast effects could mitigate the effects of the text messages. These effects can occur in the context of priming, when a prime is too obvious and the receivers have negative attitudes towards the target behaviours (Herr, 1986, Herr et al., 1983, Martin, 1986). However, in the case of participants reacting adversely to obvious primes, one would also expect some participants to purposefully please the experimenter (Fiske and Taylor, 1984), which was not the case. The steadier speeds and decelerations of the Eco-general texts group could mean that the eco-driving primes increased an activation of a few lower-level mental models where it did not require a lot of effort. A study by Beusen et al. (2009) showed that, following an eco-driving course, participants were maintaining behaviours such as coasting longer than other, possibly more effortful, behaviours related to acceleration and idling time. However, since the behaviour changes in the Eco-general texts group occurred during safety-critical scenarios and were partly confounded by Drive 1 measures, definite conclusions cannot be drawn.

The group that received safety primes displayed hardly any behavioural changes in Drive 2. For instance, in the long-range braking scenario, there was a tendency that this group released the accelerator pedal closer to the junction. Unlike higher speeds and deceleration rates, stronger accelerations are not a reliable predictor for crash risk (Gettman and Head, 2003, Lajunen et al., 1997, Young et al., 2011). In study 1 there were no significant differences between ‘normal’ and safe driving behaviour. Hence, it may be possible that such a change is not related to an activation or deactivation of safe driving mental models. Instead, this behaviour could signify increased familiarity with the driving environment (cf. Martens and Fox, 2007), possibly leading to thoughts about other, unrelated topics. It needs to be taken into account, that the large range of measures and scenarios employed in this research can lead to statistically significant results due to chance. Hence, it was decided that the sporadic differences found due to the text message interventions, for both eco- and safe driving, could be seen as indications, but definite conclusions cannot be drawn.

### 5.9.2 Effects of experimental instructions on eco-driving

In contrast to the effects of the text messages, the results of the eco-driving instructions by the experimenter support the finding of study 1 that drivers possess eco-driving mental models and activate them when asked to do so. Because no further explanations were given, it was expected that these drivers activated their eco-driving mental models and consequently applied their existing eco-driving knowledge and skills. Accordingly, the strongest effects were apparent in the Experimenter instruction group. This group drove at lower speeds and spent more time in the cruising section. When setting off from stopping at a junction, this group lowered both the mean and the variation of acceleration. In the long-range braking scenario there was a tendency that this group's mean speed decreased significantly, while it increased for the other groups. The experimental instructions also led to slower driving when the speed limit increased from 30 to 60 mph. Furthermore, in this scenario the instructed drivers accelerated more smoothly. This group also accelerated less erratically when cruising. These behavioural changes, provoked by asking drivers to eco-drive, are consistent with previous studies (Birrell et al., 2010, van der Voort et al., 2001, Waters and Laker, 1980), as well as the first study in the present thesis. It is interesting to notice that the experimental instructions had the strongest impact on driver behaviour. The explanation may be related to the way the instructions were provided. For examples, studies with prompts found that these are most effective when provided close to the target behaviour in a direct (Balas et al., 2000) and simple manner (Geller et al., 1982). Hence, the timing could have played a crucial role. In both studies in the present thesis the instructions to drive fuel-efficiently were provided directly before driving, when the participants were seated in the simulator. In contrast, the last text message was sent at 8am of the day of the second session, while the first appointment was scheduled for 9:30am and the last one for 4pm. There may have been enough opportunity to get distracted from the messages' themes before the drive began. In addition, the experimental situation could have had an effect, as participants generally tend to obey when the experimenter asks them to perform tasks such as filling in a questionnaire. The drivers could also have been compliant in order to please the experimenter. However, in that case it would have been expected the advice messages, and possibly the general prime messages had a similar effect, provided the participants guessed the study's purpose. Such compliance, however, was not the case, and several participants in the Eco-behaviour texts group reported that they had engaged with the texts.

Although it would have been possible for this group to please the experimenter, they did not do so.

However, no significant effects on fuel consumption could be found, neither for the entire Drives, nor regarding the cruising scenario separately. This could be attributed to inefficient behaviours such as driving too slowly, which is inefficient in a 30-mile zone (Samaras and Ntziachristos, 1998), and accelerating too mildly (Mensing et al., 2014, Mensing et al., 2013). The nature of the driving scenarios could have played a role as well, as they did not provide many opportunities to plan behaviour ahead. For example, slowly approaching a junction with red traffic lights did not prevent the participant from stopping, because the scenario was designed for the car to stop. Similarly, events such as changing traffic lights and a car crossing the road were triggered by the participants' approach. Hence, their effect on speed fluctuations could not be avoided with anticipatory behaviours.

### 5.9.3 Effects of the interventions on safe driving

Eco-driving text messages and experimental instructions had varying effects on the safety-critical scenarios, with the Experimenter instruction group displaying the strongest effects. Approaching a sign indicating a lower speed limit, this group decelerated at a higher rate; and their mean speed was lower altogether. Once they passed the sign their speed was significantly lower than the speed of the other groups. In this case, driving eco-friendly with the early anticipation of a lower speed limit was congruent with safe driving behaviour. It has been argued that slower driving, particularly adhering to speed limits, is considered safe (Taylor et al., 2000, Taylor et al., 2002). On the other hand, for this group the standard deviation of deceleration decreased in scenarios such as the crossing car and the sharp curve scenario. Despite these situations being safety-critical, milder decelerations were applied. Hence, eco-driving was not fully abandoned. The eco-driving prime messages resulted in sporadic effects in the safety-critical scenarios as well. This group, for example, decreased the maximum brake pedal pressure in the sharp curve scenario. For the Eco-behaviour texts group the mean speed decreased for those who drove through the amber dilemma scenario. Hence, although softer decelerations and lower speeds are in line with typical eco-driving mental models, these Intervention groups may have prioritised safety in most cases. However, in line with the scenarios relevant for eco-driving, the absence of consistent behavioural changes indicates that some of these results could have occurred due to chance and it could not be concluded that eco-driving mental models were not activated.

In scenarios relevant for safe driving the Safety-general texts group displayed several behaviour changes towards safer behaviour in Drive 2. The text messages led to a lower mean speed. Consequently, the drivers passed the traffic sign with a significantly slower. In this case, the Safety-general texts group adhered more to the speed limits, which is known to reduce crash risk (Elvik et al., 2004, Nilsson, 2004, Taylor et al., 2000, Taylor et al., 2002), particularly on curvy roads (Taylor et al., 2002). In the sharp curve scenario the maximum brake pressure decreased significantly. In the same scenario the mean deceleration decreased, and the group smoothed their deceleration. Hence, the Safety-general texts group tended to handle the sharp bend less erratically in Drive 2. Glaser et al. (2007) developed a curve navigation system and found that drivers felt safer when approaching a curve with a lower speed, as opposed to braking too far in the curve. Despite its relationship with driving safety (O'Hanlon et al., 1982), no Intervention effects for the lateral variation were found. Hence, the stable speed when navigating a curve can indicate an increased activation of safe driving mental models, but this needs to be confirmed with further studies. If such behaviour changes would be supported, it would mean that safety primes are effective and able to bring safe driving behaviours into the drivers' minds when such behaviour was beneficial. One possible explanation for the effectiveness of these messages, compared to eco-driving primes, could be that drivers are more familiar with safe driving. For example, in study 1 there were no differences between the safety and eco-driving instructions. Hence, it could have required not as much effort to activate safe driving as to activate eco-driving mental models.

### 5.9.4 The effects of the TQT on mental models of eco-driving

Drivers activate eco-driving mental models when directly instructed, but abandon them following an interruption such as the TQT. This was found in the coherence scenario, which involved following a vehicle that changed its speed in a sinusoidal manner. In each Drive this scenario was presented towards the beginning, without a workload task, and again towards the end, with the TQT. There were no Task*Intervention interaction effects, which indicates that the text messages were not influencing behaviour differentially in each Intervention group. Instead, several Task effects occurred. Performing the TQT in both Drives resulted in a lower modulus, a lower mean speed, lower variation in speed and lower variations in the lateral acceleration, compared to when the task was absent. These behavioural changes are consistent with earlier studies from the field of driver distraction (Funkhouser and Chrysler, 2007, Hatfield and Chamberlain, 2005, Salvucci et al., 2007, White et al., 2006). Therefore, the TQT, although simplified in this study, reveres any effects of the text messages and instructions. The effects of the task even lasted beyond the coherence scenario, spilling into the second long-range braking scenario. The first occurrence of this scenario in the middle of the Drive generated a number of significant effects, particularly relevant for eco-driving. In comparison, in the second occurrence of the scenario, which directly followed the TQT, all significant effects diminished. As predicted, raising the workload of the driver and talking about unrelated topics led to the regression to familiar habits (cf. Rasmussen, 1979). The distinct behaviour changes in the first study in this thesis, as well as in the Experimenter instruction group, suggest that eco-driving is not the default driving behaviour for drivers. It appears to require effort, indicated by an increased workload when no support system is present (Birrell et al., 2010). Where behavioural changes were present, it required the simple interruption by a questions task to abandon behavioural changes and to revert back to old habits.

### 5.9.5 Findings from the questionnaires

Because the questionnaires were distributed after the Drives, it needs to be taken into account that the interruption by the TQT took place before the participants filled them in. However, one interesting result could be found by comparing the attitudes questionnaires of both sessions. The Experimenter instruction group significantly lowered the ranking of ‘environment’ when asked what they think about and what they find important during driving. It is possible that these drivers, who exhibited the strongest behavioural changes following the interventions, were aware of their reversal into old, familiar habits. In some cases it is believed that people are able to access lower-level mental models and thus are aware of their actions, particularly when it is made difficult to maintain them (Vallacher and Wegner, 1987).

The open questions regarding knowledge, help with eco-driving as well as motivations provided some further insights into the drivers’ minds. Overall, the participants had a good understanding of eco-driving, mostly mentioning steady speed by avoiding accelerations and braking, and by coasting. In addition, most participants reported that in-vehicle guidance would help them to drive fuel-efficiently. The effectiveness and acceptance of such systems are well-founded, as described in section 2.3.4. Only slightly more than a quarter of the drivers mentioned information, education or training, indicating that most drivers are confident with their eco-driving knowledge. About 10 % specifically asked for reminders, and half of them were in the Experimenter instruction group. Yet, it needs to be taken into account that this questionnaire was distributed after the debrief session, when the participants were aware of the study's purpose. It was noticeable, however, that the Eco-behaviour texts group reported the techniques mentioned in the advice messages more often compared to the other groups. Although this group tended to recall about half of the advice, they did not mention that eco-driving does not necessitate driving at a lower speed. Only 3 referred to the swift acceleration. It could be the case that the information targeting misconceptions were not as successful as messages confirming existing knowledge such as messages related to coasting. However, considering the low number of participants, such findings need to be confirmed in further studies.

### 5.9.6 Gender effects

Several Gender effects were found, but only some of them can be attributed to the interventions. For instance, males drove faster, accelerated stronger and spent more time speeding, either in both or in the Drive 2 session. When setting off at junctions, males increased the maximum pedal pressure when another junction with green lights was in sight, and the time spent speeding. Females tended to keep these measures constant or lower them. In both sessions, males drove at a higher speed when approaching a junction with green traffic lights, and in Drive 2 when the speed limit increased. In the cruising scenario, males spent more time speeding in Drive 2. In contrast, females lowered their speed when passing the traffic sign with a higher speed limit following the intervention period. When it came to safety-related scenarios males and females displayed differences as well. In the short-notice braking scenario males pushed their brake pedal harder in Drive 2, while females kept the pedal pressure at about the level as before the intervention. In the sharp curve males increased and females decreased their mean acceleration in Drive 2. In several scenarios in both Drives males drove faster than females, with females also having a lower minimum speed, as well as a lower variation of lateral acceleration, which is understood to be a predictor for driving safety (O'Hanlon et al., 1982). Several interaction effects could indicate that the interventions had different effects on males and females. In addition, analyses of Drive 1 flagged up significant differences before the interventions occurred, which negate influences from the interventions. On the whole, the Gender effects are in line with previous research. It has been found that male drivers are less motivated than females to comply with traffic laws (Yagil, 1998), and are more likely to drive aggressively (Shinar and Compton, 2004). These differences can explain the dynamic driving behaviour of males in this study. In addition, the fact that males gave higher scores when asked about driving innovation and fun are in line with a literature review by Gilbert et al. (2003), showing that technology tends to appeal more to a masculine gender identity.

### 5.9.7 Discussion of the methodology

It appears that activating eco-driving mental models requires effort, indicated by an increased workload when no support system is present (Birrell et al., 2010) and the increased focus on one's own actions in study 1. As a result of such potential effort, as explained in section 3.3.1, the message content could have been simply ignored by the currently activated mental models. Priming studies tend to target more subtle behaviour changes, such as the judgement of foreign countries (Brewer et al., 2003). Increasing the accessibility of constructs and increasing their importance in one's attitudes could be easier to perform compared to changing driving behaviour. When the experimenter personally asked drivers to drive fuel-efficiently, these instructions could have been strong enough to justify such efforts. The advice messages targeting eco-driving misconceptions either did not improve eco-driving mental models or did not lead to their activation. Drivers might need to see results to confirm the correctness of the messages and increase their trust in them, before adhering to them (Risto and Martens, 2013).

Values measured with a simulator may not represent values in the real world. Therefore absolute results cannot be generated, and results need to be interpreted as relative, as suggested by Rook and Hogema (2005). However, a comparison of similar scenarios in both studies in the present thesis is provided in section 6.1, and sheds some light on the validity of the measures.

It was attempted to challenge the strength of any activated eco-driving mental models with a moderate workload task. The TQT is a conversational workload task (Horrey et al., 2009). In order to create a milder version, the experimenter questioned the participants, who then provided simple ‘yes/no’ answers to words provided in advance. The task prove to be very effective, but it can still be argued whether it required too much concentration from the drivers and appeared unnatural, possibly interrupting potential eco-driving more than a simple conversation with a passenger would. Hence, future studies could involve even more moderate and natural tasks such as simplified conversations with only one ‘answer’ for the TQT and the experimenter as passenger, for example.

### 5.9.8 General discussion and conclusions

The present research was built upon the findings of the first study in the present thesis, which found that many drivers already possess a set of eco-driving mental models. This study then attempted to activate them with primes and advice, and to compare the effects with experimental instructions. It was found that text messages including these eco-driving primes and advice led to some behavioural changes, but not consistent eco-driving. If drivers do not drive eco-friendly, it is not a simple lack of knowledge and skills (Delicado, 2012) or their unwillingness (Delhomme et al., 2013). The problem appears to be connected to routine behaviour, which is inherently difficult to change. Regular drivers are usually very skilled in tasks such as braking, accelerating and car-following. These tasks tend to be automated and can be carried out without conscious attention (Boer and Hoedemaeker, 1998, Michon, 1985). It is possible to access lower-level behaviour and change it (Vallacher and Wegner, 1987). However, bringing mental models from the skill level into consciousness requires effort, and it is convenient to revert back to old behaviours (Rasmussen, 1979). There are several ways that have been shown to be able to change drivers’ behaviour to eco-driving, and regular feedback has been shown to be particularly effective (Barkenbus, 2010). The present study showed that regular reminders do not result in sufficient behaviour changes towards eco-driving. In contrast, experimental instructions provided in person and immediately before driving were much more successful in activating eco-driving mental models. Once challenged with a workload task, however, these were interrupted, and ‘normal’ driving behaviour was resumed.

