The influence of mood and cognitive load on driver performance: using multiple measures to assess safety

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.

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Abstract

Emotions and moods are an inevitable part of human life. Previous research suggests that positive and negative moods affect human performance in many aspects: decision making, perception, reasoning and memory. The influence of mood on drivers' behaviour has been studied to a less extent and mainly with respect to negative emotions. The studies reported in this thesis are based on psychological theories regarding the differences in the effects of positive and negative moods on information processing and mind wandering.

The thesis describes two studies: a desktop study and a driving simulator study, which measure drivers' responses to the actions of other traffic, their observational patterns and driving behaviours in a variety of scenarios. The effects of neutral, happy, sad and angry moods were studied. The simulator study also investigated possible ways to disconnect drivers' minds from mood induced mind wandering by using different types of cognitive load.

The results suggest that mood valence and arousal have different effects on driving safety, with negative moods resulting in the most dangerous driving. In order to draw conclusions about the effect of mood, a combination of multiple measures (e.g. glance patterns, driving performance and drivers' physiological measures) should be analysed. The results also suggest that some amount of cognitive load, applied while driving, can have a positive effect on drivers' attention.

Further research is needed to establish the amount and type of the cognitive load necessary to improve drivers' ability to maintain their attention on the driving task. Studies with a larger number of participants and field studies are needed to validate the findings. It is suggested that the findings are used to improve in-car assistance systems able to both detect the harmful effects of a driver's emotional state and re-direct their attention to the primary task of driving.

List of abbreviations

1. ANS – autonomous nervous system
2. CNS – central nervous system
3. CH – ‘car hazard’. This includes PG and PS
4. JH – ‘junction hazard’. This includes CFL and CFR
5. CFL – ‘car from the left’. Car approaching junction from the left side road
6. CFR – ‘car from the right’. Car approaching junction from the right
7. PG - parked car in a group of parked cars
8. PS – single car, parked on a roadside
9. DRL – driving-related cognitive load
10. NDRL – non-driving related cognitive load
11. NONE – driving condition when no-load was applied
12. EDA – electro dermal activity
13. HR – heart rate
14. SCL – skin conductance level
15. SCR – skin conductance response
16. BRT – brake reaction time
17. TH – time headway
18. VF – visual field of view. The visual field is the total area in which objects can be seen in the side (peripheral) vision when vision is focused on a central point.

Glossary

1. Attentional shift – the ability of a driver to switch attention from one object to another
2. Baseline mood – participants' mood prior to the experiment
3. Baseline measurements – measurements taken before mood induction
4. Car following – the situation during a drive when a drivers' speed choice is restricted by the speed of the lead vehicle
5. Disconnection – drivers' attention disconnection from mind wandering
6. Glance measures – measures collected using an eye tracker. These include: eye fixation durations, number of eye fixations, the horizontal width of fixation spread
7. Emotion – has the same meaning as 'mood' in this thesis
8. Free drive – the situation when drivers' speed choice is restricted only by legal requirements and their hazard awareness
9. Information processing – Drivers' ability to perceive and process road related information from the surrounding environment
10. Mood – Includes 4 moods: neutral, happy, sad and angry.
11. Reaction times – refers to the total time between stimulus presentation till action

Contents

List of Tables

List of Figures

Chapter 1 Introduction

Driving has become one of the most utilised everyday tasks. For many people it is difficult to imagine life without driving or just using vehicles for getting from A to B. Sadly, road accidents are a persistent and inevitable part of driving. Moreover, road accidents are the most common cause of accidental death (World Health Organisation, 2017). Regardless of all the actions taken, in the UK alone 24,620 people were killed or seriously injured in the year ending June 2016, up by 2 percent compared to the previous year (Office for National Statistics, 2016). This highlights the importance of understanding every aspect that could directly or indirectly influence driving and road safety.

Amongst the most important factors contributing to crash likelihood are drivers' mood and attention (Dula & Ballard, 2003; He, Becic, Lee, & McCarley, 2011; Hu, Tian-Yi, Xie, & Li, 2013; Young, Regan, & Hammer, 2007). Both of these factors can equally contribute to either safer driving or accident likelihood, depending on their momentary influence on drivers' behaviours and reactions. Indeed, aggressive driving and road rage are well-known causes of traffic accidents (Ulleberg, 2001), as well as drivers' inattention (Underwood, 2007; Underwood, Chapman, Berger, & Crundall, 2003; Wang, Knipling, & Goodman, 1996). Moreover, attention and mood can interact with each other in a way that can be either beneficial or detrimental to driving safety (Eherenfreund-Hager, Taubman–Ben-Ari, Toledo, & Farah, 2017; Lee, Lee, & Boyle, 2007). The effect of drivers' mood and emotional state on their attention is an important characteristic, which requires further understanding to increase driving safety.

1.1 Gaps in the existing knowledge

Driving has become an inevitable part of everyday life for many people. By the end of March 2016, 36.7 million vehicles were licensed for use on roads in Great Britain (Office for National Statistics, 2016). Moreover, everyday services are reliant on transport for many important tasks, such as commuting to and from work, shopping, entertaining and obtaining help from emergency services. Inevitably, transport is used regardless of drivers' momentary emotional state or prolonged mood. Therefore it is important to understand how different emotions and moods can influence driving style, and whether this influence can be mediated by manipulating drivers' attention.

Emotions and moods will always be a part of human life, thus their influence on every social and interactive aspect is highly important. Moreover, to date, there is no research investigating how drivers' mood and emotional state interacts with drivers' attention. Hence, can a driver in a sad mood be distracted from their internal thoughts by influencing their attentional focus by e.g., asking them driving-related questions or general questions related to their habits? How does the interaction of attention and mood affect drivers' performance?

1.2 Highlights of relevant research

1.2.1 Influence of drivers' mood and emotions on driving safety

Research to date has mostly focused on drivers' trait characteristics and emotions caused by traffic and their effect on drivers' behaviour. For instance, Abdu, Shinar, and Meiran (2012) found that angry drivers more often crossed amber traffic lights and tended to drive faster, and Arnett, Offer, and Fine (1997) report a direct relationship between trait anger and exceeding the speed limit.

Positive emotions and their effect on driving safety have been investigated less and even so, most of these studies were not directly related to drivers' emotions, but their seating comfort (De Looz, Kuijt-Evers, & Dieen, 2003) and roadside furniture (Cackowski & Nasar, 2003). Positive emotions appeared to have a positive effect as self-reported by drivers. A recent driving simulator study, conducted by Eherenfreund-Hager et al. (2017), revealed some differences in driving styles not only with regards to drivers' emotional valence but also with regards to their physical arousal. They report that relaxing positive emotional state, which they refer to as 'affect', led drivers to less risky driving styles as compared to arousing positive and negative affect conditions.

1.2.2 Influence of drivers’ attention on driving safety

Attention has been widely studied in psychological research in general and in driving-related research in particular. Loss of attention has been named as one of the main causes of car accidents (Office for National Statistics, 2016). Therefore, a clear understanding of factors influencing drivers’ attention is necessary and vital for road safety.

Drivers’ attention is affected by various factors; experience (Crundall et al. 2012), poor road conditions and poor visibility (Konstantopoulos, 2009) as well as various distractors (He et al. 2011). The ability to anticipate traffic behaviour increases with experience (Crundall et al. 2012), whereby more experienced drivers have different road search patterns permitting for more efficient use of attention. As attentional resources are limited, it is important to prioritise the more informative parts of the road from others where situational changes are less likely to occur (Crundall et al. 2003).

Distractors can impair the ability to perform efficient observations (Caird, Simmons, Wiley, Johnston, & Horrey, 2018; Kircher & Ahlstrom, 2017; Ranney, Harbluk, & Noy, 2005). Avoiding these distractors is not always under a driver’s control. Although an activity such as talking on a mobile phone or tuning a radio while driving can be avoided, should a driver wish to do so, external-to-vehicle distractors, such as roadside advertisements, are not as easy to ignore (Wallace 2003).

Therefore, the extent to which drivers can concentrate on driving and ignore distractors is one of the main determinants of driving safety. The ability to prioritise between tasks while driving makes the best use of limited attentional resources. However, this level of performance is not always possible to maintain. Although avoiding distractors, which are under drivers’ control, should not be a problem, ways of avoiding intruders of drivers’ attention in the form of mind wandering should be thoroughly investigated.

One of the factors that could affect drivers’ attention may well be drivers’ mood and emotional state. This topic of the interaction between mood and attention has been neglected with respect to road safety, despite a lot of research being devoted to understanding this relationship in other areas. Emotions affect individual judgment about self and the surrounding environment (Blanchette and Richards 2010). Anxious individuals make negative interpretations about ambiguous scenarios, consider levels of risk being higher for self than for others and anticipate worst consequences from negative events for self (Butler and Mathews 1983). Emotion influences how people estimate the likelihood of a positive or negative outcome in relationships (Schwarz, 2000). Participants in a positive mood estimate more likelihood of long-term happiness or marriage, whereas participants in a negative mood estimate more likelihood of separation and being victims of a crime (Constans and Mathews 1993).

1.3 Novelty and original contribution

With regards to drivers’ emotions, previous studies have mostly been concerned with self-reports, drivers’ trait characteristics and emotions caused by traffic situations. Nevertheless, individuals rarely drive in a neutral mood, unaffected by any emotion. Therefore, it is important to understand how this underlying emotion can influence driving safety. Previous research also did not provide support of objectivity of emotional assessment using physiological measurements as well as eye tracking methodologies. This thesis intends to address this deficiency by assessing drivers’ emotions using physiological measurements supplemented with self-reports. With regards to drivers’ emotions, previous research was focussed on the effect of negative emotions on driving safety (Abdu et al., 2012; Cai, Lin, & Mourant, 2007; Stephens & Groeger, 2006; Wells-Parker et al., 2002). The influence of positive emotions on driving safety has not received much attention so far.

Moreover, there is no research to date using cognitive load as a tool to manipulate drivers’ attention in a way that could increase driving safety. The simulator study is innovative therefore, the first one in investigating a types of cognitive load that would be able to redirect drivers’ attention to road related variables. The manipulation of both aspects, drivers' emotions and drivers' attention, permits the investigation of each of these variables affects driving safety, as well as the relationship between them.

1.4 Practical implications

Understanding human mental workload in different situations, especially while driving, is extremely useful in designing technologies capable of fast and non-invasive measurement of this workload before it becomes too high or too low for safe driving. High emotional disruption could result in attentional distraction from the road (mind wandering), which lowers situational awareness and leads to performance decline (Borghini, Astolfi, Vecchiato, Mattia, & Babiloni, 2014). The assessment of drivers' emotional state and identification of their functional ability could help in planning their work-rest times and minimise driving-related errors. Moreover, it could help to identify and avoid drivers' attentional lapses causing significant mental underload and overload resulting in severe performance decline with dangerous consequences (Holm, 2010).

Applying some amount of cognitive load while driving could potentially disconnect drivers from mood related mind wandering and day dreaming (Smallwood, Fitzgerald, Miles, & Phillips, 2009). This thesis is the first to investigate whether cognitive load, in the form of driving related or non-driving related questions, asked while driving, can re-direct drivers' attention to the primary task of driving.

Automotive manufacturers are working towards the development of more comfortable and safer cars. Modern cars feature various driver assistance systems, such as cruise control, lane keeping assistance systems and workload managers. Workload manager systems, for example, attempts to assess whether the driver is overloaded or distracted and in such case can delay vehicle system messages. For example, can divert an incoming call to an answer machine in busy traffic situations, such as at junctions or sharp road bends (Green, 2004). Workload managers have been effective for drivers of different age groups and in situations with different traffic demands

(Teh, Jamson, & Carsten, 2018). However, they do not take into account drivers' momentary emotions and, in these situations, a driver's reaction could be substantially affected. Thus, combining a workload manager with an emotion recognition system (Kim, Bang, & Kim, 2004) could substantially improve driving safety.

1.5 Thesis objectives

This thesis focuses on the relationship between drivers' emotion and cognitive load from three perspectives; hazard perception, driving behaviour and attentional switch.

Objective One: identify the relationship between drivers' emotional state and their response time to hazards.

Objective Two: identify if and how driver's behaviour changes in response to changes in their emotional state

Objective Three: explore if any negative behavioural changes found can be mediated by applying different types of cognitive load and if this cognitive load affects the positive behavioural changes.

Objective Four: identify the relationships between drivers' emotional state, their driving behaviour and their visual search patterns of the surrounding environment.

1.6 Structure of the thesis

Chapter One outlines the problem to be investigated by describing the importance of understanding influence of drivers' emotions on road and traffic safety. It briefly describes previous research, establishing the background and motivation for this thesis and finally outlines the aims of the thesis.

Chapter Two provides a literature review of emotion-related changes in driving behaviours. It also reviews literature considering drivers' attention as a factor influencing driving safety. Finally, it provides a theoretical framework for understanding the psychological basis of behaviours influenced by different emotions and role of attention in the manipulation of these behaviours.