Further studies will be necessary to investigate the potentials found in this study. For instance, the impact of the experimental instructions can be investigated in order to find out what it was exactly that was successful in changing behaviour. It could have been the timing, which was just before the participants stated driving, or the interpersonal nature, not just anonymous text messages. Hence, in future studies text messages can be provided directly before driving, for example using an application on the participant's mobile phones. A voice message could possibly lead to more adherence as well. Besides 'strengthening' the text messages, the experimental instructions could be 'weakened'. Using an instrumented car instead of a driving simulator could help the participants feel more natural and unsupervised during driving. It would be interesting to find out whether instructions as employed in this study have the same effects in this situation, before the participants are driving away on their own. Some of the effects found in this experiment can be investigated further. For example, the behaviour changes following general the safety-themed as well as the general eco-driving text messages could be investigated with a larger number of participants in order to find out whether the effects in this study were incidental, or whether they indicate potential of the text messages, for example for behaviours that are easier to implement. Lastly, the successes of EDSS warrant further explorations, as it is possible that they do not only guide, but prompt and prime drivers, just like the text messages were designed to in this study. Such explorations can control for the types of feedback, such as suggesting gear changes, and measure whether eco-driving mental models are activated, for example by measuring changes in mean speed and acceleration behaviours.

# 6 Discussion and conclusion

## 6.1 Overview

The present thesis is concerned with the measurement and activation of eco-driving mental models. In chapter 1 several issues in past research were outlined. Of particular importance is the necessity to tackle carbon dioxide emissions, and eco-driving has the potential to achieve considerable reductions. However, despite plausible motivations, financially and environmentally, it is problematic to encourage eco-driving. In addition, education does not solve the problem, as drivers appear to already have some idea of effective behaviours. These issues highlighted the need for an in-depth exploration of drivers' eco-driving knowledge and skills. Therefore the studies reported in this thesis used the mental models approach. The first study explored what drivers do and think when they are asked to eco-drive. The second study was designed to test text message interventions to encourage drivers to activate their eco-driving mental models. One these mental models were activated, it was attempted to interrupt them with a workload task, provoking a reversal to old driving habits. Combining quantitative and qualitative methods, this research answered the questions asked at the beginning of the present thesis and arrived at the following conclusions:

- **Do drivers have mental models of eco-driving?**

The primary aim of the first study in this thesis was the exploration of mental models that drivers employ during eco-driving on different cognitive levels. For this purpose a driving simulator experiment with a varied road layout comprising urban and motorway sections was designed and enriched with think aloud protocols and open interviews. The study used simple driving task instructions to investigate changes in the participants' behaviour as well as thoughts in three conditions. Sixteen drivers with a minimum of 5 years driving experience were asked to 'Drive normally', 'Drive safely' or 'Drive fuel-efficiently'. Behavioural measures and verbalisations were compared and analysed. The emphasis of this study was on eco-driving relevant indicators such as accelerating, braking, coasting and car-following.

The results support that each of the 16 participants in this study possessed a set of eco-driving mental models. Their existence became evident, as these drivers changed their behaviour when they were asked to eco-drive. These changes resulted in a reduction of fuel consumption in some road sections. Additional consistent behaviour changes included milder accelerations, on average and at the maximum. Most drivers chose lower speeds. These patterns, as well as the results of statistical tests, are consistent with previous studies (Birrell et al., 2010, van der Voort et al., 2001, Waters and Laker, 1980). Eco-driving behaviour was not just different from ‘normal’ driving, but also from behaviour following instructions to drive safely. In fact, this ‘safe’ driving behaviour did not result in differences to the baseline condition in study 1. Hence, the behaviour change in the Eco drives cannot solely be explained by an allocation of additional attentional resources to the driving task. Further analyses of the first experiment’s data support that the participants possess and activated eco-driving mental models. For instance, the results from modelling mental model boundaries showed that drivers tended to keep longer distances to the front cars to maintain constant speeds. The think-aloud protocols and interviews recorded during and after driving, respectively, revealed that each participant was able to mention some idea of eco-driving.

- **What is the content of eco-driving mental models?**

The first study provided insights into eco-driving mental models on the higher as well as lower levels of the mental model hierarchy (cf. Rasmussen, 1983). With regard to the higher-level strategies and goals, participants mentioned the maintenance of a constant speed in the think-aloud protocols and during the interviews. This was attempted by avoiding large speed fluctuations at traffic lights and on the motorway, when other cars were cutting in front of the drivers. Referring to specific actions, most reported that they tried to closely control their speed by keeping their foot steady on the throttle, and declared that they wanted to avoid stepping on the brake. In order to leave room for a steady speed, half of the participants mentioned a longer headway during the motorway part in the Eco drive (“I was leaving more space”). Speed choice was another frequently mentioned topic. Almost all drivers planned to keep a lower speed, particularly on the motorway, where they drove slower than the speed limit of 70 mph (113 km/h). One participant explained that he had actually not planned to drive more slowly during the Eco drive, but his mild acceleration unintentionally resulted in a lower speed. Indeed, most drivers mentioned slower acceleration in the urban section (“I shouldn’t be using too much gas”). About two thirds of the participants wanted to curb their acceleration on the motorway.

With regards to behaviours associated with lower-level mental models, the first study found that the acceleration was less erratic during eco-driving compared to other driving styles. When the participants set off from a junction when a second junction with a red light was in sight, they tended to terminate their accelerations at lower speeds, possibly anticipating these traffic lights to switch to green before arriving at the junction. Approaching red traffic lights the mean deceleration decreased significantly during the Eco drives and the participants attempted to avoid stopping. Anticipation in order to limit speed fluctuations at junctions is an effective way to save fuel (Johansson et al., 2003) and therefore suggests an effective part of eco-driving mental models. These behaviours were particularly pronounced when the participants’ lane was free from other traffic, and when the drivers had sufficient time to act, for example at junctions.

The verbalisations and behaviours were not always congruent. One particular case was the cruising speed in the urban section in study 1, where the speed limit was posted at 40 mph (64 km/h). Although only 3 participants said that they would lower it, nearly every participant did so. It is possible that the avoidance of accelerations led the drivers to maintain speeds that were lower than intended, as one driver explained. In addition, the speed variation was not decreased during eco-driving, although 10 of 16 participants mentioned a steady speed as part of their strategy. Lower variations in speed can reduce fuel savings (cited in Haworth and Symmons, 2001, Nairn and Partners et al., 1994). Yet, it may be too difficult to consciously access and change the lower-level mental models, such as the usually highly automated control of the accelerator pedal (Goodrich and Boer, 2003, Rasmussen, 1983). Unfamiliarity with the desktop simulator pedals could have added to the problem.

- **How effective are the eco-driving mental models?**

Although the mental models activated during both studies resulted in a reduction in fuel consumption, the effects were not consistent and did not achieve the strong reductions suggested in the literature. Some reports mentioned savings of 5 to 25%, mostly achieved with changes in the driving style (Barkenbus, 2010, International Transport Forum, 2007). For instance, the reductions in study 1 were not significant when cruising and were relatively low in motorway sections (only changed by 2.8%).

One possible explanation is the misconception that eco-driving necessarily involves slow driving. When the participants in the first study were instructed to drive fuel-efficiently, their mean cruising speed was slower than during 'normal' and safe driving. Conversely, in the literature it has been argued that lower speeds are considered safe (Taylor et al., 2000). Other studies support that drivers consider eco-driving slow driving (Harvey et al., 2013, van der Voort et al., 2001, Waters and Laker, 1980). In an experiment by Birrell and Young (2011) drivers were reducing their speeds, although the tested eco-driving support systems did not encourage them to do so. In fact, efficient speeds are not necessarily low (Samaras and Ntziachristos, 1998). It is not more fuel-efficient to drive more slowly than an urban speed limit of 40 mph (64 km/h), but driving below the motorway speed limit of 70 mph (113 km/h) can be beneficial. As a consequence of the lower speed during eco-driving, the time needed to complete the urban part was 9% longer than in the baseline condition. Speed reductions and resulting time losses were previously explored by Eriksson and Svenson (2012). They found that such beliefs can discourage people from eco-driving. Hence, the speed choice is an aspect in eco-driving mental models that can benefit from corrections. In several experiments where participants used in-vehicle, eco-driving feedback devices, time losses were either low or not present at all (Birrell et al., 2014, Birrell and Young, 2011, Birrell et al., 2010, van der Voort et al., 2001).

Another issue can be the belief that eco-driving necessarily involves mild accelerations. Lower acceleration rates occurred during eco-driving in both studies, and were also mentioned in the verbalisations. In fact, eco-driving research tends to emphasize to avoid excessive accelerations (Ericsson, 2001, Waters and Laker, 1980), but suggests swift accelerations up to an efficient speed (Mensing et al., 2014, Mensing et al., 2013).

Elements of the experimental setup such as the driving simulator and the road layout might not have provided sufficient opportunities for reducing fuel consumption. For example, events involving hazards and junctions with red traffic lights were triggered by the participant's approach. Hence, it was not possible for the drivers to entirely prevent their effects on speed fluctuations. Furthermore, it could have been difficult for the participants to control the simulator and achieve steadier speeds, for example. Nevertheless, the results suggest that there is potential to improve the eco-driving mental models of drivers. Educational materials can provide information, but in order for drivers to accept information that is changing their mental models, they need to be sufficiently motivated to incorporate it into their knowledge. Previous research supports the provision of feedback that is reassuring drivers with the results of their efforts (Seligman et al., 1981) or making them uncomfortable with their current mental models (Minsky, 1974, Schank and Abelson, 1977), for example by illustrating potential fuel savings over time.

- **Are there individual differences in eco-driving mental models?**

The directions of the behaviours as well as statements in the drivers' verbalisations were able to give insights into the content of eco-driving mental models. Naturally, several individual differences could be identified. Generally, there was a considerable amount of coherence between participants.

Accelerating and decelerating mildly and smoothly as well as keeping the speed lower and more constant appeared throughout when drivers were asked to drive fuel-efficiently. These behaviours occurred in a variety of settings, supporting the idea that mental models are generic and not compiled for each new situation, as assumed in section 3.3.1. Yet, several behavioural differences could be observed. For example, some participants exhibited very low acceleration rates, as visualised in Figure 87, low cruising speeds as well as excessively long headways on the motorway. Such differences were a likely cause for the relatively high variability in fuel consumption figures. Hence, a subgroup of drivers could particularly benefit from means that improve eco-driving mental models.

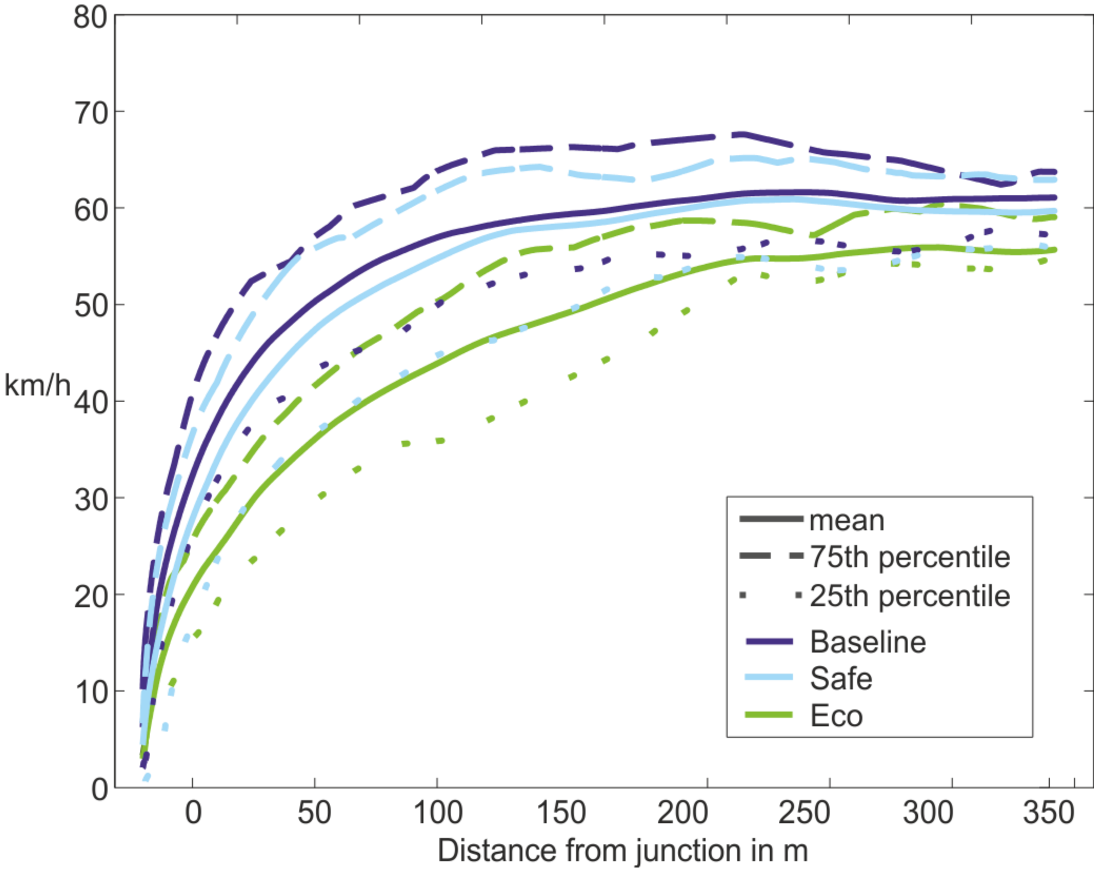


**Figure 87: Speed profiles of the acceleration scenario in study 1, see also Figure 19**

Most individual differences became apparent in the verbalisations, particularly in the think aloud protocols in study 1. While some participants spoke on a high level ("`I was leaving more space`"), or generally did not talk about their driving actions, others described details of their lower-level behaviours ("`Touching the brakes as little as possible`"). Vallacher and Wegner (1987) described how people talk in more detail about their actions during difficult tasks and novel situations. Hence, more detailed descriptions about people's actions can indicate that mental models are not well-learned.

Several Gender effects occurred, but only some of them can be attributed to the interventions. For instance, males have been found to drive faster, accelerate stronger and speed more, while females decelerated stronger in some situations. The effects are consistent with previous research. It has been found that male drivers are less motivated than females to comply with traffic laws (Yagil, 1998), and are more likely to drive aggressively (Shinar and Compton, 2004). The brake pedals in both simulators may have caused problems for people with smaller feet, and therefore resulted in the harsher braking behaviours in females. There are indeed no studies known to the author that have found similar patterns.

- **What are the implications of the existence of eco-driving mental models?**

Knowing that drivers possess eco-driving mental models leads to a new question: How can these mental models be activated? In a study by Dogan et al. (2014) reminding drivers of the reasons to eco-drive, financially or environmentally, was not as effective as feedback. According to self-reports, many people tend to be very aware of environmental issues, particularly drivers (Stradling et al., 2008), and keen to reduce their fuel expenses (Boriboonsomsin et al., 2010). The instructions in the first study involved asking the participants to 'drive fuel-efficiently' with neither further explanations nor tangible incentives. In this regard the mental model approach allowed insights beyond what the Theory of Planned Behaviour (TPB, Ajzen, 1991) would be able to provide, for example. When people carry the 'right' beliefs, attitudes as well as effective knowledge and skills, the prerequisites for eco-driving may be fulfilled. As study 1 showed, these prerequisites do not guarantee that drivers actually perform eco-driving. The fact that knowledge and skills alone are insufficient can also explain the lack of effects of educational campaigns (Delicado, 2012). The potential in the finding that many drivers possess eco-driving mental models lies in the possibility that existing eco-driving mental models could to be activated in order to for drivers to drive fuel-efficiently. When experimental instructions are sufficient to encourage the activation of eco-driving mental models, there could be other ways, which are potentially practical and cost-efficient, to encourage this.