Chapter Three defines and justifies the dependent variables used in this thesis. It documents previous findings to build a framework for the present studies.

Chapter Four describes the desktop study, which examines the reactions of drivers in various emotional states to hazardous road situations. This experiment uses a desktop computer to present potentially dangerous driving situations and uses simple measure of hazard response time. An eye tracker was used to measure drivers' glance behaviours in different emotional states.

Chapter Five describes the simulator study, which has two main aims. The first is to explore the influence of mood induced mind wandering on driving performance and drivers' glance patterns. The second aim is to explore whether different types of cognitive load can disconnect drivers from their mind wandering and redirect their attention to driving. In addition, how these types of cognitive load affect driving performance when drivers are not engaged by mind wandering is explored.

The simulator study builds on the desktop study by investigating more complex behaviours, such as speed, braking style, time headway, drivers' glance patterns, and the relationship between these parameters and drivers' mood.

Chapter Six discusses and summarises the findings of both experiments. It highlights the potential practical use of the findings and suggests directions for further research.

Chapter 2 - Emotions, attention and driving safety

The aim of this thesis is to establish the effects of emotions on drivers' attention and their driving style, and to explore how to use interventions in case of negative effects. To complete this task, firstly terms, concepts and theories used in the thesis are defined and explained (Sections 2.1 and 2.4). Further, a literature review is undertaken to understand how emotions affect decision making, memory and other aspects of human activities (Section 2.2). Sections 2.3, 2.5 and 2.6 investigate the influence of attention and mood on drivers' behaviour and their possible effects on driving safety. Finally, a theoretical background for the thesis is established and summarised (Section 2.7).

2.1 Emotion – definition and concept

The concept of emotion is wide, making it difficult to provide a precise definition. Emotions represent a substantial part of human evolutional and cultural inheritance regarding adaptation and development (Carver, 2003; Ekman & Friesen, 1971; Hammond, 2006; Izard, 1977). The role of emotion has been established in many important aspects of human life: empathy and sympathy forming human moral behaviour (Eisenberg & Miller, 1987; Hoffman, 2000), facilitating creative problem solving and defining a quality of human experience (Fredrickson & Branigan, 2005; Isen, Daubman, & Nowicki, 1987), and forming human temperament and personality (Malatesta, 1990; Watson & Clark, 1992).

The difficulty of defining emotion has been acknowledged by many authors (Kleinginna Jr & Kleinginna, 1981). Young (1975) states that the main reason for this difficulty is an abundance of viewpoints, making it virtually impossible to form a consensus, and Mandler (1980) argues that even superficially there is no acceptable definition of emotion. Even the term 'emotion' has been used differently by different researchers, sometimes implying emotion, sometimes mood or cognitive appraisal, and sometimes affect and feelings, without distinguishing between these concepts.

The difference between these concepts, however, is an important aspect of emotional research, hence must be clearly stated. Feelings have been defined as basic subjective experiences forming more complex processes named emotions (Izard, 1971). The concept of emotion includes physical and behavioural fluctuations, such as changes in breathing, surface capillaries, or heart rate (Critchley & Harrison, 2013). Moods are long lasting, diffuse, affective conditions. Emotions and moods are very similar in description but still, have significant differences. Emotions are short lived and easily affected by the environment. They are also is stronger and more extensive than mood, which is, instead, stable to changes but low in intensity (Davidson, Scherer, & Goldsmith, 2003). The concept of cognitive appraisal includes perceptual assessment of situational arousal and a stepwise response related to this action. For example, an initial appraisal of the emotional experience occurs when sensing an emotional stimulus, then the emotion is labelled, and memory is searched for preparation of control and action mechanisms to deal with the emotional situation (Plutchik, 1980).

Although the concepts of ‘mood’ and ‘emotion’ are not interchangeable, they have been used as such in contemporary research. This is due to the similarity of behaviours elicited by both of these concepts (Hu et al., 2013), partially due to ‘emotion’ being short lived and therefore easier to use in a repeated measures design (Rauscher, Shaw, & Ky, 1993). In this thesis the terms ‘emotion’ and ‘mood’ are used throughout and interchangeably; therefore, it is assumed that longer lasting moods would have the same effects on drivers’ behaviours (Hu et al., 2013).

Emotion has two important characteristics: valence and arousal (Balters & Steinert, 2015). They argue that emotional valence is a continuous array of feelings ranging from positive to negative. Emotional arousal is a state of bodily activity in response to external stimuli, which makes an individual more energetic and alert. Arousal is a response to the sympathetic nervous system indicated by increased heart rate, breathing and sweating (Levenson, 2014).

In the context of this thesis, the term ‘valence’ is used to describe polar emotional states: positive and negative. The term ‘arousal’ however, has two aspects here. One is related to emotion; it is either positive or negative emotion with high intensity. For example, a ‘happy’ emotional state is understood as a positive emotion with high energy, whereas ‘angry’ is related to a negative feeling with high energy (see Figure 1). The other use of ‘arousal’ is related to physiological arousal caused by unexpected situations (e.g. hazards) or cognitive load, which is not described in relation to any emotional valence, but is a sign of alertness. These two forms of arousal are investigated in this thesis regarding their possible influence on driving behaviours and their interaction with each other.

Low arousal in this thesis is investigated with reference to positive and negative valence. The sad mood is referred to as negative valence and low energy condition. The neutral mood is seen as low energy but positive mood. The substantial difference between the neutral and the sad moods, is the arousal level (Hill et al., 2013). Hill et al. (2013) argue that it is easy to distinguish between emotional states with high and low arousal levels, but it is difficult to differentiate between what they call ‘flat energy’ emotions, such as ‘okay’, ‘neutral’ or ‘bored’.

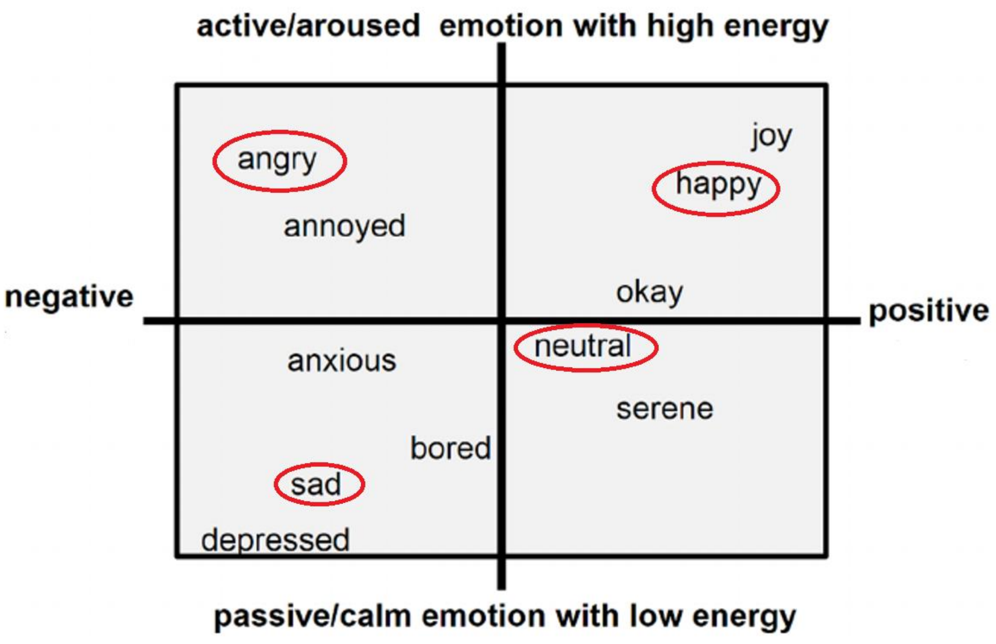


Figure 1: Activation – Evaluation emotional space. Adapted from (Hill et al., 2013)

2.2 Emotions and their role in human life

Studies on influence of emotions on human lives date back to the 19^{th} century. Darwin (1873) was the first to consider emotion as a tool for communication. Darwin regarded emotions as concepts in support for his theory of evolution. His ideas were further developed by Ekman (1992), who states that expressions of human emotions are universal and do not differ across cultures. Since first classified by Darwin, theories of emotions and their influence on human existence have constantly been studied, defined and developed.

Massey (2002) argues that emotionality preceded rationality in evolutionary sequence and, only with evolution, cognition became more important in human interactions. However, it never replaced emotionality. Instead, emotionality precedes rationality in the order of perception. External stimuli are perceived, assessed and processed emotionally well before they are cognitively appraised (LeDoux, 1998). Moreover, the actions urged by emotionality start well before rational appraisal. Massey (2002) states that the perceived stimuli pass through the thalamus and before reaching the prefrontal cortex (where rationality is processed) they pass through the amygdala, responsible for emotion processing. Thus individuals react emotionally even before the stimuli are cognitively processed. For example, if an individual is walking across the road without seeing a fast approaching car, he/she would jump or run away before conscious assessment of the danger. Massey states that this is because the input stimuli are processed by the amygdala about a quarter of a second before they reach the prefrontal cortex. Moreover, even if the functionality of the prefrontal cortex had been disabled, the individual would still jump away from the danger (Massey, 2002). Understanding these processes is important to be able to explain human behaviour, especially when humans are under the influence of their emotions.

Thompson (1994) describes emotion regulation as a process of initiating, upholding and controlling the occurrence and extent of inner feelings. However, the process of emotion regulation can be difficult and at times almost impossible (Muraven, Tice, & Baumeister, 1998). Moreover, not only are emotions difficult to control, often the form of control can be more harmful than the emotion itself (Muraven & Baumeister, 2000). For example Troy, Shallcross, and Mauss (2013) state that cognitive reappraisal, a method of emotion regulation, can either help or hurt, depending on the context. Reappraisal is beneficial when stressors are uncontrollable, but not so when stressors can be controlled (when the situation can be changed). The difficulty of emotional control and emotional prevalence in every aspect of human life makes understanding of its influence on human performance and behaviour an interesting and challenging topic.

Emotions affect many aspects of human functioning: perception, memory, decision making and reasoning. Vuilleumier, Armony, Driver, and Dolan (2001) define perception as a filter which prioritises information processing based on its momentary relevance. Hansen and Hansen (1988) found that not all emotions have the same processing speed: participants could detect an angry face among neutral faces faster than a happy face among neutral faces. These results have been explained as the threat-superiority effect and replicated a number of times (Eastwood, Smilek, & Merikle, 2001; Fox & Damjanovic, 2006). Nevertheless, other research shows that emotionally charged stimuli do not necessarily facilitate processing. For example, the phenomenon called the emotional Stroop effect shows that it takes longer to name the colour of negative adjectives, such as *ugly,* compared with the colour of positive adjectives, such as *pretty* (Pratto & John, 1991). Phaf and Kan (2007) systematically analysed emotional Stroop effect related research. They concluded a consistent processing bias with longer processing of emotional stimuli, thus strong evidence for processing automaticity of emotional words.

Since emotional events are vital to human survival, it makes sense that emotional situations are memorised stronger and in more detail. This statement is true for personal events during emergency situations, known as *flashbulb memory* (Brown & Kulik, 1977; Reisberg, Heuer, Mclean, & O’shaughnessy, 1988), as well as the emotional events when stimuli match the experienced mood, referred to as *mood-congruent memory* (Bower, 1981; Ellis & Moore, 1999). Bower (1981) explains this phenomenon by deeper processing and making more associations with mood-congruent events.

Decision making is another aspect which can be influenced by emotions. Thagard (2008) distinguished between emotional and rational decision making. Emotional decision making is more intuitive and faster, but prone to errors as they are less accurate or possibly based on irrelevant information. Rational decision making, instead, takes into account possible alternatives, pros and cons, but as a consequence is slower. In some situations, emotions can facilitate rational decision making (Damasio, 1994). Moreover, Loewenstein, Weber, Hsee, and Welch (2001) state that emotions are not separate from cognition, and as a part of it, can facilitate the decision making process.

Jung, Wranke, Hamburger, and Knauff (2014) argue that logical reasoning is affected both by participants' emotional state and the contents of the problem to be solved. They found the worst performance in a negative mood compared to a positive mood; however participants in a neutral mood outperformed a positive and a negative group responders. With respect to emotional content Jung et al. (2014) examined how participants with different phobias solved problems containing these phobias. They found that spider phobic participants' performance declined when problem content was related to spiders.

Rolls (2000) suggests that one of the most important primary function of emotion is survival. On this level the interaction between cognition and emotion can be clearly seen. Emotions narrow reaction choice and prime possible responses, but the response selection and execution are left to controlled thought processes. For example, a fearful event can trigger a fight-or-flight response, but dealing with this potential danger is responsibility of rational processing and decision making. In this way, emotions guide attention to the most important actions, helping to filter out distraction. The importance of this primary function is supported by the universality of basic emotions. Ekman (1992) distinguishes between 6 basic emotions: happiness, sadness, fear, anger, surprise and disgust. The influence of three emotions on driving safety will be studied in this thesis: happiness, sadness and anger, as these emotions together with a neutral emotional state, complete two dimensions of valence: positive and negative, and two dimensions of arousal: high and low.