Another challenge arising from study 1 is the maintenance of new behaviour. Following the eco-driving condition participants were instructed to drive 'normally' in a baseline condition. In this drive all fuel-efficient behaviour changes diminished. It appears that activating eco-driving mental models requires effort. 'Normal' driving mental models are built and refined during years of continuous driving practise, which leads to well-ingrained behaviours. By repeated practice some behaviours become automated, as they move down in the hierarchy of mental models. These skills are then difficult to access and exchange with 'unusual' mental models such as eco-driving. It was possible to activate eco-driving mental models by asking drivers directly before driving. However, instead of carrying these over into subsequent experimental conditions, such new or unusual behaviours were abandoned in favour of habitual actions. In addition, mental models do not usually incorporate complex information (Johnson-Laird, 1988). This could mean that monetary gains accrued over time are not present enough during actual driving (Harvey et al., 2013), or why intentions to perform environmentally friendly actions are neglected in many every-day behaviours (Whitmarsh, 2009). Hence, it is still a challenge to motivate drivers sufficiently to eco-drive. Accrued financial savings over time as well as the consciousness of behaving in a way that is more environmentally friendly can motivate, as several studies suggest (e.g. Dogan et al., 2014, Harvey et al., 2013). It would not be sufficient to rely on these motivations alone. Social norms, for example by communicating that others are eco-driving as well, can be very an effective addition. The following study investigated did not focus on motivations, but on repeated reminders to activate mental models that are not as habitualised and familiar as ‘normal’ driving mental models.

- **Can text primes and advice be effective in the activation of eco-driving mental models, and how do any effects compare to experimental instructions?**

The underlying question of study 2 was whether the effect of experimental eco-driving instructions can be replicated by other means that are more cost-efficient and feasible for large numbers of drivers. The results showed that sending text messages regularly, at least every second day, with eco-driving primes or behavioural advice did not effect a sufficient activation of eco-driving mental models. In contrast, the participants receiving these messages even increased their mean speed in some situations. Some measures indicate steadier speeds and milder decelerations following eco-driving primes. However, these effects were too sporadic and could have occurred due to chance. Interestingly, the safety primes had some effects regarding speed choice in safety-critical scenarios. Overall, the experimental instructions directly before driving were more effective, resulting in behaviour changes similar to those found in study 1. Accordingly, the participants who received these instructions tended to drive more slowly as well as accelerated and decelerated in milder ways.

There are various possible explanations for the lack of the effectiveness of the text messages. For instance, the time window could have been too short to have an impact. Future experiments could also increase the strength of text messages and refine their frequency. Previous research also suggests that messages are stronger when provided by human voice (Large and Burnett, 2014). Such future research questions are further explored in section 6.3.2.

- **How does a workload task affect the activation of eco-driving mental models?**

In study 2 it was found that the participants who were instructed by the experimenter to drive fuel-efficiently activated eco-driving mental models. Once these behavioural changes occurred, it was attempted to challenge the activation of these mental models with a workload task presented during a coherence scenario, which required the participants to follow a lead car with varied its speed. At the beginning of each Drive the coherence scenario was presented without the workload task. Towards the end of the Drive the coherence scenario occurred again, but this time with the driver performing the task. This task was a modified version of the TQT (Twenty Questions Task), which was more moderate and less competitive than the original version (cf. Kafer and Hunter, 1997, Mosher and Hornsby, 1966). When the task was performed, no effects attributable to the text message interventions and experimental eco-driving instructions were found. Instead, performing the TQT in both Drives resulted in slower driving and worse car-following parameters. The effects of the task even lasted beyond the coherence scenario, apparent in an additional long-range braking scenario placed at the end of the road layout. In contrast to the first long-range braking scenario, in the occurrence directly following the TQT, no significant effects for measures such as lower deceleration rates occurred. Hence, a workload task involving talking about unrelated topics led to the deactivation of eco-driving mental models. Instead, drivers were reverting to more familiar behaviours (cf. Rasmussen, 1979), in this case to 'normal' driving. The distinct behaviour changes in the first study in this thesis support the findings that eco-driving is not the default driving behaviour for drivers. Hence, drivers activate eco-driving mental models when directly instructed, but once they are interrupted by a task such as the TQT, old, more familiar driving habits are resumed. This behaviour could be similar to findings from Morrow et al. (1987) showing that people's situation models during reading texts are more accurate in locations close to the protagonist. Similarly, it can be possible that, once interrupted, the eco-driving mental models may not have been sufficiently present in the drivers' minds to be re-activated.

- **What are the implications of the activation of eco-driving mental models for driving safety?**

Both studies in the present thesis included scenarios designed to create a conflict between safe and eco-driving. If drivers attempted to keep a constant speed, for example, these scenarios would have made it unsafe to do so. Events were based on specified values for TTC, which means that these scenarios created such conflicts, even when drivers approached them with lower speeds. In such scenarios no significant differences between the safe- and eco-driving conditions were found. These results suggest that in most safety-critical scenarios safe driving was prioritised. In addition, during car-following, drivers tended to facilitate eco-driving with larger headways. When the safety margins were shorter, they prioritised safety. The only measure that differed was the headway when braking was terminated. When other vehicles cut in the front of the participants, this measure was lower during eco-driving. This implies that they braked, but ended braking at lower safety margins during eco-driving in order to avoid decreasing the speed too much. When traffic lights turned red at a short notice, behavioural differences between safe and eco-driving hardly occurred. This prioritisation of safety, however, was not unified. The fact that one participant in study 1 and three participants in study 2 crossed this junction without stopping indicates that a few drivers may well accept small risks for the benefit of a constant speed (cf. Young et al., 2011). In the second experiment the scenarios relevant for safe driving generated a few behavioural changes for those participants instructed by the experimenter to eco-drive. They tended to lower their speed, but these deceleration actions were conducted in a more gradual and steady manner. Hence, despite taking steps to safely navigate such scenarios, some drivers were still bearing the fuel efficiency goal in mind when braking.

In the first study the computation of mental model boundaries enabled an objective identification of a change in safety-critical behaviour during eco-driving. It was found that when other vehicles drove into the participants' lane, and the values for time headway and time to collision became very small, the participants tended not to compromise on their driving safety. In fact, they initiated braking actions at relatively high time headways, compared to the Safe condition.

The results of statistically analysing the verbal data indicate a shift in the focus of the drivers when they attempted to eco-drive, although most significant differences were found between the Eco and the Safe condition.

The increased focus on one’s own actions and away from unrelated thoughts can denote an increased workload. In fact, Birrell et al. (2010) found an indication for an increase in workload when people are asked to eco-drive. The main aim of their study was to test the effects of an EDSS they had designed. In one experimental condition they asked their participants to eco-drive without the system. A questionnaire revealed that, although the participants achieved reductions in fuel-consumption, their workload was elevated. Rasmussen’s taxonomy (Rasmussen, 1983) suggests that the drivers brought mental models of the rule- and skill-level that would otherwise not have been considered into consciousness. At the same time the focus was partly taken off the surroundings and other safety-critical themes, which could mean a safety risk for unassisted eco-driving. Eco-driving could also be risky for drivers whose eco-driving mental models are not sufficiently mature, and involve unnatural behaviours such as the maintenance of excessively low speeds and long headways.

These findings link back to the foundational ideas behind mental models, in particular to the understanding that mental models are placed between the outside world and human information processing. Mental models influence perception (Schank and Abelson, 1977), which could also explain the shift in focus found in the think-aloud protocols. It does not necessarily mean that cues relevant for safe driving are ignored during eco-driving, but that it might require more effort to absorb the same amount of information from the driving environment. The results of modelling mental model boundaries suggest that eco-driving can lead drivers to maintain high safety margins, which can account for deficiencies in information processing and an elevated workload.

- **Were the methods involved suitable for studying mental models of eco-driving?**

Driving simulators were ideal for the purposes of both studies in this research, which required the collection of detailed behavioural data in the face of the experimental drives, differing in single instructions and the content of text message interventions, respectively. A driving simulator provides a highly controlled environment, in which variables such as weather and traffic flow can be held constant, thus each driver is faced with the same conditions (Boyle and Lee, 2010). However, driving simulators have limitations. The sensitive nature of the desktop simulator controls could have caused the participants to drive in more erratic ways than in the more realistic motion-based simulator employed in study 2 (Jamson and Jamson, 2010). The absence of safety-related consequences can change drivers' diligence. Furthermore, motivations for participating in an experiment are related to contributing to the research, curiosity about its outcomes and financial rewards (Stunkel and Grady, 2011). In the real world people drive for reasons such as commuting to work or travelling to leisure destinations, or the enjoyment of driving itself. Participants tend to comply with experimental instructions, for example when asked to fill in a questionnaire. Hence, they could have been motivated to eco-drive, because they were asked to do so by the experimenter.

Jamson and Jamson (2010) found that a desktop simulator can result in a lack of lateral control, more time in shorter headways, and worse self-reported performance ratings. Hence, values measured with a simulator may not be consistent with values in the real world. For example, it cannot be expected that the boundaries between acceptable and unacceptable car-following states, modelled in section 4.4.7, are the same on a real motorway. Therefore absolute results cannot be generated, and results need to be interpreted as relative, as suggested by Rook and Hogema (2005). In addition, the brake pedals did not provide realistic feedback and may have been more difficult to use by people with smaller feet, and therefore caused the stronger braking actions of the female participants.

Both study 1 and study 2 included a comparable set of experimental conditions, one Baseline condition and one in which the drivers were instructed to drive fuel-efficiently. It was expected that these instructions had the same effect in both experiments, and that differences in behaviour could be attributed to the type of driving simulator used.

Table 41 displays the p-values and effect sizes of comparisons of the mean values for the Baseline and Drive 1 conditions on the one hand and for instructed eco-driving on the other. Effect sizes are important to consider, as these provide information about the size of an effect, not confounded by participant numbers (Coe, 2002). They allow the comparison of intervention effects across different contexts. The results show that Cohen's d in the case of experimental instructions was higher across several measures in study 1. The difference is most pronounced with regard to the variation of acceleration (Study 1: $p = .001$, $d = 3.10$, Study 2: $p = .013$, $d = 1.52$). This is surprising, because the motion-based simulator is more realistic and considered easier to control (Jamson and Jamson, 2010). However, the higher speed limit in the urban section in the first experiment provided more room for changes in speed as well as acceleration behaviour. In addition, the pedals in the desktop simulator are looser compared to the pedals of the motion-based version. Accordingly, in the Baseline Drive in study 1 the throttle was pressed by 47° at the maximum, resulting in a significantly less harsh acceleration in the Eco Drive (p = .001, d = 3.10). In contrast, in Drive 1 in study 2 the maximum pedal angle was only 25°, with a weaker effect following eco-driving instructions (p = .005, d = 1.79). Hence, it may have been easier to implement changes with the desktop simulator pedals.

**Table 41: p-values and Cohen's d of t-tests comparing Baseline and Instructed eco-driving conditions**

| Cruising scenario: | | | | |
|---|---|---|---|---|
| Measure | Study 1 | | Study 2 | |
| | p | d | p | d |
| Time spent in scenario | .002 | 1.99 | .018 | 1.44 |
| Mean speed | < .001 | 2.88 | .018 | 1.43 |
| Standard deviation of acceleration | .001 | 3.10 | .013 | 1.52 |
| **Acceleration scenario:** | | | | |
| Measure | Study 1 | | Study 2 | |
| | p | d | p | d |
| Mean acceleration | .001 | 3.10 | .005 | 1.79 |
| Standard deviation of acceleration | .001 | 2.08 | .002 | 2.02 |

The mental model approach has allowed gaining valuable insights, particularly in understanding driver's cognition with regards to eco-driving, beyond what theories based on the TPB or economic theories could have found. Mental model theory is relatively new as underpinning in experimental psychology, particularly in driver behaviour studies (e.g. Goodrich and Boer, 2003, Henning et al., 2008). The approach could be applicable for research questions beyond eco-driving, for example with regards to driver support systems. On the downside, in the driver behaviour studies known to the author, the mental model approach was only focussed on people's cognition and took neither emotional nor social factors into account. There is still a need to further understand other factors that influence behaviour, such as social norms, defined in section 2.3.1. The think aloud protocol was a valuable qualitative addition to the first experiment in this research. It allowed capturing momentary thoughts and finding explanations for behaviour changes. The method, however, captures incomplete data. In some places a mismatch between what the drivers said they intended to do and the behavioural data occurred. This can indicate eco-driving strategies, but the absence of a lower-level skill to execute them.

The methodology of the second study relied on text messages, delivering primes and advice about eco-driving to the participants' mobile phones. Text messages have been used widely in health interventions and achieved significant effects (Cole-Lewis and Kershaw, 2010). These effects, however, were related to higher-level actions such as attending medical appointments and enquiring about vaccinations (Phillips et al., 2014). Priming studies on the other hand have targeted subtle changes in attitudes and behaviour, often without the participants noticing the changes (Bargh et al., 1986). The question arises whether the text messages were not strong enough to replace well-learned, automated driving behaviours with less familiar eco-driving mental models.

The workload task employed in study 2 proved to be very effective, but it can still be argued whether it required too much concentration from the drivers and appeared unnatural, possibly interrupting potential eco-driving more than a simple conversation with a passenger would.

The questionnaires offered only limited insights into the attitudes of drivers. One reason is that they were distributed after the driving sessions to prevent the participants from guessing the study's goals. Because the workload task led to a reversion to old behaviours, it cannot be assumed that any effects of the interventions were still present after driving, when the questionnaires were filled in.

## 6.2 Implications

- **What are the implications for improving eco-driving?**

In the first study in the present thesis simple instructions by the experimenter resulted in each participant to perform some form of eco-driving. These instructions only involved asking the participants to ‘drive fuel-efficiently’ with no further explanations. Hence, first of all one can conclude that drivers already possess mental models of eco-driving and do not need to be taught every single aspect of it, as often assumed (Delicado, 2012). In fact, it appears that drivers carry a large part of the necessary knowledge and skills in order to reduce their fuel consumption. However, there is potential for improvement and refinement, with respect to excessively low speeds and mild accelerations, for example. Nevertheless, knowing about the presence of eco-driving mental models in many drivers’ minds means that their behaviour cannot be changed with education alone. It also signifies that efforts to encourage eco-driving can be based on the activation of present knowledge and skills. In addition, previous studies suggest that many drivers have the ‘right’ attitudes and motivations, but these results relied on self-reported measures, and are only the prerequisites for eco-driving. The second major finding of the first study is that simple instructions were sufficient to change the behaviour of drivers, and result in the activation of eco-driving mental models. It was not necessary to teach drivers, or to improve factors predicting behaviours by the Theory of Planned Behaviours such as attitudes and motivations. The impact of these simple instructions was further investigated in the second study in the present thesis. There was some variation in the behaviours and fuel consumption figures among the participants when driving ‘normally’. This could mean that some drivers already practise eco-driving to some degree during every-day driving. Still, when an experimenter asked them to drive fuel-efficiently, participants seemed to be able remember, retrieve and activate more eco-driving mental models.

The second study aimed to replicate the effect of experimental instructions by delivering eco-driving content in the form of text messages on drivers’ mobile phones. The rationale was that prime and advice messages would make such mental models more present in drivers’ minds. Yet, the messages did not have the desired effect. Hence, at this point large-scale text message campaigns for eco-driving, as employed in this research, cannot be recommended. Definite solutions for ways to activate eco-driving mental models cannot be derived.

In the studies presented in this thesis, eco-driving instructions were provided by the experimenter in person and directly before driving. It can be considered whether elements of these instructions can be effectively conveyed in messages to drivers. It is possible that the message has to be strong enough to provide the driver with enough reason to retrieve and activate the more unusual mental models. When an experimenter asks a participant to eco-drive, the instruction could be as strong as asking the participant to appear to the experimental session without wearing glasses, to read the briefing sheet and to fill in a questionnaire. Experience shows that such instructions are usually adhered to. The text messages and advice inherently provided the option to disregard them. They may have brought the idea of eco-driving into the drivers' minds, but the increased accessibility of these mental models may not have been enough to invest the effort to use them during driving. A number of ideas of how to strengthen eco-driving messages and to further investigate the effective elements of the experimental instructions are discussed in section 6.3.2.

Where drivers employed eco-driving mental models, it required the simple interruption by a questions task to abandon behavioural changes and to revert back to old habits. As new behaviours are vulnerable to interruptions, eco-driving is easily abandoned following elevated workload or unrelated thoughts. This means that the timing of an eco-driving message, provided it is effective in the first place, is crucial. First of all, communicating it just before driving appears to be necessary. Hence, it could be delivered at the point when a driver enters a car, or turns the ignition on. In addition, the message needs to be repeated, either at regular intervals or following an interruption. The latter would assure that eco-driving is continued as much as possible. The challenge lies in recognising the interruption, or the consequential deactivation of eco-driving.

- **What are the implications for sustainable behavioural change?**

The question arises whether people possess more knowledge than commonly assumed in areas beyond driving, for example regarding sustainable transport in general. It has been shown that drivers often have the 'desired' knowledge and attitudes, such as higher-than-average environmental concern (Stradling et al., 2008). Yet, during every-day life ingrained habits appear to overrule good intentions. Education and campaigns have been shown to have some effect, although they tend to set the conditions for environmentally friendly behaviour, and not result in its widespread practise. Stronger messages, such as campaigns making use of social norms, seem to create enough pressure to change behaviour (Jackson, 2005).

One long-standing problem in encouraging environmentally friendly behaviour are ingrained habits. Routine behaviour is inherently difficult to change (Goldenbeld et al., 2000). The second study in the present thesis emphasised that regular reminders have a limited effect. As daily life gets into the way of good intentions, people may simply maintain, or revert to old behaviours, particularly when new behaviours require effort (Whitmarsh, 2009). Hence, some studies on environmentally friendly behaviours with successful outcomes focussed on the most convenient behaviours, such as changing a shower head, which hardly impair every-day life (e.g. Dietz et al., 2009).

As the experimental instructions in the studies in this thesis were effective, the question arises whether such instructions can be used in areas beyond driving. An effective message could be communicated at the point when a person has the opportunity to behave in a more sustainable way. This moment can be when a person is leaving the home in the morning for work, or when planning a holiday.

## 6.3 Further research

The current thesis gained insights into mental models of eco-driving, particularly their existence, activation and interruption. At the same time this research has generated a number of questions that warrant further research.

### 6.3.1 Research potential derived from study 1

Future research needs to address the fact that drivers do not fully utilise their existing knowledge and skills. Ingrained habits appear to pose a particular barrier for behaviour change, and ways to change these habits need to be further investigated. Interventions could be influential at the stage when habits are formed. Tarkiainen et al. (2013) investigated the effects of a driver support system with eco-driving advice on novice drivers. They found the system to be effective in reducing fuel consumption. Further studies could explore the resulting formation of ‘normal’ and eco-driving mental models. Studying the formation of driving mental models also applies to eco-driving lessons for beginners in driving schools. To date the studies investigating eco-driving training courses, known to the author, were conducted with experienced drivers (af Wåhlberg, 2007, Siero et al., 1989).

The mental models of eco-driving that were identified in the first study included some misconceptions, such as believing that slow driving and very mild accelerations are always necessary to save fuel (cf. Harvey et al., 2013, van der Voort et al., 2001, Waters and Laker, 1980). In these matters informing and educating drivers should mend weaknesses and improve existing eco-driving mental models. However, the text messages giving this information did not result in behavioural changes related to speed choice and acceleration. It needs to be further investigated how eco-driving mental models can be improved. For sustainable behaviour change it is a hurdle that regular drivers tend to be very skilled in driving tasks. Some driving tasks are automated and can be carried out without conscious attention (Boer and Hoedemaeker, 1998, Michon, 1985). It can be possible to access lower-level behaviour and change it (Vallacher and Wegner, 1987). However, this requires effort, and it is convenient to revert back to old behaviours (Rasmussen, 1979). One solution could be support systems that target lower-level skills such as direct manipulation interfaces suggested by McIlroy and Stanton (2014). Such technology, for instance haptic pedals, guides people’s motion and teaches without involving the conscious mind. Research in these systems is relatively young, and warrants more exploration.

In the field of general car use the question arises what drivers know about the use of public transport, and therefore whether they have ‘public transport mental models’. The approach used in this thesis has the potential to explore the underlying cognitive mechanisms in this area as well, and to identify the information needs of drivers that could encourage them to use more sustainable modes.

Finally, simulator studies generally create a need for validation studies. The experiments presented in this thesis provide the means for controlled research, which can be suitable in early stages of novel concepts. However, further studies will be necessary, involving a larger number of participants and real-world studies bearing the findings into realistic implementations. Real-world studies are crucial, as in both studies the experimental setting could have motivated drivers to eco-drive. Hence, on-road studies could involve instructing drivers in similar ways, and measure the outcomes in less ‘experimental’ environments, for example in instrumented vehicle. In such a study instructions could be provided in person or on the telephone. Ideally, participants would feel less monitored, which could change the motivation to comply with the experimenter's instructions.

### 6.3.2 Research potential derived from study 2

Because the text messages were not sufficiently effective in the second study, future research could attempt to increase their 'strength'. Such studies could increase the frequency of the messages to several times a day (cf. Abrahamse et al., 2005) or time them closer to the point of action (cf. Seligman et al., 1981), for example by delivering them when the driver gets into the car. A longer time period of at least three weeks, as used in text message studies in the health sector (e.g. Cole-Lewis and Kershaw, 2010, Stockwell et al., 2013), could also result in stronger effects. Information that makes drivers feel uncomfortable with their usual driving practise could be effective as well (cf. Vallacher and Wegner, 1987), for example using social norms. Considering the finding that verbal instructions were effective in changing behaviour, the question arises whether the messages sent in the present study would be more effective in a vocal (cf. Large and Burnett, 2014) and more direct form (cf. Sarason and Minard, 1962). The latter could be implemented with messages such as "Drive fuel-efficiently."

The difficulty of changing ingrained habits leads to the question of the potential of eco-driving during the early formation of driving habits. Future studies need to consider novice drivers, for example when they take driving lessons. These drivers could be more susceptible to eco-driving behaviours, as the success of in-vehicle eco-driving feedback for novice drivers in the Trafisafe project (Tarkiainen et al., 2013, Tarkiainen et al., 2014) suggests. Hence, it would be interesting to repeat elements of the current experiment with people who take driving lessons or who recently passed their driving test. Conversely, the problem of clearing eco-driving misconceptions poses new questions. Possibly, simple advice messages are insufficient without presenting actual time or fuel-efficiency gains. Hence, further studies could add such information to assure drivers and increase trust in the advice (cf. Risto and Martens, 2013).

There were a few effects in the study that warrant further exploration. For instance, the Eco-general texts group displayed isolated effects such as more constant speeds and milder decelerations in some scenarios. In addition, the Eco-behaviour texts group was more able to recall messages related to coasting compared to messages targeting the misconception that lower speeds are necessary to eco-drive. These findings do not allow conclusive answers due to the sporadic effects and low participant numbers in the Intervention groups. Nevertheless, these effects pose the question whether primes have the potential to increase an activation of more convenient and familiar actions. Further studies with a larger number of drivers can consider eco-driving behaviours such as smooth speeds and coasting on the one hand, compared to actions possibly requiring more effort to change such as acceleration and speed choice. In addition, it was found that Gender confounded some of the results in this study. Experiments with only females or male participants, in larger numbers, can account for such effects.

The ecoDriver project has developed and tested the effectiveness and acceptance of a diverse range of feedback systems (e.g. Jamson et al., 2015a, Jamson et al., 2015b). It has been shown to be particularly effective in encouraging eco-driving (Barkenbus, 2010). Feedback does not only educate, but also reward, motivate (Seligman et al., 1981) and reinforce new behaviours (Fischer, 2008). Interestingly, in a study by Birrell et al. (2014) participants reduced their speed although the employed system did not advise on speed choice. Hence, it would be interesting to investigate why this unforeseen effect was arising. Further research can examine to which degree feedback causes the activation of existing eco-driving mental models. Studies could control for the types of information provided by a support system. In this way, the impact on the targeted as well as other eco-driving actions can be systematically examined. Results can provide further insights into the way feedback works; as well inform the design of more effective messages.

The effects of the workload task supported the idea that new behaviours are often vulnerable in the face of interruptions and workload. Daily stressors and unrelated thoughts can lead to old habits resurfacing (cf. Rasmussen, 1979). Future research can examine different types of interruptions drivers face when eco-driving. This way it could be found out whether there are ‘acceptable’ tasks as well as driving situations, which allow a continuation of eco-driving. Findings could also highlight situations that are likely to require another reminder or instructions for the driver to re-activate eco-driving mental models.

# 7 List of References

Abraham, C. & Michie, S. 2008. A taxonomy of behavior change techniques used in interventions. *Health Psychology,* 27**,** 379-387.

Abrahamse, W., Steg, L., Vlek, C. & Rothengatter, T. 2005. A review of intervention studies aimed at household energy conservation. *Journal of Environmental Psychology,* 25**,** 273-291.

Abric, J. C. 1987. *Coopération, competition et représentations sociales,* Cousset, Switzerland, DelVal.

af Wåhlberg, A. E. 2007. Long-term effects of training in economical driving: Fuel consumption, accidents, driver acceleration behavior and technical feedback. *International Journal of Industrial Ergonomics,* 37**,** 333-343.

Ajzen, I. 1991. The theory of planned behavior. *Organizational behavior and human decision processes,* 50**,** 179-211.

Ajzen, I. 2002. Perceived Behavioral Control, Self-Efficacy, Locus of Control, and the Theory of Planned Behavior1. *Journal of Applied Social Psychology,* 32**,** 665-683.

Alson, J., Hula, A. & Bunker, A. 2014. Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 - 2014. *Trends Report.* Ann Arbor, MI.

Amir, O., Ariely, D., Cooke, A., Dunning, D., Epley, N., Gneezy, U., Koszegi, B., Lichtenstein, D., Mazar, N., Mullainathan, S., Prelec, D., Shafir, E. & Silva, J. 2005. Psychology, behavioral economics, and public policy. *Marketing Letters,* 16**,** 443-454.

Anderson, J. R. 1982. Acquisition of cognitive skill. *Psychological review,* 89**,** 369-406.

Anderson, J. R., Bothell, D., Byrne, M. D., Douglass, S., Lebiere, C. & Qin, Y. 2004. An integrated theory of the mind. *Psychological review,* 111**,** 1036-1060.

Andrieu, C. & Pierre, G. S. 2012. Using statistical models to characterize eco-driving style with an aggregated indicator. Intelligent Vehicles Symposium (IV), IEEE, 3-7 June 2012. 63-68.

Argyris, C. & Schön, D. A. 1974. *Theory in practice: Increasing professional effectiveness,* San Francisco, California, Jossey-Bass.

Argyris, C. & Schön, D. A. 1978. *Organizational learning: A theory of action perspective,* Reading, Massachusetts, Addison-Wesley.

Arnold, A. & Mettau, P. 2006. Action facilitation and desired behavior. *In:* Verbeek, P.-P. & Slob, A. (eds.) *User Behavior and Technology Development.* Springer Netherlands.

Austrian Energy Agency. 2013. *The golden rules of ecodriving* [Online]. Vienna, Austria. Available: http://www.ecodrive.org/en/what_is_ecodriving-/the_golden_rules_of_ecodriving/ [Accessed 14/03 2013].

Baddeley, A. 1992. Working memory. *Science,* 255**,** 556-559.

Baillargeon, R. 1987. Object Permanence in 3 1/2- and 4 1/2-Month-Old Infants. *Developmental Psychology,* 23**,** 655-664.

Balas, E., Weingarten, S., Garb, C. T., Blumenthal, D., Boren, S. & Brown, G. D. 2000. Improving preventive care by prompting physicians. *Archives of Internal Medicine,* 160**,** 301-308.

Bamberg, S. & Möser, G. 2007. Twenty years after Hines, Hungerford, and Tomera: A new meta-analysis of psycho-social determinants of pro-environmental behaviour. *Journal of Environmental Psychology,* 27**,** 14-25.

Bargh, J. A. 1984. Automatic and conscious processing of social information. *In:* Wyer Jr., R. S. & Srull, T. K. (eds.) *Handbook of social cognition.* Hillsdale, NJ: Erlbaum.

Bargh, J. A., Bond, R. N., Lombardi, W. J. & Tota, M. E. 1986. The additive nature of chronic and temporary sources of construct accessibility. *Journal of Personality and Social Psychology,* 50**,** 869-878.

Bargh, J. A., Lombardi, W. J. & Higgins, E. T. 1988. Automaticity of chronically accessible constructs in person×situation effects on person perception: It's just a matter of time. *Journal of Personality and Social Psychology,* 55**,** 599-605.

Bargh, J. A. & Pratto, F. 1986. Individual construct accessibility and perceptual selection. *Journal of Experimental Social Psychology,* 22**,** 293-311.

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

Baruya, A. 1998. Speed-accident relationships on European roads. *9th International Conference on Road Safety in Europe.* Bergisch Gladbach, Germany.

Bellet, T., Bailly, B., Mayenobe, P. & Georgeon, O. 2007. Cognitive Modelling and Computational Simulation of Drivers Mental Activities. *In:* Cacciabue, P. C. (ed.) *Modelling driver behaviour in automotive environments.* Springer London.

Bellet, T. & Tattegrain-Veste, H. 1999. A framework for representing driving knowledge. *International Journal of Cognitive Ergonomics,* 3**,** 37-49.

Beusen, B., Broekx, S., Denys, T., Beckx, C., Degraeuwe, B., Gijsbers, M., Scheepers, K., Govaerts, L., Torfs, R. & 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**,** 514-520.

Birrell, S. A., Fowkes, M. & Jennings, P. A. 2014. Effect of Using an In-Vehicle Smart Driving Aid on Real-World Driver Performance. *Intelligent Transportation Systems, IEEE Transactions on,* 15**,** 1801-1810.

Birrell, S. A. & Young, M. S. 2011. The impact of smart driving aids on driving performance and driver distraction. *Transportation Research Part F: Traffic Psychology and Behaviour,* 14**,** 484-493.

Birrell, S. A., Young, M. S., Jenkins, D. P. & Stanton, N. A. 2011. Cognitive Work Analysis for safe and efficient driving. *Theoretical Issues in Ergonomics Science,* 13**,** 430-449.

Birrell, S. A., Young, M. S. & Weldon, A. M. 2010. Delivering smart driving feedback through a haptic pedal. *In:* Martin Anderson FIEHF, E. a. C.

(ed.) *Proceedings of the International Conference on Contemporary Ergonomics and Human Factors 2010.* Keele, UK: Taylor & Francis.

Birrell, S. A., Young, M. S. & Weldon, A. M. 2013. Vibrotactile pedals: provision of haptic feedback to support economical driving. *Ergonomics,* 56**,** 282-292.

Blake, J. 1999. Overcoming the 'value-action gap' in environmental policy: Tensions between national policy and local experience. *Local Environment,* 4**,** 257-278.

Boer, E. R. & Goodrich, M. A. 2005. Behavioral entropy as a measure of human operator misunderstanding. *In:* Noldus, L. P. J. J., Grieco, F., Loijens, L. W. S. & Zimmerman, P. H. (eds.) *5th International Conference on Methods and Techniques in Behavioral Research.* Wageningen, The Netherlands.

Boer, E. R., Hildreth, E. C. & Goodrich, M. A. 1998. A Driver Model of Attention Management and Task Scheduling: Satisficing decision making with dynamic mental models. *17th European Annual Conference on Human Decision Making and Manual Control.* Valenciennes, France.

Boer, E. R. & Hoedemaeker, M. 1998. Modeling driver behavior with different degrees of automation: A hierarchical decision framework of interacting mental models. *Conference on human decision making and manual control.* Valenciennes.

Boer, E. R., Ward, N. J., Manser, M. P. & Kuge, N. 2005. Driver-model-based assessment of behavioral adaptation. *Proceedings of JSAE Spring.* Yokohama, Japan.

Borden, R. J. & Francis, J. L. 1978. Who cares about ecology? Personality and sex differences in environmental concern. *Journal of Personality,* 46**,** 190-203.

Boriboonsomsin, K., Vu, A. & Barth, M. 2010. Eco-driving: pilot evaluation of driving behavior changes among US drivers. *Faculty Research.* University of California Transportation Center.

Bower, G. & Morrow, D. 1990. Mental models in narrative comprehension. *Science,* 247**,** 44-48.

Boyle, L. N. & Lee, J. D. 2010. Using driving simulators to assess driving safety. *Accident Analysis & Prevention,* 42**,** 785-787.