Anger is an emotion that elicits a fighting response. Angry individuals are more likely to confront and act aggressively in response to the source of this emotion (Buss & Shackelford, 1997). Sadness and its prolonged version – depression disengage an individual from unattainable goals and abnegate ineffective efforts (Nesse, 2000). Depression and sadness encourage attentional focus on the problem, minimising distraction to unrelated events (Andrews & Thomson Jr, 2009). Happiness, in contrast to sadness, encourages engagement in new actions, learning new skills and forming relationships (Fredrickson, 2001).

Negative emotions have received substantial empirical attention. Seligman and Csikszentmihalyi (2014) suggest this is due to the fact that negative emotions produce many serious problems for individuals. They argue that extreme manifestations of negative emotions, such as depression, suicide, phobias and violence have severe effects not only on the affected individuals. Often the affected individuals cannot cope with their problems and help is needed from those who care for them, or are professionally trained to deal with manifestations of negative emotions. Positive emotions, instead, are associated with danger to a less extent (e.g. sensation seeking from drugs) (Fredrickson, 2013). The different effects that positive and negative emotions have on individuals' actions and cognition, have encouraged researchers to develop theories explaining these differences and their causalities. This thesis uses two of these theories to explain differences in performance and cognitive processing in different emotional states; 'broaden-and-build theory' (Fredrickson & Branigan, 2005) and 'coasting theory' (Carver, 2003), explained below.

Previous research claims that positive emotions have a positive effect on human performance through enhancing attentional and cognitive abilities (Carver, 2003; Fredrickson, 2001; Isen, 2001). For instance, Fredrickson (2001) offered the 'broaden-and-build' model, which states that positive emotions broaden human perception, attention, scope of mental imagination and actions. Negative emotions, by contrast, are bound with a narrow set of specific behavioural options, thus leaving no variety of actions. For example, anger creates an urge to attack, fear the urge to flee, and disgust the urge to expel. These actions are evolutionarily predisposed as the best outcome for a particular situation. For example, when fear is experienced, the human autonomous nervous system mobilises the appropriate internal pathways, by distributing a blood supply to a muscle group responsible for this action.

Fredrickson and Branigan (2005) argue that positive emotions, unlike negative emotions, are not bound with such a narrow reaction tendency. The reason for these differences comes from human evolution and natural selection. Fredrickson (2013) explains these differences. Negative emotions mobilise resources in the event of immediate danger and as such initiate life and limb saving behaviours. These behaviours have to be emotion-specific and fast executed. Positive emotions, however, do not demand immediate action, permitting more time to broaden awareness about the surrounding environment and innovative discoveries.

Carver (2003) suggests a different explanation for the improvement in performance in a positive mood. He states that this is due to the different nature of positive and negative emotions and a ‘regulatory system’, which controls the emotions. The system does not like either positive or negative emotions. It prefers being in a neutral state, with any deviation from it being an ‘error’. If a negative emotion is experienced, the system puts in every possible effort to minimise harm and return it to a neutral level. Such actions are costly and are performed at the expense of other functions, such as attention. Attention is reduced to only the most important and salient events. Positive emotions, instead, do not bring harm and as such, there is no need to avoid them. Therefore, the system does not take efforts to minimise the emotions, as these would fade out eventually. Indeed, attentional resources are not much deployed and can thus be used for different activities, such as looking out for possible new dangers. For example, in the driving environment, the drivers would use the freed resources for better observations and looking for new potential hazards.

Both theories: Carver’s (2003) and Fredrickson & Branigan’s (2005) are relevant to the study of driver behaviour. For example, according to both theories, drivers in a positive emotional state would investigate the surrounding environment more carefully and anticipate possible traffic outcomes. Moreover, according to Fredrickson & Branigan’s (2005), drivers in a negative emotional state would concentrate on the present problem solving, ignoring any other potential dangers. However, driving is a complicated task, and possibly, emotion related outcomes cannot be that easily explained. The next section focusses on the previous research investigating an influence of mood on driving safety.

2.3 Emotions and driving

Emotions are an inevitable part of human life. The effect of emotion on every aspect of human behaviour is diverse and significant. Constantly increasing the time that people spend driving and the great responsibility a driver has to take for themselves and other road users, makes it vital to understand how different emotions can change driving style and response to the actions of the others.

The way in which different emotions affect drivers’ behaviour and driving safety has been a widely studied topic. Probably the most studied emotions in driving safety research are aggressiveness and anger. An angry driving style has been correlated with crash involvement (Wells-Parker et al., 2002). The extreme forms of it, such as physical attacks and “tailgating”, can result in road rage (Cai et al., 2007; James, 2000). Even milder forms of road rage: using the horn and offensive gestures can be harmful for both the aggressive driver and the recipient, and for drivers with a high predisposition to stress (trait stress) result in difficulties in stress coping strategies (Cai et al., 2007). Often, studies correlate aggressive driving with an individual’s disposition to aggression (Huesmann, 1998; Lajunen & Parker, 2001; Mizell, Joint, & Connell, 1997; Shinar, 1998). Wickens, Mann, and Wiesenthal (2013) and Wickens, Wiesenthal, Hall, and Roseborough (2013) described physiological and psychological processes that the driver is experiencing while driving aggressively: hands grip the steering wheel more forcefully, heart rate increases, sweating increases, the mouth gets dry, neck, shoulder and arm muscles become tense. Critchley et al. (2005) found different heart rate and brain activity in response to viewing emotional face expressions. Importantly, heart rate correlated with the brain activity. These physiological reactions are similar to reactions while driving under high cognitive load conditions. For example Pohlmeyer and Coughlin (2008) recorded higher heart rate while driving and performing continuous performance task and Zhang, Lipp, and Hu (2017) recorded higher skin conductance level after anger provocation (Figure 2).

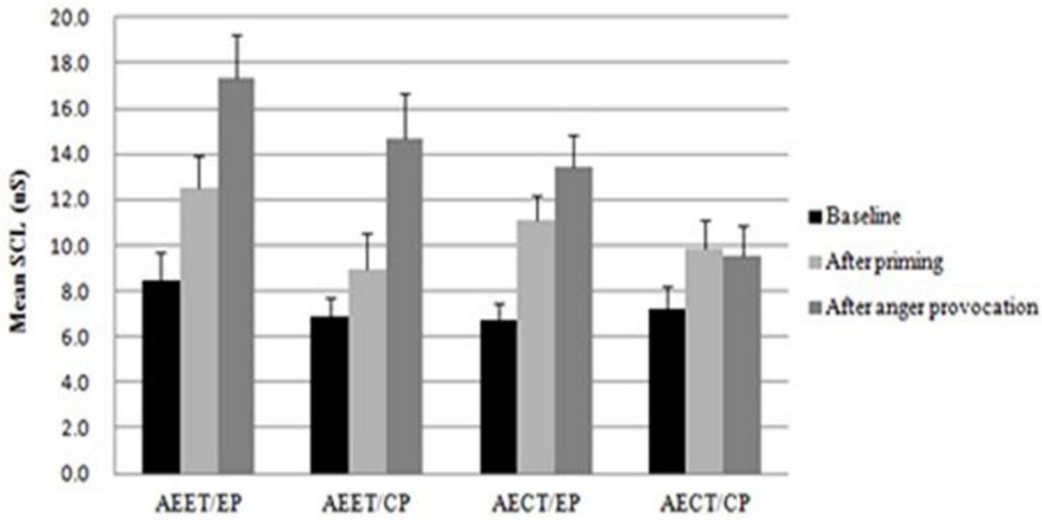


Figure 2: Increase in skin conductance level across the three measurement points (baseline, after priming and after anger provocation) from (Zhang et al, 2017)

One limitation of previous studies is the method of investigation. Most of them used self-report questionnaires and interviews, reporting links between anger and self-reported near accidents (Underwood et al. 1999), and between self-rated driving performance and anxiousness, depression or hostility (Groeger, 1997). Drivers also reported increased anger when they had to reduce speed due to various traffic events (Stephens & Groeger, 2006). Other studies have used observational methods for the assessment of driving performance. For example, drivers who scored high on anger, depression and fatigue were less cautious (Garrity & Demick, 2001) and drivers who scored high on trait questionnaire, also showed greater situational anger and adopted more aggressive and dangerous driving style (Deffenbacher, Lynch, Oetting, & Yingling, 2001).

A driving simulator was also used to study the way emotions can influence driving safety. Cai et al. (2007) conducted a driving simulator study examining driving styles of drivers under different conditions: anger, neutral and excitation. They connected driving simulators in a platoon and induced mood using an imagery technique for the angry mood and playing racing video games for excitement. Neutral participants were asked to stay calm while driving. Heart rate and skin conductance, were higher in angry and exciting conditions. Neutral drivers checked mirrors more often. Cai et al. (2007) reported on the suitability of using a platoon of driving simulators as the method of measuring mood and driving situation elicited changes in drivers' psychophysiological conditions and their driving performance. They found higher speed, shorter time-to-line crossing and larger deviation of steering wheel angle in anger and excitement conditions, compared to the neutral condition. Unfortunately, no inferential statistics were reported to indicate whether these changes were significant. Faster driving and crossing amber lights more often after anger induction were also recorded in a driving simulator study by Abdu et al. (2012).

Similarly to anger, sadness is a negative emotion, but with a rather low level of arousal. Regardless of the fact that many people experience sadness on different levels, from being mildly unhappy to being depressed, its influence on driving safety remains an under-researched topic. Dula and Geller (2003) argue that sadness, similar to anger, can have a harmful effect on driving safety, as both of these negative emotions affect drivers' attentional ability. However, these two emotions vary in the intensity of aggressive behaviours against other road users. Stecklov and Goldstein (2004) examined the influence of a terror attack on driving performance and found an increase in traffic accidents of 35% on the third day after attacks. They attribute this rise to passiveness and increased reaction time caused by sadness and frustration. Bulmash et al. (2006) examined the psychomotor disturbance in drivers diagnosed with Major Depressive Disorder (MDD). Drivers diagnosed with MDD had slower steering reaction times and increased number of crashes, compared to controls. These results are consistent with previous research associating depression with reaction deficits when solving cognitively effortful tasks. Pêcher, Lemercier, and Cellier (2009) investigated the effects of different mood music on drivers' behaviours in a driving simulator study. They manipulated participants' mood using music and measured driving speed and lane deviation. The sad drivers were found to decrease speed and proportion of short 'time to line crossing' keeping closer to the centre lane, thus maintaining a "no risk" driving behaviour. The drivers also reported having a withdrawn attitude and orientation to personal emotional events.

Pêcher et al. (2009) in the same experiment examined the influence of happy mood. The authors found that speed decreased significantly while listening to happy music and only slightly when listening sad music. Happy music also caused deterioration in lateral control with participants showing the tendency to drive closer to the hard shoulder. While driving, participants felt happy and joyful and tended to tap on the steering wheel with the tempo of the music. Pêcher and colleagues concluded that the changes seen while listening to the happy music were instigated to compensate for mood-related distraction.

A recent study by Eherenfreund-Hager et al. (2017) attempted to combine emotional valence and arousal in a driving simulator experiment. They looked at the 'effects of affect' induction on risk-taking behaviour and links between self-esteem and sensation seeking on risky driving. The induced emotional states were relaxing positive, arousing positive, negative and neutral. They concluded that arousing positive and negative affects have a similar negative effect on driving safety, through exceeding the speed limit, shorter headway distance and more time travelled in the opposite lane.

Summarising the research to date, it can be concluded that negative emotions have a detrimental effect on driving safety as shown by the evidence from all research fields: self-reports, observations and driving simulator studies. With regards to positive emotions, there is a gap; it is not clear what is most influential, emotional valence or emotional arousal. The only study that tried to distinguish between high and low arousal in positive emotional valence is Eherenfreund-Hager et al. (2017), who found a performance decrease in high arousal + positive valence condition. Drivers in this condition, drove faster and maintained shorter time headways, similarly to drivers in negative emotional condition. However, positive valence + low arousal seems to be under-investigated. Moreover, from the research conducted by Eherenfreund-Hager et al. (2017) it is not clear how relaxing positive and neutral affects are distinguished. Research clearly lacks more detailed understanding of the precise effects of emotional valence and emotional arousal on driving behaviour.

2.4 Attention – definition and concept

Attention, as an important aspect of human life, has been widely investigated. This thesis is interested in two aspects of the emotion-attention relationship: how emotions can affect drivers' attention, and whether drivers' attention can be re-directed from task-unrelated to task-related objects. In this section, different types of attention are defined and explained. This provides background information and a basis for developing interventions in case of attentional lapses while driving.

The term 'attention' is often used to describe a wide variety of processes from simple sensory processing to complicated decision making. In essence, attention refers to the processing of some of the input stimuli while ignoring others. Kahneman (1973) distinguishes four types of attention; sustained, selective, alternating and divided. All these types of attention are used while driving, thus will be described below.