Brett, G. S. 1921. *Medieval & Early Modern Period,* London, UK, George Allen and Unwin.

Brewer, P. R., Graf, J. & Willnat, L. 2003. Priming or Framing: Media Influence on Attitudes Toward Foreign Countries. *Gazette: The International Journal for Communication Studies,* 65**,** 493-508.

Brookhuis, K., Waard, D. D. & Mulder, B. E. N. 1994. Measuring driving performance by car-following in traffic. *Ergonomics,* 37**,** 427-434.

Brunswik, E. 1934. *Wahrnehmung und Gegenstandswelt: Grundlegung einer Psychologie vom Gegenstand her,* Leipzig, Germany, F. Deuticke.

Brunswik, E. 1956. *Perception and the representative design of psychological experiments,* Berkeley and Los Angeles, California, Univ of California Press.

Camerer, C., Issacharoff, S., Loewenstein, G., O'donoghue, T. & Rabin, M. 2003. Regulation for Conservatives: Behavioral Economics and the Case for" Asymmetric Paternalism". *University of Pennsylvania Law Review,* 151**,** 1211-1254.

Cameron, M. H. & Elvik, R. 2010. Nilsson's Power Model connecting speed and road trauma: Applicability by road type and alternative models for urban roads. *Accident Analysis & Prevention,* 42**,** 1908-1915.
Chapman, L. 2007. Transport and climate change: a review. *Journal of Transport Geography,* 15**,** 354-367.
Chapman, P., Underwood, G. & Roberts, K. 2002. Visual search patterns in trained and untrained novice drivers. *Transportation Research Part F: Traffic Psychology and Behaviour,* 5**,** 157-167.
Charmaz, K. 2006. *Constructing grounded theory: A practical guide through qualitative analysis,* Thousand Oaks, CA, Sage.
Charniak, E. 1972. *Toward a model of children's story comprehension.* Doctoral Dissertation, Massachusetts Institute of Technology.
Chiang, D. P., Brooks, A. M. & Weir, D. H. 2001. An experimental study of destination entry with an example automobile navigation system. *Society of Automotive Engineers Special Publication.* SAE Technical Paper.
Chisholm, S. L., Caird, J. K., Lockhart, J., Fern, L. & Teteris, E. 2007. Driving performance while engaged in MP-3 player interaction: Effects of practice and task difficulty on PRT and eye movements. *4th International Driving Symposium on Human Factors in Driver Assessment, Training, and Vehicle Design.* Washington D.C.
Christie, I. & Jarvis, L. 2001. How green are our values? *In:* Park, A., Curtice, J., Thomson, K., Jarvis, L. & Bromley, C. (eds.) *British Social Attitudes: The 18th Report.* London.
Coe, R. 2002. *It's the effect size, stupid: What effect size is and why it is important* [Online]. Leeds, UK: University of Leeds. Available: http://www.leeds.ac.uk/educol/documents/00002182.htm [Accessed 20 October 2015].
Cole-Lewis, H. & Kershaw, T. 2010. Text Messaging as a Tool for Behavior Change in Disease Prevention and Management. *Epidemiologic Reviews,* 32**,** 56-69.
Collins English Dictionary. 2015. *Collins English Dictionary - Complete & Unabridged* [Online]. HarperCollins Publishers. Available: http://www.collinsdictionary.com/dictionary/english/instantiation [Accessed 08 July 2015].
Cotter, S. & Mogilka, A. 2007. HUMANIST: Methodologies for the assessment of ITS in terms of driver appropriation process over time. *Deliverable E.6.*
Crandall, B., Klein, G. A. & Hoffman, R. R. 2006. *Working Minds: A Practitioner's Guide to Cognitive Task Analysis,* Massachusetts, MIT Press.
Cristea, M., Paran, F. & Delhomme, P. 2012. The role of Motivations for eco-driving and Social Norms on behavioural Intentions Regarding Speed Limits and Time Headway. *World Academy of Science, Engineering and Technology,* 6**,** 918-923.
Davis, D. R. 1958. Human errors and transport accidents. *Ergonomics,* 2**,** 24-33.
Davis, F. D. 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly,* 13**,** 319-340.
Davis, G. A. 2002. Is the claim that 'variance kills' an ecological fallacy? *Accident Analysis & Prevention,* 34**,** 343-346.

de Boer, R. J. & Badke-Schaub, P. 2013. Interaction Between Emotions and Mental Models in Engineering and Design Activities. *In:* Fukuda, S. (ed.) *Emotional Engineering 2.* London, UK: Springer

de Bruin, W. B., Downs, J. S., Fischhoff, B. & Palmgren, C. 2007. Development and Evaluation of an HIV/AIDS Knowledge Measure for Adolescents Focusing on Misconceptions. *Journal of HIV/AIDS Prevention in Children & Youth,* 8**,** 35-57.

de Groot, S., de Winter, J. C. F., García, J. M. L., Mulder, M. & Wieringa, P. A. 2011. The Effect of Concurrent Bandwidth Feedback on Learning the Lane-Keeping Task in a Driving Simulator. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 53**,** 50-62.

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.

Delicado, A. 2012. Environmental education technologies in a social void: the case of 'Greendrive'. *Environmental Education Research,* 18**,** 831-843.

Denney, D. R. 1973. Reflection and impulsivity as determinants of conceptual strategy. *Child Development,* 44**,** 614-623.

Denney, N. W. & Connors, G. J. 1974. Altering the Questioning Strategies of Preschool Children. *Child Development,* 45**,** 1108-1112.

Dietz, T., Gardner, G. T., Gilligan, J., Stern, P. C. & Vandenbergh, M. P. 2009. Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. *Proceedings of the National Academy of Sciences,* 106**,** 18452-18456.

Dingus, T. A., Hulse, M. C., Antin, J. F. & Wierwille, W. W. 1989. Attentional demand requirements of an automobile moving-map navigation system. *Transportation Research Part A: General,* 23**,** 301-315.

Dingus, T. A., Klauer, S. G., Neale, V. L., Petersen, A., Lee, S. E., Sudweeks, J., Perez, M. A., Hankey, J., Ramsey, D., Gupta, S., Bucher, C., Doerzaph, Z. R., Jermeland, J. & Knipling, R. R. 2006. The 100-Car Naturalistic Driving Study: Phase II—Results of the 100-Car Field Experiment. *DOT HS 810 593.* Springfield, Virginia: NHTSA.

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**,** 413-422.

Dogan, E., Steg, L. & Delhomme, P. 2011. The influence of multiple goals on driving behavior: The case of safety, time saving, and fuel saving. *Accident Analysis & Prevention,* 43**,** 1635-1643.

El-Shawarby, I., Ahn, K. & Rakha, H. 2005. Comparative field evaluation of vehicle cruise speed and acceleration level impacts on hot stabilized emissions. *Transportation Research Part D: Transport and Environment,* 10**,** 13-30.

Elvik, R. 2013. A re-parameterisation of the Power Model of the relationship between the speed of traffic and the number of accidents and accident victims. *Accident Analysis & Prevention,* 50**,** 854-860.

Elvik, R., Christensen, P. & Amundsen, A. 2004. Speed and road accidents. *An evaluation of the Power Model. TØI report.* Oslo, Norway: The Institute of Transport Economics (TOI)

Engström, J., Johansson, E. & Östlund, J. 2005. Effects of visual and cognitive load in real and simulated motorway driving. *Transportation Research Part F: Traffic Psychology and Behaviour,* 8**,** 97-120.

Erb, H.-P., Bioy, A. & Hilton, D. J. 2002. Choice preferences without inferences: Subconscious priming of risk attitudes. *Journal of Behavioral Decision Making,* 15**,** 251-262.

Ericsson, E. 2001. Independent driving pattern factors and their influence on fuel-use and exhaust emission factors. *Transportation Research Part D: Transport and Environment,* 6**,** 325-345.

Ericsson, K. A. & Fox, M. C. 2011. Thinking aloud is not a form of introspection but a qualitatively different methodology: reply to Schooler (2011). *Psychological bulletin,* 137**,** 351-354.

Ericsson, K. A. & Simon, H. A. 1980. Verbal reports as data. *Psychological review,* 87**,** 215-251.

Eriksson, G. & Svenson, O. 2012. Driving faster or slower? *In:* Stanton, N. A. (ed.) *Advances in Human Aspects of Road and Rail Transportation.* Boca Raton, FL: CRC Press.

Eriksson, G., Svensson, O. & Eriksson, L. 2013. The time-saving bias : judgements, cognition and perception. *Judgment and decision making,* 8**,** 492-497.

European Commission 2007. Communication from the Commission to the Council and the European Parliament 6 Results of the review of the Community Strategy to reduce CO2 emissions from passenger cars and light-commercial vehicles Brussels: Commission of the European Communities.

European Environment Agency 2014. Annual European Union greenhouse gas inventory 1990–2012 and inventory report 2014. *EEA Technical report.* Luxembourg.

European Environment Agency. 2015. *National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism* [Online]. Copenhagen, Denmark. Available: http://www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer [Accessed 01 August 2014].

Evans, L. 1979. Driver Behavior Effects on Fuel Consumption in Urban Driving. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 21**,** 389-398.

Fazio, R. H. 1986. How do attitudes guide behavior. *In:* Sorrentino, R. M. & Tory, E. (eds.) *Handbook of motivation and cognition: Foundations of social behavior.* New York, NY: The Guilford Press.

Fazio, R. H., Roskos-Ewoldsen, D. R. & Powell, M. C. 1994. Attitudes, perception, and attention. *In:* Kitayama, P. M. N. S. (ed.) *The heart's eye: Emotional influences in perception and attention.* San Diego, CA, US: Academic Press.

Feltovich, P. J., Bradshaw, J. M., Clancey, W. J. & Johnson, M. 2007. Toward an ontology of regulation: Socially-based support for coordination in human and machine joint activity. *7th International Workshop on Engineering Societies in the Agents World, ESAW 2006.* Dublin.

FESTA. 2014. *FESTA Handbook, Version 5 (Field opErational teSt supportT Action)* [Online]. FOT-Net. Available: http://wiki.fot-

net.eu/index.php/FESTA_Handbook [Accessed 19 October 2015 2015].
Fischer, C. 2008. Feedback on household electricity consumption: a tool for saving energy? *Energy Efficiency,* 1**,** 79-104.
Fischer, M. & Lotz, S. 2014. Is Soft Paternalism Ethically Legitimate? - The Relevance of Psychological Processes for the Assessment of Nudge-Based Policies. *Cologne Graduate School Working Paper Series.* Cologne, Germany: Cologne Graduate School in Management, Economics and Social Sciences.
Fiske, S. T. & Taylor, S. E. 1984. *Social cognition,* Reading, MA, Addison-Wesley.
Fiske, S. T. & Taylor, S. E. 2013. *Social cognition: From brains to culture,* London, UK, Sage.
Fitts, P. M. 1964. Perceptual-motor skill learning. *In:* Melton, A. W. (ed.) *Categories of human learning.* New York: Academic Press.
Fjeldsoe, B. S., Marshall, A. L. & Miller, Y. D. 2009. Behavior Change Interventions Delivered by Mobile Telephone Short-Message Service. *American Journal of Preventive Medicine,* 36**,** 165-173.
Flynn, R., Bellaby, P. & Ricci, M. 2009. The 'value-action gap' in public attitudes towards sustainable energy: the case of hydrogen energy. *The Sociological Review,* 57**,** 159-180.
Ford, P., Hodges, N. J. & Williams, A. M. 2005. Online Attentional-Focus Manipulations in a Soccer-Dribbling Task: Implications for the Proceduralization of Motor Skills. *Journal of Motor Behavior,* 37**,** 386-394.
Fors, C., Kircher, K. & Ahlström, C. 2015. Interface design of eco-driving support systems – Truck drivers' preferences and behavioural compliance. *Transportation Research Part C: Emerging Technologies,* 58, Part D**,** 706-720.
Fox, M. C., Ericsson, K. A. & Best, R. 2011. Do procedures for verbal reporting of thinking have to be reactive? A meta-analysis and recommendations for best reporting methods. *Psychological bulletin,* 137**,** 316.
Funkhouser, D. & Chrysler, S. T. 2007. Assessing Driver Distraction Due to In-vehicle Video Systems Through Field Testing at the Pecos Research and Testing Center. *Report No. SWUTC/07/473700-00082-1.* College Station, TX: Southwest Region University Transportation Center, Texas Transportation Institute, Texas A&M University System.
Garnham, A. 1997. Representing information in mental models. *In:* Conway, M. A. (ed.) *Cognitive models of memory.* Cambridge, MA: MIT Press.
Geller, E. S., Paterson, L. & Talbott, E. 1982. A behavioral analysis of incentive prompts for motivating seat belt use. *Journal of Applied Behavior Analysis,* 15**,** 403-413.
Geller, E. S., Wylie, R. G. & Farris, J. C. 1971. An Attempt at Applying Prompting and Reinforcement Toward Pollution Control. *American Psychological Association Meeting 79th Annual Convention.* Washington, D.C.
Gentner, D. & Schumacher, R. M. 1986. Use of structure-mapping theory for complex systems. *Proceedings of the 1986 IEEE international conference on systems, man, and cybernetics.*

Georgeon, O., Henning, M. J., Bellet, T. & Mille, A. 2007. Creating cognitive models from activity analysis: A knowledge engineering approach to car driver modeling. *International Conference on Cognitive Modeling.* Ann Arbor, Michigan: Taylor & Francis/Psychology Press.

Gettman, D. & Head, L. 2003. Surrogate Safety Measures from Traffic Simulation Models. *Transportation Research Record: Journal of the Transportation Research Board,* 1840**,** 104-115.

Gibbs, N. 2012. *Your life is fully mobile* [Online]. New York, NY: Time. Available: http://techland.time.com/2012/08/16/your-life-is-fully-mobile/ [Accessed 20 November 2014.

Gifford, R. 1997. *Environmental Psychology: Principles and Practice,* Needham Heights, MA, Allyn & Bacon.

Gilbert, D., Lee-Kelley, L. & Barton, M. 2003. Technophobia, gender influences and consumer decision-making for technology-related products. *European Journal of Innovation Management,* 6**,** 253-263.

Glaser, S., Nouveliere, L. & Lusetti, B. 2007. Speed Limitation Based on an Advanced Curve Warning System. *Intelligent Vehicles Symposium, 2007 IEEE.* Istanbul, Turkey: IEEE.

Gold, J., Lim, M., Hellard, M., Hocking, J. & Keogh, L. 2010. What's in a message? Delivering sexual health promotion to young people in Australia via text messaging. *BMC Public Health,* 10.

Goldenbeld, C., Levelt, P. B. M. & Heidstra, J. 2000. Psychological perspectives on changing driver attitude and behaviour. *Recherche - Transports - Sécurité,* 67**,** 65-81.

Goodrich, M., Stirling, W. & Frost, R. 1996. A satisficing fuzzy logic controller. *Proceedings of the Fifth IEEE International Conference on Fuzzy Systems.* New Orleans, LA IEEE.

Goodrich, M. A. & Boer, E. R. 1998. Semiotics and mental models: Modeling automobile driver behavior. Intelligent Control (ISIC), 1998. Held jointly with IEEE International Symposium on Computational Intelligence in Robotics and Automation (CIRA), Intelligent Systems and Semiotics (ISAS), Proceedings, 1998 Gaithersburg, MD. IEEE, 771-776.

Goodrich, M. A. & Boer, E. R. 2003. Model-based human-centered task automation: a case study in ACC system design. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on,* 33**,** 325-336.

Goodrich, M. A., Boer, E. R. & Inoue, H. 1998a. Brake initiation and braking dynamics: A human-centered study of desired ACC characteristics. *Basic Research, Nissan Research and Development, Inc.* Citeseer.

Goodrich, M. A., Stirling, W. C. & Frost, R. L. 1998b. A theory of satisficing decisions and control. *Systems, Man and Cybernetics, Part A: Systems and Humans, IEEE Transactions on,* 28**,** 763-779.