Sustained attention is defined as the ability to maintain one's focus and concentration on something or someone for a long period, ignoring various distractors and inhibiting attentional shift to task unrelated objects (Ko, Komarov, Hairston, Jung, & Lin, 2017). This kind of attention is beneficial in learning and working activities. Ko et al. (2017) also state that individuals cannot maintain the optimal level of attention for a long time. High attentional demand results in mental and cognitive fatigue, which decreases the ability to suppress irrelevant information, increasing reaction time and number of errors. Mental fatigue caused attentional lapses is most likely to appear during lengthy, monotonous tasks, such as driving or reviewing scientific papers.

Selective attention is related to the processing of particular aspects or factors of some informational inputs at the expense of others. Kahneman (1973) argues that humans have mechanisms that control the choice of stimuli. This selection is maintained at a conscious or unconscious level and can be a result of conditioning or a result of voluntary selection. As an example of unconscious selection Kahneman (1973) describes an experiment conducted in a Russian laboratory when a dog is presented with the same sound for a period of time. The dog would stop reacting to that sound and perceive it as background noise. As soon as it is presented with a tone of a different pitch, the dog would react, showing that it noticed something unusual. Kahneman (1973) also states that processing of stimuli can be voluntarily selected, when an individual attends to task relevant stimuli, ignoring others. An example of selective attention while driving is passing through familiar roads, drivers would selectively attend only to changes in the surrounding environment and ignore the usual road signs and road furniture (Young & Stanton, 2002).

Alternating attention refers to the ability to switch one's attention from one activity to another. Underwood, Chapman, Brocklehurst, Underwood, and Crundall (2003) suggest that drivers’ ability to alternate and allocate visual attention is one of the major causes of traffic accidents. They also distinguish between two main factors of optimal attention allocation: endogenous and exogenous. MacLean et al. (2009) refer to endogenous attention as top-down or goal driven attention which can be engaged explicitly to select one thing over another. Exogenous attention is determined by external events in the environment which are generated externally by the physical properties of stimuli, such as brightness or shape. Underwood, Chapman, Brocklehurst, et al. (2003) argue that endogenous attentional shift deficiency is determined by the lack of experience when, in case of high workload, reduced cognitive resources limit drivers’ hazard anticipation and variety of possible solutions to dangerous road situations. An exogenous attentional shift is triggered by unexpected changes in the visual field, such as the appearance of another road user in the drivers' visual field. These changes require the driver to change their focus of attention immediately, to be able to react in time. Moreover, the reaction time depends not only on drivers' momentary reactions upon hazard detection, but on their ability to alternate attention to the most informative parts of the road and keep a dynamic record of the fast changing location of their own vehicle with reference to other traffic (Endsley, 1995).

Divided attention is the ability of an individual to focus, perform or process more than one environmental factor, or activity at the same time, often referred to as multitasking. The ability of humans to perform two or more tasks at the same time depends on the nature of these tasks (Wickens, 1991). Wickens (1991) states that performance of any task demands resources, which are limited in their availability. Therefore, when the combined demand of performed tasks exceeds resource availability, the quality of performance drops in either of these tasks depending on task demands. Moreover, performance decline becomes more evident if task demands increase. For example, conversation with ground control would decrease flight performance. If the flight task demand is increased by heavy turbulence, the conversation with ground control would be disrupted, or the flight performance could degrade (Wickens, 1991).

Wickens (1991) also states that if two tasks are using the same processing modality (e.g. visual, auditory) or shared processing instruments (e.g. requirements for manual input), their processing competition and performance decline would be more evident. For example, listening to auditory commands would be more disrupted by demands to understand an auditory description rather than visual representation.

Attentional demands required for task completion can be reduced by making some of the processing automatic (Schneider & Shiffrin, 1977). Automaticity has been described as fast and effortless processing, as opposed to controlled processing, which requires effort to be completed. Automaticity can be developed as a result of many repetitions and practising (Schneider and Shiffrin 1977; Shiffrin and Schneider 1977). They distinguish between two types of information processing: automatic and controlled. Automatic processing does not require attentional control and occurs as an activation of a sequence of learned components in long-term memory. Controlled processing, instead, requires attentional control to execute a sequence of learned components. As attention is of limited capacity, this process is slower and usually sequential in nature. An important feature of cognitive processing is that it, with training and practice, becomes automatic. This transformation is relevant to all forms of learning: reading comprehension and fluency, numeracy, writing, memory and balance (Gray, 1996, 2004). Driving, as a learned cognitive and motor skill, follows the same pattern: first, learners have to think about every movement they perform, and there is not much attention left for the road information processing. Once mechanical skills are better developed, drivers can pay more attention to the road and react more efficiently to road hazards (Gibson & Crooks, 1938; Groeger, 2001).

2.5 Attention in driving

Driving, as a complicated skill requires all four types of attention; sustained attention or the ability to concentrate on the road and traffic and not become distracted by unrelated activities, such as conversation or mind wandering (Edkins & Pollock, 1997). Selective attention is needed in driving to be able to select from many perceptual inputs in the surrounding environment, the most important and the most safety critical factors (Underwood, Chapman, Brocklehurst, et al., 2003). Alternating attention is necessary to process quickly the changing road environment and switch from one hazard to another (Crundall, Underwood, & Chapman, 2002). Divided attention is critical in cases when drivers have to operate in-car controls and devices and maintain their attention on the road at the same time (Östlund et al., 2004).

Driving-related research is mostly focused on inattention and distraction rather than attention (Kircher & Ahlstrom, 2017). They argue that attention is mostly defined through a relationship to these terms. For example, distraction is defined as a lack of attention in a particular period. Definitions are often dichotomous; either a momentary loss of attention from driving-related targets, even if the driving task is not affected, or attentional shift away from the driving task, but only if it is a potential risk for self or other road users.

One important aspect of attention in driving is drivers' ability to process and perform automatically actions, which are repeated day after day (Gibson & Crooks, 1938). Ranney (1994) argued that, without this skill, driving would be very dangerous and almost an impossible task. Hale, Stoop, and Hommels (1990) offer a driving learning model: when learner drivers are at the beginning of their learning process, a lot of attention is needed to operate the car controls. With skill development, all levels of basic controls as well as while navigating through familiar roads and familiar intersections, are operated automatically. However, when a situation becomes unfamiliar, controlled processing predominates.

This automation of the driving process is beneficial to driving safety, as it reserves some processing capacity to attend other road and traffic-related information, instead of focusing on car controls. However, at the same time, automaticity can have a negative effect on driving safety. Young and Stanton (2002) proposed a malleable attentional resource theory, suggesting flexibility of attentional capacity. They performed a driving simulator study manipulating the level of automaticity and found a reduction of mental workload allied with an increase in the level of automation. They concluded that the attentional capacity could shrink and expand depending on the momentary needs. Brookhuis and De Waard (1993) suggests that a reduction in mental load can lead to drivers' underload, which results in loss of attention. Torsvall (1987), argues that this inattention is related to under-arousal. Smallwood and Schooler (2006) state that underload while driving is dangerous as it can encourage mind wandering. They argue that tasks that heavily rely on controlled processing are less susceptible to mind wandering due to working memory being occupied with the task at hand. As soon as cognitive load minimises, task-unrelated thoughts occur. Smallwood and Schooler (2006) relate this to decoupling and attentional shift away from the primary task since an alternative goal is triggered in the absence of primary processing needs. As driving can be a boring task, due to repeating the same schedules day after day, this can cause a lapse of attention, which develops when performing tedious tasks requiring low processing intensity (He et al., 2011).

Although many drivers’ actions become automatic with experience (e.g. operating controls), thus lowering the amount of necessary attention, a lot of attention to other events (e.g. monitoring road and traffic) is still necessary to maintain safety. This process requires drivers to sustain their attention for the whole period of driving. The ability to sustain attention has been investigated from two aspects: factors decreasing this ability and interventions capable of increasing it (Brice & Smith, 2001). Brice and Smith (2001) argue that one of the most common reasons for attentional failure is fatigue, caused by long working hours, sleep deprivation or cardiac factors. They also investigated the effects of caffeine on drivers’ ability to maintain a high level of accuracy and the ability to sustain attention. They found that the use of 3 mg/kg caffeine significantly improved steering accuracy. De Waard and Brookhuis (1991) used a car-following task to examine the influence of alcohol and cognitive underload caused by monotonous driving on drivers’ ability to sustain attention. Alcohol significantly decreased drivers’ reactions to speed variations of the lead vehicle. Monotonous driving did not have a significant effect on drivers’ reactions, however, after two and a half hours of driving drivers significantly decreased the distance between their own car and the lead vehicle,

Selective attention is another important aspect of drivers’ attention. From the beginning, learner drivers are trained to look at the most informative parts of the road; they are trained to anticipate hazards and possible situational outcomes (Duggan, 2018; Gibson & Crooks, 1938; Groeger, 2001). With experience, most of the information processing during driving occurs without a driver’s acknowledgement. For example, drivers with experience tend to direct their attention to the most important parts of a road, where hazards are most likely to occur (Crundall, Underwood, & Chapman, 1998). This tendency was especially evident on dual-carriageways, where difficult driving conditions prompted novice drivers to concentrate their vision towards the centre of the road. These observational patterns could result in a delayed reaction if a hazard appeared from a side road.

Alternating attention has also been found to depend on drivers' experience. Underwood, Chapman, Brocklehurst, et al. (2003) examined differences between novice and experienced drivers on three road types: rural, sub-urban and dual-carriageways. Regardless of road type, after checking mirrors or roadsides, drivers looked at the road far ahead. This alternation of visual attention was more evident among novice drivers. Underwood, Chapman, Brocklehurst, et al. (2003) suggested that novice drivers were more concerned about looking away from the road, or less using peripheral vision.

The ability to monitor peripheral events while looking forward or elsewhere is an important skill, necessary when operating car controls while driving. The ability to divide attention between different tasks and the consequences of these actions have been widely examined in driving safety-related research (Ohta, 1993; Ranney et al., 2005; Strayer & Drews, 2007a, 2007b). Dual tasking generally has been found to affect quality of performance (Heuer, 1996). The performance in dual-tasks heavily depends on a level of automaticity, the input and output modality and task difficulty (Heuer, 1996; Tombu & Jolicœur, 2003). Regardless of dual-tasking being dangerous and safety-critical while driving, it is an unavoidable process due to the complexity of contemporary vehicles and driving demands. This concern encourages researchers and vehicle manufacturers to extensively investigate ways of minimising the harmful effect of dual tasking and develop in-car assistance systems that not only make driving more pleasurable but, more importantly, a safer task (Östlund et al., 2004).

If the processing demands exceed processing capacity, some of the inputs will be given priority, and some others will have to queue (Wickens, 1991). Wickens (1991) further explains that this is true for all the input modalities, however, it is the most evident for the inputs from the same modality. For example, it is very difficult or almost impossible to listen to the music and lecture at the same time or to watch a film and read a book simultaneously. Nevertheless, some tasks are impossible to complete even if they come from different input modalities, such as talking while reading. Understanding these principles is especially important in relation to driving, with it being a complicated task, operating inputs from different modalities at the same time (e.g. vision, hearing) (Pashler, 1994).

Drivers constantly have to observe the road ahead, junctions on approach and monitor the situation behind by checking mirrors: vision is the most important source of information. The earlier a possible obstruction is detected, the more time is left to deal with it. Time is an important factor in a fast-changing driving environment, especially with developments of new vehicles capable of reaching high speeds in short time intervals and contemporary roads, adapted for fast velocity. For example, a car traveling at speed 70 miles per hour covers 300 feet in 3 seconds. This also is how much time is needed for a car to stop in an emergency. If a driver takes his/her eyes off the road for these 3 seconds, for example, to tune a radio, they would not be able to avoid a collision, should something unexpected happen (Green, 2000).

These safety issues have inspired researchers and car manufacturers to seek alternative ways of operating ancillary car controls and develop in-car assistance systems. The most researched topic in this area is the impact that talking on a mobile phone can have on driving safety. Caird et al. (2018) conducted a meta-analysis on driving safety and mobile phone use, examining 106 studies with a total of 4382 participants, published between 1991 and 2015. Overall, the studies agreed that hand-held and hands-free devices negatively impact driving performance. Moreover, driver conversation with passengers showed a similar negative effect. This is only one example of in-car activities that are performed while driving. Nevertheless, besides phone conversations, drivers complete many other actions, such as operating windscreen wipers, tuning the radio, opening windows etc. The effect of other vehicle systems on driving safety has also been widely investigated. Östlund et al. (2004) designed a study to develop assessment guidelines for In-Vehicle Information Systems (IVIS). They compared the effects of visual and cognitive tasks in simulator and field studies on motorways, rural and urban roads. They found effects of both tasks, with the visual task resulting in degradation of lateral control, whereas the cognitive task resulted in improved steering and lateral control but gaze concentration increased towards the middle of the road.