Graesser, A. C., Singer, M. & Trabasso, T. 1994. Constructing inferences during narrative text comprehension. *Psychological review,* 101**,** 371-395.

Graving, J. S., Manser, M. P. & Becic, E. 2010. Reduction in Fuel Consumption Depends on the Fuel Economy Display and Driver Sex: An Observed Interaction. *Adjunct Proceedings of the Second International Conference on Automotive User Interfaces and*

*Interactive Vehicular Applications (AutomotiveUI 2010).* Pittsburgh, Pennsylvania, USA.

Greenhouse, S. W. & Geisser, S. 1959. On methods in the analysis of profile data. *Psychometrika,* 24**,** 95-112.

Greeno, J. G. 1989. Situations, mental models, and generative knowledge. *In:* Klahr, D. & Kotovsky, K. (eds.) *Complex Information Processing: The Impact of Herbert A. Simon.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Guo, F., Klauer, S., Hankey, J. & Dingus, T. 2010. Near Crashes as Crash Surrogate for Naturalistic Driving Studies. *Transportation Research Record: Journal of the Transportation Research Board,* 2147**,** 66-74.

Haigney, D. E., Taylor, R. G. & Westerman, S. J. 2000. Concurrent mobile (cellular) phone use and driving performance: task demand characteristics and compensatory processes. *Transportation Research Part F: Traffic Psychology and Behaviour,* 3**,** 113-121.

Halasz, F. G. & Moran, T. P. 1983. Mental models and problem solving in using a calculator. *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems.* Boston, Massachusetts, USA: ACM.

Halford, G. S. 1993. *Children's understanding: The development of mental models,* Hillsdale, NJ, Lawrence Erlbaum Associates.

Harvey, J., Thorpe, N. & Fairchild, R. 2013. Attitudes towards and perceptions of eco-driving and the role of feedback systems. *Ergonomics,* 56**,** 507-521.

Hasan, B. & Ahmed, M. U. 2007. Effects of interface style on user perceptions and behavioral intention to use computer systems. *Computers in Human Behavior,* 23**,** 3025-3037.

Hasvold, P. E. & Wootton, R. 2011. Use of telephone and SMS reminders to improve attendance at hospital appointments: a systematic review. *Journal of Telemedicine and Telecare,* 17**,** 358-364.

Hatfield, J. & Chamberlain, T. 2005. The effects of in-vehicle audiovisual display units on simulated driving. Sydney, Australia: NSW Injury Risk Management Research Centre, University of New South Wales.

Haworth, N. & Symmons, M. 2001. The relationship between fuel economy and safety outcomes. Victoria, Australia: Monash University Accident Research Centre.

Heijs, W. J. M. 2006. Technology and behavior. *In:* Verbeek, P.-P. & Slob, A. (eds.) *User Behavior and Technology Development.* Springer Netherlands.

Hellström, E. 2005. *Explicit use of road topography for model predictive cruise control in heavy trucks.* Linköping University, Department of Electrical Engineering.

Hendrickx, L. & Uiterkamp, A. J. M. S. 2006. Technology and behavior: The Case of Passenger Transport. *In:* Verbeek, P.-P. & Slob, A. (eds.) *User Behavior and Technology Development.* Springer Netherlands.

Henning, M. J., Georgeon, O., Wynn, T. & Krems, J. F. 2008. Modelling driver behaviour in order to infer the intention to change lanes. *Proceedings of European Conference on Human Centred Design for Intelligent Transport Systems.*

Herr, P. M. 1986. Consequences of priming: Judgment and behavior. *Journal of Personality and Social Psychology,* 51**,** 1106-1115.

Herr, P. M. 1989. Priming Price: Prior Knowledge and Context Effects. *Journal of Consumer Research,* 16**,** 67-75.

Herr, P. M., Sherman, S. J. & Fazio, R. H. 1983. On the consequences of priming: Assimilation and contrast effects. *Journal of Experimental Social Psychology,* 19**,** 323-340.

Hibberd, D., Jamson, H., Jamson, S., Pauwelussen, J., Obdeijn, C., Stuiver, A., Hof, T., van der Weerdt, C., Paradies, G., Brignolo, R., Barberi, C., Iviglia, A. & Mazza, M. 2013. D12.2: Multi-modal in-vehicle and nomadic device eco-driving support for car drivers and truck drivers. *ecoDriver Project.*

Hibberd, D. L., Jamson, H. & Jamson, S. L. 2015. The design of an in-vehicle assistance system to support eco-driving. *Transportation Research Part C: Emerging Technologies,* 58**,** 732–748.

Higgins, E. T. 1989. Knowledge accessibility and activation: Subjectivity and suffering from unconscious sources. *In:* Uleman, J. S. & Bargh, J. A. (eds.) *Unintended thought.* New York, NY: The Guilford Press.

Higgins, E. T., Bargh, J. A. & Lombardi, W. J. 1985. Nature of priming effects on categorization. *Journal of Experimental Psychology: Learning, Memory, and Cognition,* 11**,** 59-69.

Higgins, E. T., King, G. A. & Mavin, G. H. 1982. Individual construct accessibility and subjective impressions and recall. *Journal of Personality and Social Psychology,* 43**,** 35-47.

Hines, J. M., Hungerford, H. R. & Tomera, A. N. 1987. Analysis and Synthesis of Research on Responsible Environmental Behavior: A Meta-Analysis. *The Journal of Environmental Education,* 18**,** 1-8.

Hiraoka, T., Nishikawa, S. & Kawakami, H. 2011. Driver-assistance system to encourage spontaneous eco-driving behavior. *Proceedings of 18th World Congress on Intelligent Transport Systems.* Orlando, Florida.

Hiraoka, T., Nishikawa, S., Yamabe, S. & Matsumoto, S. 2010. Sustainability verification of eco-driving behavior based on driving simulator experiments. *Proceedings of 17th World Congress on Intelligent Transport Systems.*

Hof, T. 2008. Strategies to influence habitual road user behaviour. 21st ITCT Workshop Proceedings (4), 2008 Riga, Latvia.

Hof, T., Conde, L., Garcia, E., Iviglia, A., Jamson, S., Jopson, A., Lai, F., Merat, N., Nyberg, J., Rios, S., Sanchez, D., Schneider, S., Seewald, P., Weerdt, C. v. d., Wijn, R. & Zlocki, A. 2012. D11.1: A state of the art review and user's expectations. *ecoDriver project.*

Hofstetter, A. M., Vargas, C. Y., Kennedy, A., Kitayama, K. & Stockwell, M. S. 2013. Parental and provider preferences and concerns regarding text message reminder/recall for early childhood vaccinations. *Preventive Medicine,* 57**,** 75-80.

Horberry, T., Anderson, J., Regan, M. A., Triggs, T. J. & Brown, J. 2006. Driver distraction: The effects of concurrent in-vehicle tasks, road environment complexity and age on driving performance. *Accident Analysis & Prevention,* 38**,** 185-191.

Horrey, W. J., Lesch, M. F. & Garabet, A. 2009. Dissociation between driving performance and drivers' subjective estimates of performance and workload in dual-task conditions. *Journal of Safety Research,* 40**,** 7-12.

Hutchins, E. 1995. *Cognition in the wild,* Cambridge, Massachusetts, The MIT Press.
International Air Transport Association. 2014. *New IATA Passenger Forecast Reveals Fast-Growing Markets of the Future* [Online]. Montreal, Canada: IATA. Available: http://www.iata.org/pressroom/pr/Pages/2014-10-16-01.aspx [Accessed 28 October 2015].
International Transport Forum 2007. Workshop on eco-driving: Findings and messages for policy makers. Paris, France.
Iqbal, S. T., Zheng, X. S. & Bailey, B. P. 2004. Task-evoked pupillary response to mental workload in human-computer interaction. *CHI '04 Extended Abstracts on Human Factors in Computing Systems.* Vienna, Austria: ACM.
Iyengar, S. & Kinder, D. R. 1987. *News that matters: Television and American Opinion,* Chicago, IL, The University of Chicago Press.
Jackson, T. 2005. Motivating sustainable consumption. *A review of evidence on consumer behaviour and behavioural change. A report to the Sustainable Development Research Network, Surrey: Centre for Environmental Strategies.* Guildford, Surrey, UK.
Jamson, A. H., Hibberd, D. L. & Merat, N. 2015a. Interface design considerations for an in-vehicle eco-driving assistance system. *Transportation Research Part C: Emerging Technologies,* 58, Part D**,** 642-656.
Jamson, S., Chorlton, K. & Carsten, O. 2012. Could Intelligent Speed Adaptation make overtaking unsafe? *Accident Analysis & Prevention,* 48**,** 29-36.
Jamson, S., Lai, F. & Jamson, H. 2010. Driving simulators for robust comparisons: A case study evaluating road safety engineering treatments. *Accident Analysis & Prevention,* 42**,** 961-971.
Jamson, S. L., Hibberd, D. L. & Jamson, A. H. 2015b. Drivers' ability to learn eco-driving skills; effects on fuel efficient and safe driving behaviour. *Transportation Research Part C: Emerging Technologies,* 58, Part D**,** 657-668.
Jamson, S. L. & Jamson, A. H. 2010. The validity of a low-cost simulator for the assessment of the effects of in-vehicle information systems. *Safety Science,* 48**,** 1477-1483.
Jelsma, J. 2006. Technology and behavior. *In:* Verbeek, P.-P. & Slob, A. (eds.) *User Behavior and Technology Development.* Springer Netherlands.
Johansson-Stenman, O. & Martinsson, P. 2006. Honestly, why are you driving a BMW? *Journal of Economic Behavior & Organization,* 60**,** 129-146.
Johansson, H., Färnlund, J. & Engström, C. 1999. Impact of EcoDriving on emissions and fuel consumption: A pre-study. *Swedish National Road Administration Report* Borlange, Sweden.
Johansson, H., Gustafsson, P., Henke, M. & Rosengren, M. 2003. Impact of EcoDriving on emissions. *Transport and Air Pollution. Proceedings from the 12th Symposium.* Avignon.
Johnson-Laird, P. N. 1983. *Mental models: Towards a cognitive science of language, inference, and consciousness,* Cambridge, UK, Cambridge University Press.

Johnson-Laird, P. N. 1988. *The computer and the mind: An introduction to cognitive science,* Cambridge, Massachusetts, Harvard University Press.

Johnson-Laird, P. N. & Byrne, R. M. 1990. Meta-logical problems: knights, knaves, and rips. *Cognition,* 36**,** 69-84.

Johnson-Laird, P. N. & Byrne, R. M. 1991. *Deduction,* Hove, UK, Lawrence Erlbaum Associates, Inc.

Johnson-Laird, P. N. & Byrne, R. M. 2002. Conditionals: a theory of meaning, pragmatics, and inference. *Psychological review,* 109**,** 646-678.

Josephson, W. L. 1987. Television violence and children's aggression: Testing the priming, social script, and disinhibition predictions. *Journal of Personality and Social Psychology,* 53**,** 882-890.

Junell, J. & Tumer, K. 2013. Robust predictive cruise control for commercial vehicles. *International Journal of General Systems,* 42**,** 776-792.

Kafer, K. L. & Hunter, M. 1997. On testing the face validity of planning/problem-solving tasks in a normal population. *Journal of the International Neuropsychological Society,* 3**,** 108-119.

Kamal, M. A. S., Mukai, M., Murata, J. & Kawabe, T. 2010. On board eco-driving system for varying road-traffic environments using model predictive control. *Control Applications (CCA), 2010 IEEE International Conference on.* Yokohama, Japan.

Kant, I. & Erdmann, B. 1884. *Immanuel Kant's Kritik der reinen Vernunft,* Hamburg, Germany, Verlag von Leopold Voss.

Kiefer, R., Cassar, M., Flannagan, C., LeBlanc, D., Palmer, M., Deering, R. & Shulman, M. 2003. Forward Collision Warning Requirements Project: Refining the CAMP Crash Alert Timing Approach by Examining" Last-Second" Braking and Lane Change Maneuvers Under Various Kinematic Conditions. U.S. Department of Transportation.

Kieras, D. E. & Bovair, S. 1984. The Role of a Mental Model in Learning to Operate a Device. *Cognitive Science,* 8**,** 255-273.

Kim, S. Y. & Kim, Y. S. 2012. A Virtual Driving System for Enhancing Efficient Driving Style. *International Journal of Multimedia and Ubiquitous Engineering,* 7**,** 291-296.

Kircher, A., Vogel, K., Törnros, J., Bolling, A., Nilsson, L., Patten, C., Malmström, T. & Ceci, R. 2004. Mobile telephone simulator study. *Report No. 969A.* Sweden: Swedish National Road and Transport Research Institute.

Klouda, G. V. & Cooper, W. E. 1990. Information search following damage to the frontal lobes. *Psychological Reports,* 67**,** 411-416.

Knowles, M., Scott, H. & Baglee, D. 2012. The effect of driving style on electric vehicle performance, economy and perception. *International Journal of Electric and Hybrid Vehicles,* 4**,** 228-247.

Kollmuss, A. & Agyeman, J. 2002. Mind the Gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research,* 8**,** 239-260.

Laberge, J., Scialfa, C., White, C. & Caird, J. 2004. Effects of Passenger and Cellular Phone Conversations on Driver Distraction. *Transportation Research Record: Journal of the Transportation Research Board,* 1899**,** 109-116.

Laine, M. & Butters, N. 1982. A preliminary study of the problem-solving strategies of detoxified long-term alcoholics. *Drug and Alcohol Dependence,* 10**,** 235-242.

Lajunen, T., Karola, J. & Summala, H. 1997. Speed and acceleration as measures of driving style in young male drivers. *Perceptual and Motor Skills,* 85**,** 3-16.

Large, D. R. & Burnett, G. E. 2014. The effect of different navigation voices on trust and attention while using in-vehicle navigation systems. *Journal of Safety Research,* 49**,** 69-75.

Latinus, M. & Belin, P. 2011. Human voice perception. *Current Biology,* 21**,** R143-R145.

Lave, C. A. 1985. Speeding, Coordination, and the 55 MPH Limit. *The American Economic Review,* 75**,** 1159-1164.

Lee, D. N. 1976. A theory of visual control of braking based on information about time-to-collision. *Perception,* 5**,** 437-459.

Lee, J. D., Young, K. L. & Regan, M. A. 2009. Defining driver distraction. *In:* Regan, M. A., Lee, J. D. & Young, K. L. (eds.) *Driver distraction: Theory, effects, and mitigation.* Boca Raton, FL: CRC Press.

Lee, S.-S., Lim, Y.-k. & Lee, K.-p. 2011. A long-term study of user experience towards interaction designs that support behavior change. *CHI '11 Extended Abstracts on Human Factors in Computing Systems.* Vancouver, BC, Canada: ACM.

Levi, I. 1983. *The enterprise of knowledge: An essay on knowledge, credal probability, and chance*, MIT press.

Lombardi, R. 2003. Mental models and language registers in the psychoanalysis of psychosis: An overview of a thirteen-year analysis2. *The International Journal of Psychoanalysis,* 84**,** 843-863.

Lynam, T., Mathevet, R., Etienne, M., Stone-Jovicich, S., Leitch, A., Jones, N., Ross, H., Du Toit, D., Pollard, S. & Biggs, H. 2012. Waypoints on a journey of discovery: mental models in human environment interactions. *Ecology and Society: a journal of integrative science for resilience and sustainability,* 17**,** 23-33.

Man, W., Bie, J. & van Arem, B. 2010. User needs in Green ITS: the Result of a Questionnaire Survey on Dutch and Japanese drivers. *Proceedings 17th ITS World Congress* Busan, South Korea.

Mandel, N. & Johnson, Eric J. 2002. When Web Pages Influence Choice: Effects of Visual Primes on Experts and Novices. *Journal of Consumer Research,* 29**,** 235-245.

Manser, M. P., Ward, N. J., Kuge, N. & Boer, E. R. 2004. Influence of a Driver Support System on Situation Awareness and Information Processing in Response to Lead Vehicle Braking. *Proceedings of the Human Factors and Ergonomics Society 48th Annual Meeting.* New Orleans, LA.

Martens, M. H. 2011. Change detection in traffic: Where do we look and what do we perceive? *Transportation Research Part F: Traffic Psychology and Behaviour,* 14**,** 240-250.

Martens, M. H. & Fox, M. R. J. 2007. Do familiarity and expectations change perception? Drivers' glances and response to changes. *Transportation Research Part F: Traffic Psychology and Behaviour,* 10**,** 476-492.

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.
Martin, L. L. 1986. Set/reset: Use and disuse of concepts in impression formation. *Journal of Personality and Social Psychology,* 51**,** 493-504.
McCall, J. C., Achler, O., Trivedi, M. M., Haue, J. B., Fastrez, P., Forster, D., Hollan, J. D. & Boer, E. 2004. A collaborative approach for human-centered driver assistance systems. *Proceedings of the 7th International IEEE Conference on Intelligent Transportation Systems, 2004* Washington, D.C., USA.
McCarthy, J. 2007. What is artificial intelligence? *Technical report.* Computer Science Department, Stanford University.
McGehee, D. V., Mazzae, E. N. & Baldwin, G. H. S. 2000. Driver Reaction Time in Crash Avoidance Research: Validation of a Driving Simulator Study on a Test Track. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting.*
McGregor, W. B. 2009. *Linguistics: an introduction,* London, Continuum.
McIlroy, R. C. & Stanton, N. A. 2014. Climbing Decision Ladders To Analyse Ecodriving: The First Rung on the Way to Fuel-Efficient Driving. *In:* Ahram, T., Karwowski, W. & Marek, T. (eds.) *5th International Conference on Applied Human Factors and Ergonomics AHFE.* Krakow, Poland.
McIlroy, R. C. & Stanton, N. A. 2015. Ecological Interface Design Two Decades On: Whatever Happened to the SRK Taxonomy? *Human-Machine Systems, IEEE Transactions on,* 45**,** 145-163.
McIlroy, R. C., Stanton, N. A., Harvey, C. & Robertson, D. 2013. Sustainability, transport and design: reviewing the prospects for safely encouraging eco-driving. *Proceedings of the 5th International Conference on Automotive User Interfaces and Interactive Vehicular Applications.* Eindhoven, The Netherlands: ACM.
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.
Mensing, F., Bideaux, E., Trigui, R. & Tattegrain, H. 2013. Trajectory optimization for eco-driving taking into account traffic constraints. *Transportation Research Part D: Transport and Environment,* 18**,** 55-61.
Merat, N., Jamson, A. H., Lai, F. C. H. & Carsten, O. 2012. Highly Automated Driving, Secondary Task Performance, and Driver State. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 54**,** 762-771.
Merrill, M. D. 2000. Knowledge objects and mental models. *Advanced Learning Technologies, 2000. IWALT 2000. Proceedings. International Workshop on.*
Meschtscherjakov, A., Wilfinger, D., Scherndl, T. & Tscheligi, M. 2009. Acceptance of future persuasive in-car interfaces towards a more economic driving behaviour. *Proceedings of the 1st International Conference on Automotive User Interfaces and Interactive Vehicular Applications (Automotive UI).* Essen, Germany: ACM.

Michon, J. A. 1985. A critical view of driver behavior models: What do we know, what should we do. *In:* Evans, L. & Schwing, R. C. (eds.) *Human behavior and traffic safety.* New York, NY: Plenum.
Miles, M. B. & Huberman, A. M. 1994. *Qualitative data analysis,* Thousand Oaks, CA, Sage.
Miller, G. A. 1956. The magical number seven, plus or minus two: some limits on our capacity for processing information. *Psychological review,* 63**,** 81-97.
Milot, M.-H., Marchal-Crespo, L., Green, C., Cramer, S. & Reinkensmeyer, D. 2010. Comparison of error-amplification and haptic-guidance training techniques for learning of a timing-based motor task by healthy individuals. *Experimental Brain Research,* 201**,** 119-131.
Minsky, M. 1974. A framework for representing knowledge. *In:* Winston, P. (ed.) *The Psychology of Computer Vision.* New York: McGraw-Hill.
Moray, N. 1987. Intelligent aids, mental models, and the theory of machines. *International Journal of Man-Machine Studies,* 27**,** 619-629.
Morgan, M. G., Fischhoff, B., Bostrom, A. & Atman, C. J. 2002. *Risk communication: A mental models approach,* Cambridge, UK, Cambridge University Press.
Morrow, D. G., Bower, G. H. & Greenspan, S. L. 1989. Updating situation models during narrative comprehension. *Journal of Memory and Language,* 28**,** 292-312.
Morrow, D. G., Greenspan, S. L. & Bower, G. H. 1987. Accessibility and situation models in narrative comprehension. *Journal of Memory and Language,* 26**,** 165-187.
Moscovici, S. 1961. *La psychanalyse, son image et son public,* Paris, France, Presses Universitaire de France.
Mosher, F. A. & Hornsby, J. R. 1966. On asking questions. *In:* Bruner, J. S. (ed.) *Studies in cognitive growth.* New York, NY: John Wiley & Sons.
Nairn and Partners, Leonie Segal Economic Consultants & Watson 1994. Victorian transport externalities study 3. Strategies for reducing emissions of greenhouse gases and ozone precursors from land-based transport. Melbourne: Report prepared for EPA.
Newell, A. 1973. Productions systems: Models of control structures. *In:* Chase, W. G. (ed.) *Visual information processing.* New York, NY: Academic Press.
Newell, A. & Simon, H. A. 1961. GPS, a program that simulates human thought. *In:* Feigenbaum, E. A. & Feldman, J. (eds.) *Computers and Thought.* New York, NY: McGraw-Hill.
Nilsson, G. 2004. Traffic safety dimensions and the power model to describe the effect of speed on safety. Lund, Sweden: Lund University.
Nisbett, R. E. & Ross, L. 1980. *Human inference: Strategies and shortcomings of social judgment,* Englewood Cliffs, NJ, Prentice-Hall Inc.
Norman, D. A. 1983. Some observations on mental models. *In:* Gentner, D. & Stevens, A. L. (eds.) *Mental models.* Hillsdale, New Jersey, USA: Lawrence Erlbaum Associates Inc.
Nouvelière, L., Mammar, S. & Luu, H. T. 2012. Energy saving and safe driving assistance system for light vehicles: Experimentation and analysis. *Networking, Sensing and Control (ICNSC), 2012 9th IEEE International Conference on.* Beijing.

Nozaki, K., Hiraoka, T., Takada, S., Shiose, T. & Kawakami, H. 2012. Effect of active effort in eco-driving support system on proficiency of driving skill. *SICE Annual Conference (SICE), 2012 Proceedings of.*

O'Hanlon, J., Haak, T., Blaauw, G. & Riemersma, J. 1982. Diazepam impairs lateral position control in highway driving. *Science,* 217**,** 79-81.

Oaksford, M. & Chater, N. 1991. Against Logicist Cognitive Science. *Mind & Language,* 6**,** 1-38.

Ogden, P. G. 2001. Human computer interaction in complex process control: developing structured mental models that allow operators to perform effectively. *Human Interfaces in Control Rooms, Cockpits and Command Centres, 2001. People in Control. The Second International Conference on (IEE Conf. Publ. No. 481).*

Olivier, J. G., Janssens-Maenhout, G., Muntean, M. & Peters, J. A. 2013. Trends in global CO2 emissions: 2013 Report. The Hague, the Netherlands: PBL Netherlands Environmental Assessment Agency

Päätalo, M., Peltola, H. & Kallio, M. 2001. Intelligent speed adaptation–effects on driving behaviour. *Proceedings of Traffic Safety on Three Continents Conference.* Moscow, Russia.

Patten, C. J. D., Kircher, A., Östlund, J. & Nilsson, L. 2004. Using mobile telephones: cognitive workload and attention resource allocation. *Accident Analysis & Prevention,* 36**,** 341-350.

Payne, B. K. & Iannuzzi, J. L. B. 2012. Automatic and controlled decision making: A process dissociation perspective. *In:* Krueger, J. I. (ed.) *Social judgment and decision making.* New York, NY: Taylor & Francis.

Perkins, D. N. & Salomon, G. 1992. Transfer of learning. *In:* Husen, T. & Postlethwaite, T. (eds.) *The international encyclopedia of education.* Oxford, UK: Elsevier Science Ltd.

Phillips, A. L., Kumar, D., Patel, S. & Arya, M. 2014. Using text messages to improve patient–doctor communication among racial and ethnic minority adults: An innovative solution to increase influenza vaccinations. *Preventive Medicine,* 69**,** 117-119.

Pianelli, C., Saad, F. & Abric, J. 2007. Social representations and acceptability of LAVIA (French ISA system). *14th world congress of Intelligent Transport Systems.* Beijing, Peoples' Republic of China.

Putnam, H. 1975. Is semantics possible? *In:* Putnam, H. (ed.) *Mind, Language and Reality. Philosophical Papers.* Cambridge, UK: Cambridge University Press

Radvansky, G. A. & Zacks, R. T. 1997. The retrieval of situation-specific information. *In:* Conway, M. A. (ed.) *Cognitive models of memory.* London, UK: MIT Press.

Rasmussen, J. 1979. Notes on human error analysis and prediction. *In:* Apostolakis, G. & Volta, G. (eds.) *Synthesis and Analysis Methods for Safety and Reliability Studies.* London, UK: Plenum Press.

Rasmussen, J. 1983. Skills, rules, and knowledge; signals, signs, and symbols, and other distinctions in human performance models. *Systems, Man and Cybernetics, IEEE Transactions on,* SMC-13**,** 257-266.

Rasmussen, J. & Vicente, K. J. 1989. Coping with human errors through system design: implications for ecological interface design. *International Journal of Man-Machine Studies,* 31**,** 517-534.

Rexeis, M., Hausberger, S., Riemersma, I., Tartakovsky, L., Zvirin, Y. & Cornelis, E. 2005. Heavy-duty vehicle emissions. *Final report of WP 400.* ARTEMIS (Assessment and Reliability of Transport Emission Models and Inventory Systems); DGTREN Contract 1999-RD.10429.
Rice, R. E. & Atkin, C. K. 2002. Communication Campaigns: Theory, Design, Implementation, and Evaluation. *In:* Bryant, J. & Zillmann, D. (eds.) *Media effects: Advances in theory and research.* 2 ed. Mahwah, NJ: Lawrence Erlbaum Associates.
Richalet, J. 1993. Industrial applications of model based predictive control. *Automatica,* 29**,** 1251-1274.
Rimini-Döring, M., Keinath, A., Nodari, E., Palma, F., Toffetti, A., Floudas, N., Bekiaris, E., Portouli, V. & Panou, M. 2005. Considerations on Test Scenarios. *AIDE deliverable 2.1.3*
Rips, L. J. 1989. The psychology of knights and knaves. *Cognition,* 31**,** 85-116.
Risto, M. & Martens, M. H. 2013. Factors influencing compliance to tactical driver advice: An assessment using a think-aloud protocol. *Intelligent Transportation Systems - (ITSC), 2013 16th International IEEE Conference on.* The Hague, The Netherlands: IEEE.
Robinson, D. N. 1995. *An intellectual history of psychology,* New York, NY, Macmillan.
Rook, A. M. & Hogema, J. H. 2005. Effects of human-machine interface design for intelligent speed adaptation on driving behavior and acceptance. *Transportation Research Record: Journal of the Transportation Research Board,* 1937**,** 79-86.
Roskos-Ewoldsen, D. R., Roskos-Ewoldsen, B. & Carpentier, F. R. D. 2002. Media priming: A synthesis. *In:* Bryant, J. & Zillmann, D. (eds.) *Media effects: Advances in theory and research.* Hillsdale, NJ: Lawrence Erlbaum Associates.
Rouzikhah, H., King, M. & Rakotonirainy, A. 2013. Examining the effects of an eco-driving message on driver distraction. *Accident Analysis & Prevention,* 50**,** 975-983.
Rumelhart, D. E. 1980. Schemata: The building blocks of cognition. *In:* Spiro, R. J., Bruce, B. C. & Brewer, W. F. (eds.) *Theoretical issues in reading comprehension: perspectives from cognitive psychology, linguistics, artificial intelligence, and education.* Hillsdale, NJ: Erlbaum.
Salvucci, D. D., Markley, D., Zuber, M. & Brumby, D. P. 2007. iPod distraction: Effects of portable music-player use on driver performance. *Proceedings of the SIGCHI conference on Human factors in computing systems.* New York, NY: ACM Press.
Samaras, Z. & Ntziachristos, L. 1998. Average hot emission factors for passenger cars and light duty trucks. *Methodologies for estimating air pollutant emissions from transport (MEET) - Deliverable 7.* Thessaloniki, Greece: Lab. of Applied Thermodynamics, Aristotle University of Thessaloniki.
Sarason, I. G. & Minard, J. 1962. Test anxiety, experimental instructions, and the Wechsler Adult Intelligence Scale. *Journal of Educational Psychology,* 53**,** 299-302.

Schank, R. C. & Abelson, R. P. 1977. *Scripts, plans, goals and understanding: An inquiry into human knowledge structures,* Hillsdale, NJ, Lawrence Erlbaum Associates.

Schießl, C., Fricke, N. & Staubach, M. Identification and analysis of motivators for eco-friendly driving within the eCoMove project. 8th ITS European Congress Intelligent Mobility, 6 - 9th June 2011 2010 Lyon, France.

Schön, D. A. 1983. *The reflective practitioner: How professionals think in action,* New York, NY, Basic books.

Schooler, J. W. 2011. Introspecting in the spirit of William James: comment on Fox, Ericsson, and Best (2011). *Psychological Bulletin,* 137**,** 345-350.

Schwartz, S. H. 1977. Normative Influences on Altruism. *In:* Berkowitz, L. (ed.) *Advances in experimental social psychology.* New York: Academic Press.

Schweitzer, L., Brodrick, C.-J. & Spivey, S. E. 2008. Truck driver environmental and energy attitudes – an exploratory analysis. *Transportation Research Part D: Transport and Environment,* 13**,** 141-150.

Seligman, C., Becker, L. J. & Darley, J. M. 1981. Encouraging residential energy conservation through feedback. *In:* Baum, A. & Singer, J. E. (eds.) *Advances in environmental psychology.* Hillsdale, New Jersey: Lawrence Erlbaum Associates.

Semenza, J. C., Hall, D. E., Wilson, D. J., Bontempo, B. D., Sailor, D. J. & George, L. A. 2008. Public Perception of Climate Change: Voluntary Mitigation and Barriers to Behavior Change. *American Journal of Preventive Medicine,* 35**,** 479-487.

Shai, I., Schwarzfuchs, D., Henkin, Y., Shahar, D. R., Witkow, S., Greenberg, I., Golan, R., Fraser, D., Bolotin, A., Vardi, H., Tangi-Rozental, O., Zuk-Ramot, R., Sarusi, B., Brickner, D., Schwartz, Z., Sheiner, E., Marko, R., Katorza, E., Thiery, J., Fiedler, G. M., Blüher, M., Stumvoll, M. & Stampfer, M. J. 2008. Weight Loss with a Low-Carbohydrate, Mediterranean, or Low-Fat Diet. *New England Journal of Medicine,* 359**,** 229-241.

Shinar, D. & Compton, R. 2004. Aggressive driving: an observational study of driver, vehicle, and situational variables. *Accident Analysis & Prevention,* 36**,** 429-437.

Siero, S., Boon, M., Kok, G. & Siero, F. 1989. Modification of driving behavior in a large transport organization: A field experiment. *Journal of Applied Psychology,* 74**,** 417-423.

Simmons, R. F. 1972. Semantic networks: their computation and use for understanding English sentences. Austin, TX: Department of Computer Sciences and Computer-Assisted Instruction Laboratory, University of Texas.

Simon, H. A. 1969. *The sciences of the artificial,* Cambridge, MA, MIT press.

Smith, E. R. & Semin, G. R. 2004. Socially situated cognition: Cognition in its social context. *Advances in experimental social psychology,* 36**,** 57-121.