Generally, research agrees that dual-tasking has a negative effect on driving safety. However, other studies came to conflicting conclusions. For example Ma and Kaber (2005) argue that reduced mental workload improves situational awareness and driving safety, but Smallwood et al. (2009) and Young and Stanton (2002) warn that mental underload can be equally detrimental to driving safety. Drivers underload and loss of situation awareness has been widely investigated in driving automation studies. It has been argued that situation awareness reduces with increased driving automation (Casner, Hutchins, & Norman, 2016; Miller & Parasuraman, 2007). The most crucial for driving safety is transition from automatic to manual control (Merat, Jamson, Lai, & Carsten, 2012), thus the importance of keeping drivers in the loop when implementing fully automated driving is essential (Merat et al., 2012).

These controversies highlight the importance of developing an in-car system able to monitor drivers' mental workload. However, not only can drivers' mental workload affect driving safety, drivers' physiological conditions, such as fatigue, stress and mood can reduce attention to the road (Abdu et al., 2012; Milosevic, 1997; Öz, Özkan, & Lajunen, 2010). Thus in-car assistance systems, that could take into account drivers' physiological condition and provide the right amount of intervention, are a necessary component of contemporary vehicles. For successful functioning of these systems, it is necessary to understand the influence of mood on drivers' behaviours. The first step to get this understanding is to examine how moods affect attention and drivers' responses.

2.6 The impact of positive and negative mood on attention

The rapid information processing of the environment is a vital process for human survival, particularly in a fast-changing driving environment. During this process, mental representations of any given external object or stimulus are created (Brosch, Pourtois, & Sander, 2010). However, not all of these representations are consciously processed. Attention permits processing of only some simultaneously presented objects at the expense of others. Which objects are processed, depends on momentary intentions and requirements (Driver, 2001). Moreover, sometimes people are challenged with stimuli that are more directly relevant to their well-being and survival than others, for example, those signalling danger or death, such as hostile rivals or dangerous animals. Whereas other stimuli might signal potential satisfaction or pleasure, such as potential entertainment. Such stimuli necessitate faster reactions, to be able to avoid threats or to approach positive rewards. To achieve these rapid responses, perceptual processing of such stimuli should be prioritised. In line with this, research suggests that emotional stimuli are somehow prioritised even on the perceptual level (Winkielman, Berridge, & Wilbarger, 2005; Zajonc, 1980).

Kellermann et al. (2011) argue that this prioritisation can be amended by external or internal factors. She states that cognitive processing is influenced by the emotional context of the stimuli and emotional state of an individual. Schachter and Singer (1962) suggest that emotional states are considered as a function of cognitive appraisal and emotional arousal, where cognitive appraisal determines the perceived emotion. In a classic experiment, they injected epinephrine, which induces arousal, to two groups of participants. The first group was entertained by an actor, who acted happily and silly. The actor in the second group acted angrily and bothered the participants. When asked to describe their feelings, the first group reported being happy, and the second group claimed feeling anger and irritation. Thus, regardless of both groups being equally aroused, they interpreted the arousal according to the situational context. Similarly, emotional state is influenced by cognitive processes regarding intensity and difficulty of information to be processed. For example, depression can be a reason for cognitive decline (Brown, Scott, Bench, & Dolan, 1994), and on the other hand, cognitive processes can be enhanced or inhibited, depending on an individual’s emotional valence (Gray, 2001). Thompson (1994) argues that attention can be used as emotion regulatory mechanism, through the management of emotionally arousing information, for example, redirection of attention, limiting knowledge about potentially harmful information, gaining access to coping resources or altering the interpretation of the emotional information.

Emotions and attention can interact in numerous ways (Kellermann et al., 2011). Pessoa, McKenna, Gutierrez, and Ungerleider (2002) state that attention captures visual stimuli fairly early. However, not all of the perceived stimuli are further processed (Lavie, 1995). Stimuli outside the focus of attention are largely ignored, and participants can even fail to remember large changes in scenery (Simons & Levin, 1997). Processing of emotional stimuli is a key exception from this principle (Vuilleumier et al., 2001). Vuilleumier and colleagues argue that emotional stimuli are processed automatically without attentional involvement. Moreover, they noted that sometimes emotional stimuli could be processed even without conscious awareness. Regarding the emotion-attention relationship concept, research also focused on selective processing of presented stimuli, with processing priority for emotional information. The emotional information is processed faster and is less susceptible to attentional blink (Anderson & Phelps, 2001).

By virtue of limited attentional capacity, the ability to process information automatically is an important skill for successful functioning (Schneider, Dumais, & Shiffrin, 1982). It is generally assumed that attentional resources are utilised flexibly, during attention-demanding processes, according to momentary priorities (Pashler & Sutherland, 1998). They argue that attentional resources are of limited capacity, and if more attention is needed to complete one task, the other task would be delayed. One of the most important questions in emotion-attention relationship research is whether emotions can compete for attention. Yates, Ashwin, and Fox (2010) argue that this competition is evident only under low perceptual load. When high perceptual load is applied, all attentional resources are used to process these stimuli. Yates et al. (2010) also state that processing of emotional stimuli is dependent on general capacity limits.

Limited capacity implies the necessity to select relevant information and inhibit distractors. The successful choice of relevant information depends on both perceptual information and higher level cognitive representations

(Jallais, Gabaude, & Paire-Ficout, 2014). Drivers perceptually capture road information, such as intersection layout or type of a road on unconscious level. This information is then processed, assessed and a decision is made on how to deal with a situation most effectively. Every time contextual effects of these actions are stored in memory. Jallais and colleagues called these effects schemata and proposed that objects stored in “schemata”, with practice and experience, are encountered automatically and promptly.

General knowledge stored as schemata can be affected by mood and emotions (Bless et al., 1996). Positive mood leads to an increase in heuristic approach, whereas a negative mood encourages analytical processing and detailed analysis (Schwarz, 1990). However, two negative mood conditions can result in a different processing approach. Bodenhausen, Sheppard, and Kramer (1994) found that angry individuals process information more automatically, similarly to individuals in a positive mood, and only sad individuals are predisposed to analytic processing. Similarly to happy individuals, angry individuals rely more on their general knowledge (Gilet & Jallais, 2011) and employ similar driving styles to happy individuals (Pêcher et al., 2009). These concepts have been applied to the driving environment by Jallais et al. (2014). They concluded that angry drivers detect atypical hazards slower, and sad drivers’ attentional processing is impaired due to attentional self-focus.

It has also been found that emotions have a different effect on participants’ peripheral attention. Some emotions attract more attention to the centre, some more to the periphery. For example, positive mood broadens visual scope and facilitates peripheral vision (Fredrickson, 2001; Wadlinger & Isaacowitz, 2006). Anxious individuals, instead show impaired attention to peripheral stimuli (Shapiro & Lim, 1989). This factor can greatly influence driving safety, as drivers are required to have a good understanding of the traffic conditions, both in front and in the periphery.

Isen (2001) summarised research examining the effects of positive mood on different aspects of human cognitive function. Positive mood has been recorded to facilitate more efficient and systematic decision making, facilitate creativity and creative problem solving, lower risk-taking behaviours and enable cognitive flexibility in negotiations. Cognitive flexibility permits for better coping with potential problems, switch perspectives and understand better an opposite point of view, and thus come up with feasible and practical solutions. Applying these conclusions to a driving environment would mean that drivers in a good mood would be less responsive to road rage, as they are better understanding the other party’s point of view and therefore less defensive. Cognitive flexibility, facilitated by a positive mood, would permit drivers to cope with stress caused by road and traffic conditions and efficient decision making which is crucial in a dynamic and fast-changing road environment.

Attention is a necessary element of driving safety (Gibson & Crooks, 1938; Hale et al., 1990). Emotions represent an inevitable part of human life (Carver, 2003). The likelihood of their interaction while driving is therefore entirely predictable. This interaction varies across different emotions and has different implications for the attention-emotion relationship. Therefore, the theoretical framework of relevant theories explaining emotions, attention and their relationship is discussed in Chapter 3. Some of the theories have already been tested in the driving environment, some others have found support in other domains, but possibly could be applied to the same extent to a driving environment.

This section has described the huge influence that emotional valence has on human cognitive functioning. However, driving is a complex task, requiring that many cognitive and motor functions act swiftly and in a timely manner, and, more importantly, in harmony with each other (Young et al., 2007). It involves multiple functionalities of a performer; permanent decision making (Summala, 1988), retaining information in short-term memory, and its retrieval when necessary (Kahneman, 1973), updating one's skills (Young & Stanton, 2007), automated and controlled processing (Gibson & Crooks, 1938), to name a few. All the factors named above are related to attention in one or the other way. Therefore, the next sections will describe and critically evaluate the theories explaining behaviours caused by these factors.

2.7 Theoretical frameworks related to this thesis

Although research suggests that one of the causes underlying road accidents is a lack of attention (Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006) and attentional failure (Plainis, Murray, & Pallikaris, 2006), attention can be affected by so many variables that the influence of all of them is impossible to study in this thesis. This thesis therefore focuses on attentional lapses as defined by two psychological theories; mind wandering (Smallwood & Schooler, 2006) and the effect of different moods on information processing (Carver, 2003; Fredrickson, 2001).

2.7.1 Information processing theories

Information processing, attention and decision making are closely intertwined and affected by mood and momentary emotional states. The likelihood of positive or negative outcomes is estimated based on what an individual feels at any given moment. (Izard, 1977; Schwarz, 2000). Similarly, processing strategy is influenced by an individuals' affective state. Individuals in a positive mood adopt heuristic and individuals in a negative mood adopt systematic processing strategy (Schwarz, 2000). Schwarz states that heuristic processing adopts a top-down strategy with low attention to details and high reliance on the previous knowledge. On the other hand, systematic processing adopts a bottom-up strategy, characterised by great attention to the detail and little reliance on previous knowledge.

Luce, Bettman, and Payne (1997) observed that negative emotions elicit more extensive processing, characterised by focusing on one aspect at a time. This serial out manner extends information processing time. Gasper (2004) noted that not only do sad individuals adopt systematic and happy individuals heuristic processing styles, happy individuals also adopt more global and less local information processing compared to sad individuals.

Both studies came to a similar conclusion; a more detailed and thorough processing style slows down processing speed.

It has also been found that not all emotions with the same valence have the same outcomes. Raghunathan and Pham (1999) observed risk-taking behaviours in a gambling experiment. They found that anxious individuals are most likely to choose a low-reward instead of a high-reward if it is accompanied by low-risk. Sad individuals instead, choose high-risk and high-reward options. They concluded that sadness primes a goal for reward replacement, and anxiety a goal of uncertainty reduction. Both these emotions are the same in valence but differ in arousal.

Thus arousal is another factor that can influence information processing. The most notorious theory explaining a relationship between task performance and arousal was proposed by Yerkes and Dodson (1908a). They proposed that an optimal level of arousal is necessary for the most productive work; over-arousal and under-arousal reduces task performance. Humphreys and Revelle (1984) summarised research investigating influence of emotion valence and arousal on human performance in cognitive processing related tasks. Concerning arousal, the results were ambiguous. Performance in short-term memory related tasks declined in high arousal conditions. They concluded that tasks that require information holding for a short period are likely to show deficits associated with high arousal, whereas tasks related to sustained information transfer, do not show any performance decrement. This is caused by increased cognitive resources responsible for information processing, which are the result of increased arousal. Moreover, high arousal causes reallocation of resources from one task to another one which possibly has higher importance to an individual. This reallocation facilitates activation of resources responsible for this particular task processing. More recently Jamieson, Mendes, Blackstock, and Schmader (2010) examined the influence of arousal on examination scores and found that higher arousal facilitated better performance in tests.

Kahneman (1973) explains degraded information processing under high arousal conditions by increased reliance on heuristics, which inhibits and slows down the process. However, these characteristics are evident only when arousal exceeds a certain level, lower levels of arousal can facilitate information processing. Zajonc (1965) came to similar conclusions. He states that performance in simple, well-learned tasks can be facilitated by high arousal. In complex tasks, however, high arousal inhibits performance. Sinclair and Mark (1995) manipulated both emotional valence and arousal to examine how these variables influence cognitive processing. They concluded that individuals in a positive emotional state, regardless of arousal, invested less effort in task details, therefore creating more errors. Negative emotions, again regardless of arousal, led to more detailed and systematic processing, and resulted in fewer errors.

Byrne and Byrne (1993) found that as much as emotions influence actions, actions can influence emotions. For example, frustration can be minimised by physical exercise. Morrow and Nolen-Hoeksema (1990) compared the influence of physical and cognitive distraction on neutralising participants' emotions. Cognitive distraction appeared to be more effective. Morrow and Nolen-Hoeksema suggested that participants could still hold their negative thoughts while moving around, whereas cognitive tasks completely disconnected them from negative feelings. The effectiveness of cognitive load as an activity disconnecting from negative emotions was further explored by Van Dillen and Koole (2007). They used working memory load for negative mood attenuation to examine how different levels of working memory demands can affect mood-congruent processing. They proposed that this attenuation is due to a limited processing capacity in working memory. By occupying working memory with distracting activities, less capacity is left for negative thought processing. The less negative thoughts are processed, the more individual's attention is drawn away from experienced mood towards neutral mood.

In summary:

Negative emotions slow down information processing, but the processing is detailed. Positive emotions facilitate information processing, but only for the whole picture - some details are lost as a consequence. Arousal can facilitate information processing, but only to a certain level. Over-arousal, similarly to under-arousal, inhibits information processing ability. The arousal level facilitates performance only in simple tasks, and can inhibit performance in more complex tasks. In a complex driving environment, fast changing road information should be processed rapidly and in sufficient detail, thus emotional valence and arousal are important for driving safety. For example, a driver should perform effective observations of the surrounding environment, thus too high negative emotion involvement could inhibit their reaction to hazard appearance due to prolonged hazard assessment time. On the other hand, low attention to detail among happy drivers might cause a delay in noticing a hazard onset. These factors make the investigation of emotion and influence of mood on drivers' information processing an important topic in contemporary research.

2.7.2 Mind wandering

The emotion-attention relationship is not limited only to a processing competition. Mind wandering is another aspect associated with this relationship. Mind wandering is defined as an attentional shift from the main task to task unrelated thoughts, for instance, memories (Smallwood & Schooler, 2006). It tends to occur when an individual is performing a task which does not require much attention, such as driving on familiar roads, reading unexciting text or other activities with low vigilance. Following these conditions, individuals tend not to remember adjacent surroundings, due to being preoccupied with their internal thoughts (Smallwood, Obonsawin, & Heim, 2003).

Mind wandering has raised great interest in scientists and researchers in the last couple of decades. To investigate the effects and consequences of mind wandering, laboratory and field experiments have been conducted. It was found that mind wandering is a normal default mode of brain functioning. Evidence for these statements was obtained from both behavioural and physiological research. Studies using EEG have shown different brain activity during mind wandering and focusing on a task. Braboszcz and Delorme (2011) observed a decrease in alpha (9-11 Hz) and beta (15-30 Hz) activity and an increase in theta (4-7 Hz) and delta (2-3.5 Hz) activity in the brain during mind wandering compared to task activity. Smallwood, Beach, Schooler, and Handy (2008) used event-related potentials to examine brain activity during mind wandering. They found that the P300 component for non-target events was reduced during mind wandering. P300 has been found to reliably reflect the stimulated process of decision making as well as being involved in stimulus assessment and classification (Kleih et al., 2011) Hence the reduction in P300 activity indicates effortless processes. Smallwood et al. (2008) collected behavioural data as well. The data suggested that during mind wandering there is a reduction in the profundity of cognitive analysis, as indicated by a higher error rate. Neuroimaging studies came to similar results. The human brain always has some cortical activity, regardless of being in both active thinking and other performance process or during a rest. The distinction between these processes reflects brain activation in different areas responsible for corresponding activity (Christoff, 2012). During mind wandering the pre-frontal-cortex (PFC), precuneus, insula and cingulate are activated. The same brain areas are activated in a brain resting state. As the resting brain pulls images of an individual's internal thoughts, it was concluded that mind wandering causes something similar to daydreaming (Christoff, 2012; Mason et al., 2007).

Although resting brain areas are activated during mind wandering, it still requires some control from executive processing. Executive processing has been defined as a higher level cognitive function which regulates human thought and behavioural processes (Miyake et al., 2000). Evidence for this statement comes from both behavioural and neuroimaging studies. Teasdale et al. (1995) recorded disruption of executive processing as indexed by the performance of a random number generation task during mind wandering. This suggests some use of executive processing resources, which would normally be devoted to the primary task. Neuroimaging studies support these findings and show that mind wandering recruits not only brain default network but the executive network as well (Christoff, 2012; Christoff, Gordon, Smallwood, Smith, & Schooler, 2009).

A notable study by Harvard psychologists Killingsworth and Gilbert (2010) found that individuals are engaged in mind wandering just below 50% of their time. They conducted a study using a phone app, where 2250 adults from 83 different countries were asked to answer some questions, such as ‘How are you feeling now?’, ‘What are you doing now?’ and ‘Are you thinking about something other than what you’re currently doing?” Participants were mind wandering regardless of what they were doing at the moment, except those who were making love.

Not surprisingly, inattention caused by mind wandering has been associated with vehicle accidents (Galéra et al., 2012). They performed a large naturalistic survey, involving 955 drivers who were injured in car accidents. More than a half of them admitted some form of mind wandering shortly before the accident. The authors argue that mind wandering results in drivers overlooking hazards and making more driving errors due to disengagement from the driving task.

Mind wandering can be experienced when an individual is affected by emotions. It has been long assumed that emotion and cognition are inextricably linked. This assumption has been strongly supported by neurophysiological studies. Although emotional induction activates inferior medial prefrontal cortex, which is distinct from dorsolateral prefrontal cortex activated by cognitive tasks, both activations significantly overlap (Davidson & Irwin, 1999; Steele & Lawrie, 2004). Mind wandering is an area where cognition and emotion can overlap. Smallwood et al. (2009) found that emotions with different valence have a different effect on participants. Negative mood was recorded to induce more mind wandering, less attention to the task as well as difficulty to re-engage in the task after an attentional lapse. Jonkman, Markus, Franklin, and van Dalfsen (2017) found that after negative mood induction participants reported more mind wandering compared to after positive mood induction. This mind wandering was reported for both task-unrelated thoughts and task-related interfering thoughts. Sutherland, Newman, and Rachman (1982) also argue that unwanted, intrusive thoughts are more difficult to remove compared to neutral thoughts. This shows the importance of understanding the relationship between emotion and attention in both of these aspects; limited capacity and mind wandering.

As mind wandering has been defined as an attentional withdrawal from the task at hand, the reasons for causing this withdrawal have been widely investigated. Mind wandering was found to be more frequent in individuals with lower working memory capacity in both healthy individuals and students diagnosed with attention deficit disorder (McVay & Kane, 2009; Shaw & Giambra, 1993). Apart from individual differences, a different effect of attentional properties on mind wandering also has been studied. Hu, He, and Xu (2012) found that those individuals who experienced more mind wandering, showed impaired orienting attention. They concluded that uninformative peripheral cues cause less automatic attentional shift for those who are less responsive to irrelevant external stimuli.

In summary:

Individuals are engaged in some form of mind wandering most of the time. Mind wandering engages executive brain function, thus interfering with the task at hand information processing. This processing deficit can cause car accidents due to drivers overlooking hazards. Mind wandering can be initiated by individuals' emotional state, with negative emotions having more effect and being more difficult to eliminate.

2.8 Summary and conclusions

The way individuals process information is hugely affected by their momentary emotional state. Positive emotions elicit a heuristic style of processing, which is characterised by more surfaced and global information handling. Negative emotions encourage a systematic information processing style which is characterised by slower and more detailed information handling.

Moreover, these different behavioural manifestations are predisposed by human evolution and development. Evolutionary positive and negative emotions serve different purposes, with negative emotions requiring fast actions with very little behavioural variety, and positive emotions stimulating exploration and creativity. This results in different ways of dealing with positive and negative emotions. Negative emotions require effort to minimise their harm, so not much attention is left for anything else. Positive emotions, instead, do not require minimisation, leaving relatively more attention for additional events.

Apart from emotional valence, emotional arousal influences individual information processing styles. High arousal acts similarly to positive emotions, adopting a heuristic processing style, whereas low arousal facilitates more detailed processing. An important point to bear in mind when explaining the influence of arousal on processing is the level of arousal. Optimal performance is observed from medium aroused individuals; either being under aroused or over aroused negatively affects individual processing ability.

The human brain tends to reduce activity and minimise effort towards task completion if the task requires low cognitive involvement. This mind wandering is more evident when individuals are affected by negative emotions compared to positive emotions. It also has been named as a sign of impaired attentional shift, therefore, predicting more difficult attentional shift for sad individuals. As yet, the influence of arousal on mind wandering seems not to be empirically investigated. The study, conducted by Killingworth and Gilbert (2010), was the only one that widely investigated occasions when mind wandering would appear most likely.

Apart from the considerable contribution that attention and emotion invest in information processing, they extensively interact with each other. Although emotionally affected individuals experience more mind wandering, adding cognitive load by increasing task difficulty, can minimise this effect. In relation to road safety – mind wandering can negatively affect drivers' attention by inducing traffic unrelated thoughts. It is necessary to understand whether emotional valence and arousal have different effects on mind wandering. The effect of mind wandering, resulting from cognitive underload can be minimised by increasing the amount of information to be processed. However, this intervention should be added with caution, as too high level of cognitive load can result in overload and performance failure. Cognitive load could possibly have different effects on drivers' behaviour dependent on their mood valence and arousal. It is necessary to find the relationship between these variables to establish the most appropriate interventions.

Three main conclusions can be drawn from this chapter:

- The way in which information is processed is affected by individuals' momentary emotional state, with a more global and less detailed processing style in positive moods, and a more detailed processing style in negative moods.
- Individuals tend to reduce attention and effort if tasks require low cognitive involvement.
- Mind wandering caused by low cognitive and high emotional involvement has a negative effect on individuals' attention.

The impact of these processes on human life and actions have been investigated in many areas, including driving. However, research is lacking in a number of areas:

- The interaction of mood and attention in the driving environment.
- How driving parameters (e.g. speed, acceleration, braking) are affected by drivers' mood, and how these parameters shape drivers' hazard anticipation and behaviour in hazardous situations.
- Whether adding some amount of cognitive load can redirect drivers' attention to their primary task – driving.

The next chapter will describe the measures available to assess driving safety, including glance patterns, physiological measures, driving parameters (e.g. speed, braking) and measures of drivers' reactions (e.g. hazard response time and ability to keep a consistent distance from the car ahead).

Chapter 3 Measures used to establish the effect of Mood and Cognitive Load on driving behaviour

This chapter will describe the methods available to examine the impact of drivers' emotional state and different types of cognitive loads on their visual search patterns, reaction times and driving performance. First, an introduction section will describe the importance of driving safety-related research and variables affecting drivers' behaviours. Second, self-assessment and physiological measures of drivers' emotional state and their cognitive load will be described, and their advantages and disadvantages will be discussed. These measures act as dependent variables in cognitive load and assessment of emotions. However, at the same time, they are independent variables as well, as they have been used for experimental manipulations. Third, eye movement measures and their use in driving safety research will be discussed. Finally, measurements, directly related to driving performance (e.g. speed, acceleration, time headway) will be defined and described.

3.1 Measures used in driving safety research

Psychological, social and behavioural research has been studying emotions, attention and their interactions extensively. The findings have been applied to almost every aspect of human life. Predictably driving and road safety research has used results from these fields to explain and predict drivers' behaviours. For many individuals, driving is an everyday task, and as such, it is performed in different emotional states and attentional ability. Much research has been performed to understand which drivers' behaviours are safety relevant, and the causes of these behaviours (e.g. emotional state, attention failure) (for reviews see Young, Regan and Hammer 2007, Östlund *et al.* 2004, Lee 2008). Researchers agree that in the vast majority of occasions the driver is responsible for an accident (Klauer et al., 2006; Lajunen, Karola, & Summala, 1997; Lord & Mannering, 2010; West, French, Kemp, & Elander, 1993). These studies define driving performance measurements (e.g. speed, time headway) and discuss their effects on driving safety. This information is used to critically assess which actions are safe to perform during a drive and which actions are to be avoided for safety reasons. Many different tools are used to collect this information; driving simulators, eye tracking systems, instrumented cars, self-assessment and observational methods.

Drivers' performance is determined by available attentional resources (Baddeley, 1992; Brookhuis & De Waard, 2010; Jonkman et al., 2017). If a task requires more attention than is available, the driver has to compensate either by reducing task demand (e.g. by decreasing speed) or increasing mental effort to maintain the level of attention (Smallwood et al., 2009; Young & Stanton, 2002). Measuring attention, and determining how much attention is necessary is difficult. Experienced drivers progress to using more automatic skills (Underwood, 2007), thus less attention is needed. Nevertheless, the freed attention is not necessarily used for reading road information and early hazard detection (Young et al., 2007). Young and Stanton (2002) proposed the Malleable Attentional Resources Theory stating that the acquisition of automated driving skills does not always mean that more attention would be devoted to road and traffic conditions. Individuals tend to use only as much attention as is necessary to survive, and as much as they consider to be enough to be safe. This can be beneficial as drivers can add some more of their attentional resource, should it be needed at a certain point in time. Kircher and Ahlstrom (2017) introduced a minimum required attention theory. The theory states that drivers tend to invest in the driving task as much attention as it is necessary for external requirements and their personal motivation. If a driver maintains sufficient attention to a situation at hand, he/she is considered being attentive to a situation, regardless of whether he/she performs a secondary task while driving.