Smith, R. 1982. Wilhelm Wundt Resurrected. *The British Journal for the History of Science,* 15**,** 285-293.

Srull, T. K. & Wyer, R. S. 1979. The role of category accessibility in the interpretation of information about persons: Some determinants and implications. *Journal of Personality and Social Psychology,* 37**,** 1660-1672.

Srull, T. K. & Wyer, R. S. 1980. Category accessibility and social perception: Some implications for the study of person memory and interpersonal judgments. *Journal of Personality and Social Psychology,* 38**,** 841-856.

Stachl, C. & Buehner, M. 2015. Show me how you drive and I'll tell you who you are – Recognizing gender using automotive driving parameters. *In:* Stanton, N. A. & Landry, S. (eds.) *5th International Conference on Applied Human Factors and Ergonomics AHFE 2014,.* Las Vegas, NV.

Steg, L., van den Berg, A. E. & De Groot, J. I. 2012. *Environmental psychology: An introduction,* Chichester, UK, BPS Blackwell.

Stern, D. N., Sander, L. W., Nahum, J. P., Harrison, A. M., Lyons-Ruth, K., Morgan, A. C., Bruschweiler-Stern, N. & Tronick, E. Z. 1998. Non-interpretive mechanisms in psychoanalytic therapy: The "something more" than interpretation. *International journal of Psychoanalysis,* 79**,** 903-921.

Stern, P. C. 2000. New Environmental Theories: Toward a Coherent Theory of Environmentally Significant Behavior. *Journal of Social Issues,* 56**,** 407-424.

Stern, P. C., Dietz, T. & Kalof, L. 1993. Value orientations, gender, and environmental concern. *Environment and behavior,* 25**,** 322-348.

Stillwater, T. 2011. Comprehending Consumption: The Behavioral Basis and Implementation of Driver Feedback for Reducing Vehicle Energy Use. Davis, California: Institute of Transportation Studies, University of California, Davis.

Stillwater, T. & Kurani, K. 2011. Field Test of Energy Information Feedback. *Transportation Research Record: Journal of the Transportation Research Board,* 2252**,** 7-15.

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.

Stockwell, M. S., Kharbanda, E., Martinez, R., Vargas, C. Y., Vawdrey, D. K. & Camargo, S. 2012. Effect of a text messaging intervention on influenza vaccination in an urban, low-income pediatric and adolescent population: A randomized controlled trial. *JAMA,* 307**,** 1702-1708.

Stockwell, M. S., Westhoff, C., Kharbanda, E. O., Vargas, C. Y., Camargo, S., Vawdrey, D. K. & Castaño, P. M. 2013. Influenza Vaccine Text Message Reminders for Urban, Low-Income Pregnant Women: A Randomized Controlled Trial. *American Journal of Public Health,* 104**,** e7-e12.

Stradling, S., Anable, J., Anderson, T. & Cronberg, A. 2008. Car use and climate change: do we practise what we preach? *In:* Park, A., Curtice, J., Thomson, K., Phillips, M., Johnson, M. & Clery, E. (eds.) *British Social Attitudes: the 24th Report.* London: Sage.

Stunkel, L. & Grady, C. 2011. More than the money: A review of the literature examining healthy volunteer motivations. *Contemporary Clinical Trials,* 32**,** 342-352.

Sullman, M. J. M., Dorn, L. & Niemi, P. 2015. Eco-driving training of professional bus drivers – Does it work? *Transportation Research Part C: Emerging Technologies,* 58, Part D**,** 749-759.

Summala, H. 1988. Risk control is not risk adjustment: the zero-risk theory of driver behaviour and its implications. *Ergonomics,* 31**,** 491-506.

Summala, H. 2005. Traffic psychology theories: towards understanding driving behaviour and safety efforts. *In:* Underwood, G. (ed.) *Traffic and Transport Psychology.* St. Louis, MO: Elsevier.

Summala, H. 2007. Towards Understanding Motivational and Emotional Factors in Driver Behaviour: Comfort Through Satisficing. *In:* Cacciabue, P. C. (ed.) *Modelling driver behaviour in automotive environments: Critical Issues in Driver Interactions with Intelligent Transport Systems.* London, UK: Springer

Sunstein, C. R. 2014. Nudging: A Very Short Guide. *Journal of Consumer Policy,* In press.

Syme, G. J., Seligman, C., Kantola, S. J. & Macpherson, D. K. 1987. Evaluating a Television Campaign to Promote Petrol Conservation. *Environment and behavior,* 19**,** 444-461.

Takahashi, H. & Kuroda, K. 1996. A study on mental model for inferring driver's intention. *Decision and Control, 1996., Proceedings of the 35th IEEE Conference on.* Kobe.

Tarkiainen, M., Peltola, H., Koskinen, S., Salenius, S. & Kiuru, J. 2013. Trafisafe - Supporting learning in novice drivers. *20th ITS World Congress.* Tokyo, Japan.

Tarkiainen, M., Peltola, H., Koskinen, S. & Schirokoff, A. 2014. Trafisafe - Feedback for novice drivers. *10th ITS European Congress.* Helsinki, Finland.

Taylor, M., Lynam, D. & Baruya, A. 2000. The effects of drivers' speed on the frequency of road accidents. *TRL Report 421.* Berkshire, UK: Transport Research Laboratory Crowthorne.

Taylor, M. C., Baruya, A. & Kennedy, J. V. 2002. The relationship between speed and accidents on rural single-carriageway roads. *TRL report TRL511.* Crowthorne, Berkshire: TRL.

Tertoolen, G., van Kreveld, D. & Verstraten, B. 1998. Psychological resistance against attempts to reduce private car use. *Transportation Research Part A: Policy and Practice,* 32**,** 171-181.

Thaler, R. H. & Sunstein, C. R. 2008. *Nudge: Improving decisions about health, wealth, and happiness,* New Haven, CT, Yale University Press.

Thøgersen, J. 2004. A cognitive dissonance interpretation of consistencies and inconsistencies in environmentally responsible behavior. *Journal of Environmental Psychology,* 24**,** 93-103.

Tijerina, L., Parmer, E. & Goodman, M. J. 1998. Driver workload assessment of route guidance system destination entry while driving: A test track study. *Proceedings of the 5th ITS World Congress.* Seoul, South Korea.

Trick, L. M. & Enns, J. T. 2009. A Two-Dimensional Framework for Understanding the Role of Attentional Selection in Driving. *In:* Castro,

C. (ed.) *Human factors of visual and cognitive performance in driving.* Boca Raton, Florida: CRC Press.
Trommer, S., Ho, x & ltl, A. 2012. Perceived usefulness of eco-driving assistance systems in Europe. *Intelligent Transport Systems, IET,* 6**,** 145-152.
Tsimhoni, O., Smith, D. & Green, P. 2004. Address Entry While Driving: Speech Recognition Versus a Touch-Screen Keyboard. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 46**,** 600-610.
Tulusan, J., Staake, T. & Fleisch, E. 2012. Providing eco-driving feedback to corporate car drivers: what impact does a smartphone application have on their fuel efficiency? *Proceedings of the 2012 ACM Conference on Ubiquitous Computing.* Pittsburgh, Pennsylvania: ACM.
UK Government. 2015a. *Motorways (253 to 273)* [Online]. London, UK: Government Digital Service. Available: https://www.gov.uk/motorways-253-to-273/lane-discipline-264-to-266 [Accessed 26 September 2015].
UK Government. 2015b. *Speed limits* [Online]. London, UK: Government Digital Service. Available: https://www.gov.uk/speed-limits [Accessed 26 September 2015].
University of Leeds. 2013. *University of Leeds Driving Simulator (UoLDS)* [Online]. Leeds, UK: University of Leeds. Available: http://www.uolds.leeds.ac.uk/ [Accessed 16 September 2013].
US Department of Energy (USDOE) 1980. Driver Efficiency Program Manual : Techniques and Resources for Conserving Transportation Fuel. Washington, D.C.: The Office.
USEPA 2011. Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2011 US Environmental Protection Agency.
Vallacher, R. R. & Wegner, D. M. 1987. What do people think they're doing? Action identification and human behavior. *Psychological review,* 94**,** 3-15.
van der Voort, M., Dougherty, M. S. & van Maarseveen, M. 2001. A prototype fuel-efficiency support tool. *Transportation Research Part C: Emerging Technologies,* 9**,** 279-296.
van Dijk, T. A. & Kintsch, W. 1983. *Strategies of discourse comprehension,* New York, NY, Academic Press
van Elslande, P. & Faucher-Alberton, L. 1997. When expectancies become certainties: A potential adverse effect of experience. *In:* Rothengatter, T. & Vanya, E. (eds.) *Traffic and transport psychology. Theory and application.* Tarrytown, NY: Pergamon.
van Erp, J. B. F. & van Veen, H. A. H. C. 2004. Vibrotactile in-vehicle navigation system. *Transportation Research Part F: Traffic Psychology and Behaviour,* 7**,** 247-256.
van Oijen, R. 1996. *De autotypekeuze van zakelijke automobilisten,* Groningen, the Netherlands, Interfacultaire Vakgroep Energie en Milieukunde (IVEM), Rijksuniversiteit Groningen.
van Someren, M. W., Barnard, Y. F. & Sandberg, J. A. 1994. *The think aloud method: A practical guide to modelling cognitive processes,* London, Academic Press Limited.

Venables, L. & Fairclough, S. H. 2009. The influence of performance feedback on goal-setting and mental effort regulation. *Motivation and Emotion,* 33**,** 63-74.
Vlek, C. & Steg, L. 2007. Human Behavior and Environmental Sustainability: Problems, Driving Forces, and Research Topics. *Journal of Social Issues,* 63**,** 1-19.
Vogel, K. 2002. What characterizes a “free vehicle” in an urban area? *Transportation Research Part F: Traffic Psychology and Behaviour,* 5**,** 15-29.
Vogt, C. & Schaefer, M. 2012. Seeing things differently: Expert and consumer mental models evaluating combined oral contraceptives. *Psychology and Health,* 27**,** 1405-1425.
Vosniadou, S. & Brewer, W. F. 1992. Mental models of the earth: A study of conceptual change in childhood. *Cognitive Psychology,* 24**,** 535-585.
Wada, T., Yoshimura, K., Doi, S. I., Youhata, H. & Tomiyama, K. 2011. Proposal of an eco-driving assist system adaptive to driver's skill. *Intelligent Transportation Systems (ITSC), 2011 14th International IEEE Conference on.* Washington, DC, USA.
Wang, C., Quddus, M. A. & Ison, S. G. 2013. The effect of traffic and road characteristics on road safety: A review and future research direction. *Safety Science,* 57**,** 264-275.
Ward, N. J., Manser, M. P., de Waard, D., Kuge, N. & Boer, E. 2003. Quantifying Car following Performance as a Metric for Primary and Secondary (Distraction) Task Load: Part A — Modification of Task Parameters. *Proceedings of the 47th Annual Meeting of the Human Factors and Ergonomics Society.* Santa Monica, CA: Human Factors and Ergonomics Society.
Waters, M. H. L. & Laker, I. B. 1980. Research on Fuel Conservation for Cars. Crowthorne, England: Transport and Road Research Laboratory.
Watson, R. I. 1963. *The great psychologists: from Aristotle to Freud,* Oxford, England, Lippincott.
Weick, K. E. 1990. The Vulnerable System: An Analysis of the Tenerife Air Disaster. *Journal of Management,* 16**,** 571-593.
White, C., Fern, L., Caird, J., Kline, D., Chisholm, S., Scialfa, C. & Mayer, A. 2006. The effects of DVD modality in drivers' performance. *Proceedings of the 37th Annual Conference of the Association of Canadian Ergonomists.* Banff, Alberta, Canada.
Whitmarsh, L. 2009. Behavioural responses to climate change: Asymmetry of intentions and impacts. *Journal of Environmental Psychology,* 29**,** 13-23.
Whitmarsh, L. & O'Neill, S. 2010. Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. *Journal of Environmental Psychology,* 30**,** 305-314.
Whitten, A. & Tygar, J. D. 1999. Why Johnny can’t encrypt: A usability evaluation of PGP 5.0. *Proceedings of the 8th USENIX Security Symposium.* McGraw-Hill.
Winograd, T. 1972. Understanding natural language. *Cognitive Psychology,* 3**,** 1-191.
Wittgenstein, L. 1953. *Philosophical investigations,* New York, Macmillan.

Wuebbles, D. J. & Jain, A. K. 2001. Concerns about climate change and the role of fossil fuel use. *Fuel Processing Technology,* 71**,** 99-119.

Wyer Jr, R. S. & Radvansky, G. A. 1999. The comprehension and validation of social information. *Psychological review,* 106**,** 89-118.

Wynn, T., Richardson, J. H., Georgeon, O., Bellet, T., Henning, M. & Krems, J. 2008. Cognitive activity modelling: a case study of lane change schemas and sensation seeking. *In:* Brusque, C. (ed.) *Proceedings of the European Conference on Human Interface Design for Intelligent Transport Systems.* Lyon: Humanist Publications.

Yagil, D. 1998. Gender and age-related differences in attitudes toward traffic laws and traffic violations. *Transportation Research Part F: Traffic Psychology and Behaviour,* 1**,** 123-135.

Young, K. L., Salmon, P. M. & Cornelissen, M. 2012. Missing links? The effects of distraction on driver situation awareness. *Safety Science,* In Press**,** 36-43.

Young, M. S., Birrell, S. A. & Stanton, N. A. 2011. Safe driving in a green world: A review of driver performance benchmarks and technologies to support ‘smart’ driving. *Applied Ergonomics,* 42**,** 533-539.

Zwaan, R. A. & Radvansky, G. A. 1998. Situation models in language comprehension and memory. *Psychological bulletin,* 123**,** 162-185.

# 8 Appendix A

## Results for the analysis of the questionnaire following Drive 1 in study 2

**Table 42: Significant differences in questionnaire items† in the Drive 1 session**

| Question | Males | Female | Differences | p | U/Z |
|---|---|---|---|---|---|
| I have a good understanding of innovations in vehicle automation | 3.65 | 2.08 | Male > Female | < .001 | 144/ -4.696 |
| I am happy to pay more for a car that has good information and entertainment systems | 3.22 | 2.44 | Male > Female | .012 | 293.5/ -2.510 |
| It is important to me that my driving style is dynamic | 3.43 | 2.60 | Male > Female | .006 | 280/ -2.722 |
| Drivers generally drive safely | 2.97 | 2.40 | Male > Female | .014 | 301.5/ -2.449 |
| I have a good understanding of what driving behaviours lead to saving fuel | 4.22 | 3.52 | Male > Female | .001 | 250.5/ -3.224 |
| Drivers generally know how to drive safely | 3.38 | 2.44 | Male > Female | < .001 | 227/ -3.527 |
| I am happy to pay a bit more for fuel if it means I can drive the way I want | 2.81 | 2.28 | Male > Female | .041 | 327.5/ -2.041 |

| Question | Males | Female | Differences | p | U/Z |
|---|---|---|---|---|---|
| In-car information and entertainment systems are important to me | 3.46 | 2.44 | Male > Female | .001 | 238/ -3.349 |
| Most drivers think it is a good idea to drive safely | 3.86 | 3.16 | Male > Female | .012 | 302/ -2.517 |
| I buy certain products to increase my status | 2.36 | 1.60 | Male > Female | .011 | 286/ -2.530 |
| I find partially and fully automated cars innovative | 3.73 | 2.56 | Male > Female | < .001 | 192.5/ -4.022 |
| It is important to me what my friends think about my car | 2.53 | 1.60 | Male > Female | .002 | 251/ -3.072 |
| I have a good understanding of what driving behaviours are environmentally friendly | 4.16 | 3.52 | Male > Female | .002 | 262/ -3.086 |
| Ranking: When you drive what do you think about? – fuel-efficient driving behaviours | 3.54 | 2.84 | Male > Female | .023 | 308.5/ -2.269 |

† Likert scale from 1 (strongly disagree) to 5 (strongly agree)