This 'flexible attention' leads to difficulty in defining what drivers' behaviours manifest unsafe driving. Specifically, it is challenging to establish the borderline between safe and unsafe, and how much additional load can be applied to a driver in any moment of driving and not overload their attention to a critical extent. One approach to defining these borderlines is based on individual differences (Anastasi, 1958). Generally, driving behaviours resemble individual everyday behaviours. Individuals with dissociative personality traits, who make more errors and lack attention in everyday tasks, tend to possess the same qualities in driving as well (Ledesma, Montes, Poó, & López-Ramón, 2010). Some of the most influential individual differences are age, gender, education, personality, attitudes and stress (Lancaster & Ward, 2002).

Sometimes there is no agreement as to particular safety margins between authorities and cultures. For example, safe time headway ranges from 1,8 - 3 seconds in different countries (Vogel, 2003). Nevertheless, most researchers agree on a comparative explanation of driving behaviours, such as speed, time headway, braking and acceleration. For example, decreased speed is a sign of a driver compensating for a mental overload (Törnros & Bolling, 2005), or reduced visibility (Mueller & Trick, 2012). Boyle and Mannering (2004) also found that drivers decrease speed in response to received in-vehicle and out-of-vehicle messages. Nevertheless, after such speed reduction, drivers might compensate for the lost time by increasing speed. Therefore, the overall safety effect of a temporary speed reduction is ambiguous.

Different measures have different sensitivity to workload, which can cause dissociation between these measures (Yeh & Wickens, 1988). The authors argue that metrics dissociate when changes in one measure do not correspond to changes in another measure. For example, one measure indicates a decrease in a workload and the other indicates an increase. Myrtek et al. (1994) recorded discrepancies between self-reported mental workload and physiological measures in train drivers. They argue that workload analysis cannot be done adequately using only self-reported ratings. Instead, physiological measures should be used to get a full picture of experienced stress. The following sections will look at advantages and disadvantages of different methods of measuring emotions, and possible combinations of methodologies for more detailed conclusions.

3.2 Methods of measuring emotions and cognitive load

Traditionally, emotions are described from two different perspectives: discrete and dimensional terms. Discrete emotions are described as unique physiological entities, such as anger, happiness or sadness (Ekman, 1992). The dimensional perspective characterises emotions as entities varying in valence and arousal (Barrett & Russell, 1999). This thesis is mostly concerned with the dimensional perspective of emotions. Although the experimental manipulations are named as discrete emotions, this research is not concerned with a particular emotion, but rather with a range of valence and arousal of an emotion. For example, an angry emotion is seen as a range of angry feelings with negative valence and high arousal.

With the development of fundamental knowledge of emotions, the concept of emotion as part of the human being has emerged (Izard, 1977). Emotions now are not considered arbitrary and unpredictable from individual to individual, but rather as precise and recurrent patterns directing human behaviour. Therefore, how human behaviours are shaped by emotions has been extensively researched (Chen, Epps, Ruiz, & Chen, 2011; De Rivecourt, Kuperus, Post, & Mulder, 2008; Nguyen & Zeng, 2014). Balters and Steinert (2015) highlighted two important aspects of emotion research: one is about understanding exactly which emotion is experienced and how it is expressed, and the other is understanding whether other individuals are experiencing emotions. Both of these concepts are used in this thesis. In assessment of emotions, it is important to understand which emotion is experienced, to be able to assign recorded behaviours to this particular emotion. All techniques have advantages and disadvantages. Therefore, a combination of different measurements can provide the best understanding of emotion elicited behaviours.

Emotions are computable subjective components and measurable somatic responses of autonomic nervous system activation (Scherer, 2005). Various tools can be employed to measure emotions quantitatively; self-reported measures, glance measures behavioural measures and physiological measures. These are discussed in the following sections.

3.2.1 Self-reported measures

Self-reports of emotion are recorded using questionnaires and surveys. They are widely used due to being relatively inexpensive (regarding time and cost), suitable for wide distribution among large samples and able to measure constructs, such as trait characteristics, which would be difficult to do using physiological tools. Self-assessment also can represent an individual's subjective appraisal of experienced emotion. Examples of self-assessment questionnaires used in this thesis are the Brief Mood Introspection Scale (BMIS) (Mayer & Gaschke, 1988) and 'The affect grid' developed by (Russell & Bullock, 1985). A description and justification of each of these scales is provided in the method sections of the relevant study; BMIS – desktop study, section 4.2.1 and 'The affect grid' – simulator study, section 5.2.1.

Similarly, self-reported task difficulty or cognitive load can be measured by questionnaires developed for these purposes, such as NASA Task Load Index (TLX) (Hart & Staveland, 1988) or Paas Cognitive Load Scale (Paas, 1992). Measurement scales have been found to be a useful and reliable tool in a load and attention assessment (Hart, 2006). However, the present research did not employ any of these questionnaires, as detailed attention and load analysis was not in scope of this thesis. Simple self-assessment questions were considered to provide enough information.

Self-reports have been widely used in studies investigating driver attitudes and behaviours influenced by different emotions (Mauss & Robinson, 2009; Muckler & Seven, 1992). Muckler and Seven (1992) argue that the subjectivity of self-reports is their strength. They state that no one knows better what individuals are feeling than the individuals themselves, and this judgement is critical to data interpretation. Muckler and Seven (1992) argue that differences in measurement of feelings are hidden in objective measures until the breakdown self-reported information makes them obvious.

Yet, self-reported methods have been criticised for being too susceptible to individual differences. For example, what one individual rates as '7' out of '10', for another individual could be equal to '5'. Response bias is another criticism of self-reports. Individuals might give an answer that they think is the most desirable for a researcher, or the answer that is more socially acceptable (Fan et al., 2006; Mauss & Robinson, 2009). One of the ways to overcome these disadvantages and obtain a more reliable assessment of drivers' emotion state and load is by recording their physiological arousal. These recordings together with self-reports provide more reliable conclusions about drivers' mental state than each of these tests separately.

3.2.2 Physiological measures

Physiological measures include measures of the autonomic nervous system (ANS) and central nervous system (CNS). In this thesis, only ANS measurements of arousal are used. ANS consists of sympathetic and parasympathetic nervous systems which are responsible for arousal and relaxation. The advantage of these measures is that they do not require an explicit response, e.g. most of the data can be collected continuously while a participant is performing another task of interest. Kramer (1991) warns about the disadvantages of physiological measures, as they require special equipment and expertise to operate. Further, the acquired data can be analysed only after pre-processing and checking for noise and other artefacts. Moreover, the individual differences need to be minimised using special techniques.

There is not much argument about the validity of arousal measurements recorded from an individual. For example, an increase in heart rate or skin conductance indicates an increase in arousal (Kramer, 1991). However, studies attempting to distinguish discrete emotions through physiological measures show rather contradicting results. This is especially evident when measurements are used to distinguish discrete emotions. For example, finger temperature decreases less in anger than in fear but does not change for other emotions (Cacioppo, Berntson, Larsen, Poehlmann, & Ito, 2000). However, it is impossible to conclude whether anger or fear is experienced, solely from finger temperature data. Even the assumption that arousal is caused by emotions is arguable. Similarly, arousal can be caused by other factors, such as digestion, attention or effort (Stemmler, 2004). To obtain reliable conclusions about experienced emotion, experiments should control as many extraneous variables as possible and conclude from the experimental context, not based on arousal itself (Mauss & Robinson, 2009). Moreover, physiological measurements should be used together with self-reports to contextualise their meaning (Nacke, 2009). The most commonly used ANS measurements are electro dermal activity and cardiovascular recordings.

3.2.2.1 Heart rate measurements

The most common cardiovascular measure, used in driving safety research is heart rate (HR). This measure provides a reliable assessment of drivers' emotional state and their arousal, and thus will be used in this thesis.

HR is recorded as the number of heartbeats per minute. A normal resting HR for healthy adults ranges from 60 to 100 beats per minute, with the possibility to be as low as 40 beats per minute for well-trained athletes (British Heart Fundation, 2017).

In emotion research, an increase in HR has been associated with an increase in arousal. However, clear differentiation between discrete emotions is still problematic (Cacioppo et al., 2000). Cacioppo and colleagues in their meta-analysis found higher HR for anger, fear, happiness and sadness compared to disgust, and higher heart rate for happiness compared to disgust as well. HR responses also were higher in anger compared to happiness, fear compared to happiness and in fear compared to sadness. Although HR increased during negative discrete emotions compared to positive ones, it is difficult to conclude which emotion is experienced just from HR recordings (Cacioppo et al., 2000). This differentiation becomes almost impossible outside of an experimental context, or in the comparison between different studies. One cannot conclude, for example, that 120 beats per minute indicate anger, or happiness, or any other possible emotion.

Heart rate measures are sensitive to changes in emotional affect, mental workload and physical activity (Jahn, Oehme, Krems, & Gelau, 2005). Jahn and colleagues (2005) attributed a decrease in HR to a decrease in emotion tension. However, workload was recorded to increase HR, regardless of emotion tension. They concluded that HR is a sensitive but not selective measurement of emotion arousal and mental workload, and a proportional contribution of each of these variables cannot be determined.

The use of heart rate measurements in driving experiments

HR measures are very popular for assessing drivers’ arousal, stress and workload in driving-related experiments (Borghini et al., 2014; De Waard, 1996; O'Donnell & Eggemeier, 1986). De Waard (1996) suggests several reasons for this: the measurement is well established and reliable, the measurement tool is easy to use and non-invasive.

Brookhuis and De Waard (2010) state that neither low (vigilance) nor too high (stress) workload is beneficial for driving safety. They underline the importance of studying drivers’ mental workload in a driving simulator, as this provides an opportunity for a safe environment for experimental manipulations. These manipulations can be captured and analysed using state of the art devices for the continuous recording of drivers’ heart rate. Brookhuis and De Waard (2010) found a large effect of mental workload, with HR increase of about 5 beats per minute compared with resting in both conditions: driving under the influence of MDMA (MethyleneDioxyMethAmphetamine) and without. HR is sensitive to both low and high cognitive load. In relation to workload, increased HR has been related to increased load (Borghini et al., 2014) and decreased HR is evidence of low load during monotonous driving (Borghini et al., 2014; Lal & Craig, 2001).

3.2.2.2 Electro dermal activity

Electro dermal activity (EDA) is a measure of human skin conductivity, which provides information about changes in the sympathetic nervous system. When an individual experiences emotion activation, increased cognitive load or is physically active, the brain sends signals to the skin to increase the level of sweating (Treaty, 2004). It is a widely used measurement, and the main attractions include: simplicity of recording, sensitivity to single stimuli and its non-intrusive nature (Heino, Molen, & Wilde, 1990). EDA consists of long-duration measurements known as skin conductance level (SCL) and short duration measurements - skin conductance response (SCR) (Heino et al., 1990). SCL is the average level of EDA with a relatively stable character and slow changes dependent on long-term influence of stimulus. SCR or phasic arousal is a short-term increase in skin conductance in response to representation of novel, discrete stimuli. Both these arousal conditions can be studied independently to each other.

Similarly to HR data, EDA does not provide a clear understanding of the exact emotion experienced by an individual. For example, a meta-analysis conducted by Cacioppo et al. (2000) showed that skin conductance increased less in happiness than in disgust. Skin resistance decreased more during sadness compared to fear, anger, or disgust. However, they noted that disgust data was no different from control levels. Cacioppo et al. (2000) also investigated whether autonomic responses differ for positive and negative discrete emotions. All the parameters which were examined, including HR, showed greater activation during negative discrete emotions compared to positive ones. Electro dermal responses, however, did not differentiate positive emotions from negative ones. However, skin conductance levels have been highly correlated with self-reported levels of arousal (Cacioppo, Tassinary, & Berntson, 2007; Mandryk & Atkins, 2007), and self-reported cognitive activity levels (Boucsein, 2012).

EDA measures are used in both emotion and attention research. The continuity of EDA recordings facilitates tracking changes in skin conductance with changes in arousal levels. Changes in EDA have been associated with varying levels of emotional arousal and cognitive load, with skin conductance rapidly increasing immediately after load is applied (Reimer, Mehler, Coughlin, Godfrey, & Tan, 2009). However, Dawson, Schell, and Filion (2007) argue that an electro dermal response has a delay window of 1 – 3 seconds. Hence, skin response changes within this time window, following stimuli presentation, are considered to be elicited by those particular stimuli Dawson et al (2007) also introduced methods of normalising two other aspects of skin conductance; large variability due to individual differences and skin conductance habituation. Individual differences in skin conductance can range from very small, just above 0 conductance, to large numbers, such as 8 to 12. Skin conductance habituation is defined as a decline in conductance response with repetition of presented stimuli.

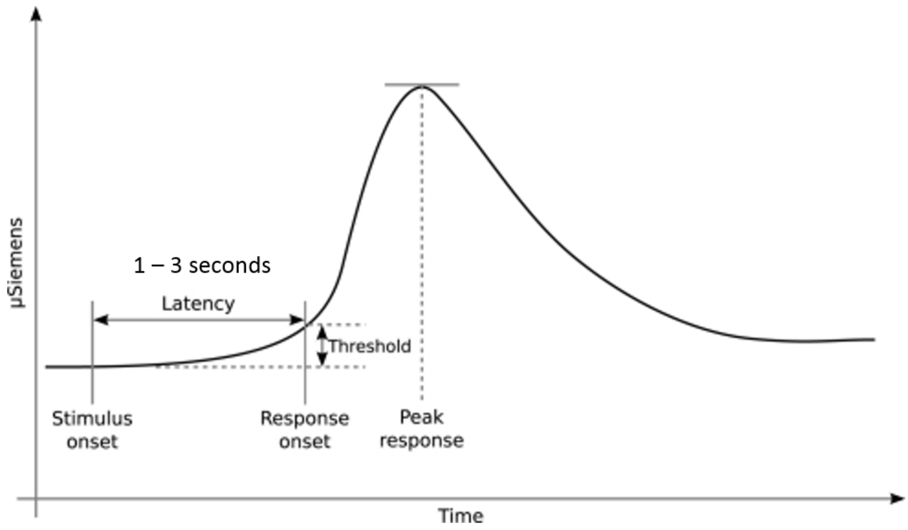


Figure 3: Skin response latency. Adopted from Combe and Fujii (2011)

The use of EDA in driving experiments

According to Fowles (1980) an increase in HR indicates effort, whereas an increase in skin conductance is more indicative of arousal. Schmidt-Daffy (2012) agree with this conclusion, stating that EDA increases with driving speed and increased speed positively correlates with arousal. Healey and Picard (2005) used EDA to determine drivers' stress in a real driving setting. They found a correlation between drivers' self-reported stress levels and their EDA levels and developed a stress recognition algorithm, which could be used for automatic driver stress level calculation.

Collet, Petit, Priez, and Dittmar (2005) studied skin conductance response as a function of driving performance. They asked participants to complete a 14 minute circuit, composed of different road types including intersections. At the end of the drive, a car crossed the participant's path and suddenly stopped. Given the speed of both cars, sudden braking was not enough to avoid a collision - in addition to braking, participants, had to steer. Braking only was considered as an incorrect manoeuvre, because it did not prevent a collision. The proportion of participants who performed the incorrect manoeuvre was 51%, 45% did it correctly, and 4% of the participants did not perform any action at all. The performance of drivers manoeuvring correctly, was compared with the performance of those who performed the incorrect manoeuvre. Skin conductance level (SCL) increased in both groups compared to baseline. SCL measured after the collision showed that those who performed well had significantly higher SCL than those who collided with the obstacle. Collet et al. (2005) argued that the successful performance was due to high arousal levels, as higher arousal is necessary to deal with problematic situations under harsh time restrictions.

Interestingly, a relationship has been found between the number of skin conductance responses, driving speed and accident rate (Taylor, 1964). Moreover, EDA measurements have also been used for assessing demands of rural road segments (Richter, Wagner, Heger, & Weise, 1998) and as a tool for measuring drivers' workload (Collet, Salvia, & Petit-Boulanger, 2014). Collet and colleagues conducted a real-world experiment using controlled and emergency braking to examine whether EDA can reliably discriminate between different workloads. They found a linear relationship between workload demand, as a function of vehicle braking, and EDA, with the strongest braking producing the most EDA. Generally, in research, EDA increase is related to increased arousal, stress and workload, and has been found to be a reliable indicator.

3.3 Glance behaviour measures

Glance measures are collected using eye tracker tools. While there are many different types of eye trackers, generally they can be divided into two types: head mounted and remote. Both have their advantages and disadvantages, however, they work on a similar principle. Holmqvist et al. (2011) explain eye tracking as a principle of recording where, when and how long individuals are looking. The most common metrics of glance behaviour include;

- Gaze points and fixations - gaze point constitutes the basic unit in glance measurements. The eye stops moving for a period and fixates on a point in the visual field. Aggregated gaze points with a duration above a certain time are called *fixations*. This metric is used in both studies in this thesis.
- Saccades - rapid eye movements from one gaze point to another. During a saccade, no visual information is recorded by a viewer, as the movement is too fast.

One of the main reasons for using glance behaviour measures is that, in most cases they reflect visual attention (Duchowski, 2002).

3.3.1 Visual search strategies

Hughes and Cole (1988) argue that selective attention to relevant stimuli indicates the importance of the information. Wilson and Eggemeier (1991) relate fixation frequency to the importance of presented stimuli or fragments of stimuli (e.g. important places in a visual scene), and fixation durations to the difficulty in information extraction and processing. Fixation durations have also been related to an increase in workload (O'Donnell & Eggemeier, 1986) and visually high demanding situations (Backs & Walrath, 1992). Backs and Walrath (1992) also state that self-terminated tasks produce longer fixations as compared to exhaustive search, and explained these differences by an altered search strategy.

Cognitive processes involved in task completion and action control, are mirrored in eye movement recordings (Land, 2006). Eye movement patterns change with practice and proficiency in many cognitive tasks. For instance, expert chess players’ search patterns are more efficient (Charness, Reingold, Pomplun, & Stampe, 2001), and expert radiologists can detect cancer in a mammogram in less than a second (Gegenfurtner, Lehtinen, & Säljö, 2011).

The duration of eye fixations and number of fixations is directly related to information processing and comprehension. However, nowadays there is still some confusion over whether fixation durations are more related to processing speed and number of fixations to attentional shift, or if both of these measures are related to both attentional shift and processing. Previous research was not clear in distinguishing between these concepts. Rayner (1998) summarised research on comprehension differences in self-paced reading and rapid-serial-visual-presentation (RSVP). In the RSVP, words were presented at a rate of 100 or 200 msec. The results showed that short sentences were processed without comprehension impairment, in the same way as normal reading. However, longer sentences resulted in cognitive overload and some impaired understanding ability. This tendency was especially evident when reading sentences containing syntactic ambiguity, thus indicating some delay in information processing. Processing speed has also been named as an individual difference. Shorter fixations are made by faster readers and bilingual readers in their dominant language (Altarriba, Kroll, Sholl, & Rayner, 1996). Longer fixations were recorded from dyslexic readers, beginners and overall bad readers (Hyönä & Olson, 1995; Shen et al., 2010).

The difference in the number of fixations was also noted as an individual difference. For example, children who do not stutter made fewer fixations than children who stutter (Rayner, 1998). More evidence for a relationship between the number of fixations and information processing was obtained from the comparison of speed readers with normal readers. Speed readers were struggling to answer questions about those details in the text which they skimmed over without fixating. Normal readers did not struggle with the same details. However, they showed a higher number of fixations on these objects (Just & Carpenter, 1987; Just, Carpenter, & Woolley, 1982).

Clearly, the number of fixations is linked to information processing speed. The evidence for this statement was obtained from examining the development of reading skills in children. Although researchers used different methodologies, the results were consistent, showing that with the development of reading skills, the number of fixations reduces (McConkie et al., 1991; Rayner, 1985; Taylor, 1965).

The number of fixations also increases with an increase of task difficulty (Zelinsky & Sheinberg, 1997). They found the increase when the search target is similar to distractors. The number of fixations also increases when observing more complex scenery. The first fixations provide the gist of a scene, and subsequent fixations are used to fill in details (Zangemeister, Sherman, & Stark, 1995). The more fixations are made on a particular object the more detail could be recalled afterwards, thus relating the number of fixations to memory (Christianson, Loftus, Hoffman, & Loftus, 1991).

Both fixation numbers and fixation durations are strongly linked to cognitive processing. More complicated problem-solving results in an increased number and longer fixations. This was true for both the difficulty of a single task and dual tasking (Brysbaert, 1995; Pashler, Carrier, & Hoffman, 1993). Shorter fixations, instead, indicate faster information processing and hence faster attentional shift from subject to subject (Duchowski, 2002).

3.3.2 Eye movements and visual attention in driving

In a driving environment, visual attention deficiencies, such as underdeveloped visual search strategies, are responsible for a large proportion of traffic accidents (Konstantopoulos, 2009; Sabey & Taylor, 1980; Strayer, Drews, & Johnston, 2003). Thus, the way drivers search the road scene plays a crucial role in accident avoidance. The awareness of a hazard is reliant on drivers' gaze behaviour. Lee (2008), in his review of 50 years of driving safety research, argued that insufficient road observation would inevitably result in a collision. Gaze measures are used to evaluate changes in drivers' visual attention (Velichkovsky et al., 2003). Eye movement research commonly agrees that gazes are typically directed on the most informative parts of a road scene (Chapman & Underwood, 1998a; Rayner, 1998). Pollatsek, Narayanaan, Pradhan, and Fisher (2006) stressed the importance of observational patterns facilitating hazard awareness, as more attention is needed in places where hazards are more likely to appear. They emphasised the importance of experience in developing hazard awareness and argued that drivers with experience start fixating more on the areas where hazards are most likely to appear.

Similar to chess players, experienced drivers' visual search patterns differ greatly from novice drivers (Crundall et al., 1998), with a greater number of fixations produced by experienced drivers. This was named as a reason for novice drivers to be more often involved in accidents. Moreover, search patterns of police drivers differ not only from novice drivers, but from experienced drivers as well, with the police drivers having significantly wider horizontal search spread (Crundall, Chapman, Phelps, & Underwood, 2003). Differences in scene processing for both novice and experienced drivers also were recorded, with fewer and longer fixations in rural areas and more but shorter fixations in urban areas. Chapman and Underwood (1998b) argue that an increase in fixation duration is due to more complex and busy scenery in an urban area. Shorter fixations in an urban area are needed, as for a driver it is more important to be able to switch attention from subject to subject.

The idea that an increase in the number of fixations together with a decrease in fixation duration is caused by the need and ability to switch drivers' attention from subject to subject was first proposed by Shinar, McDowell, and Rockwell (1977). They noted that drivers fixated more often on road curves than on a straight road. Zwahlen (1993) obtained similar results examining drivers' glance behaviours on curvy roads. He related these results to the American Automobile Association's advice of using a 'brief glance technique' during driving. The technique advises drivers to keep glances on the road for a shorter time to avoid attention capture. These findings are contradictory to those documented in the research literature. Clearly, curve negotiation requires more processing. Nevertheless, driving on road curves did not increase fixation durations. Crundall, Underwood, and Chapman 1998) argue that this is due to the necessity of attentional shift in more difficult road conditions. Rahimi, Briggs, and Thom (1990) support the idea of the relationship between the increases in the number of fixations together with the decrease in fixation durations as a consequence of cognitive demand caused by the road layout. In a naturalistic road study, they found this relationship when comparing glances on busy and quite road intersections. Similar effects are caused by traffic density, overtaking and narrower roads (Hella, Laya, & Neboit, 1996; Miura, 1979).

Underwood, Crundall, and Chapman (1998) compared fixation durations when a hazard was present with mean fixation durations during the rest of the drive. They concluded that longer fixations in the event of a hazard are determined by longer processing time needed to fully apprehend a possibility of a potential hazard to develop into a real one. These results somehow contradict those discussed above. However, Underwood et al. (1998) noted that mean fixation durations still changed as a function of road complexity. Hence, increase in fixation durations at hazard appearance is due to the localisation of attention on an unexpected stimulus and proximity to potential danger.

Drivers typically concentrate their gazes on the visual field straight in front of their car, where objects appear stationary, and only occasionally look at the road edge and the road furniture (Chapman & Underwood, 1998a). Chapman and Underwood called this point a ‘focus of expansion’. The reason for these observational patterns is that this is the place that provides references for movement direction for the driver and is the place where potential future hazards are most likely to appear. These observational patterns develop with experience; inexperienced drivers do not distinguish between different road types, such as rural roads or urban roads, experienced drivers, instead, fixate more often while driving through busy urban roads (Chapman & Underwood, 1998b). Chapman and Underwood concluded that novice drivers still have not developed their optimal search patterns. This conclusion is supported by Norman and Shallice (1986) schemata development theory; the better schemata are developed in response to a particular action, the less time participants need to complete this action. Consequently, drivers’ search patterns should correlate with drivers’ hazard response times.

Crundall, Underwood, and Chapman (1999) examined the relationship between driver experience and the visual field of view. They compared participants’ ability to detect a small light that would randomly appear on the edges of the screen. Experienced drivers outperformed novices and non-drivers, and novices outperformed non-drivers in the stimulus detection. Crundall and colleagues concluded that experience is an important factor determining drivers' ability to detect peripheral hazards. Kountouriotis and Merat (2016) examined changes in visual search patterns while performing visual and cognitive secondary tasks. They found a reduced visual field of view, as indicated by SD yaw angle, in the presence of a simultaneously presented cognitive task. Kountouriotis and Merat (2016) argue that reduced visual angle, especially when coupled with improved lane keeping, could be caused by additional attentional resources involved, and could result in impaired peripheral hazard detection. Thus, research provides a lot of evidence that eye movements and visual attention are closely related (Velichkovsky et al., 2003).

The duration of gazes is an important determinant of viewers' attention. Typically, shorter gazes are associated with increased visual scene complexity (e.g. busy roads) (Chapman & Underwood, 1998a; Robinson, Erickson, Thurston, & Clark, 1972). Similarly, emotional parts of the scenery attract more attention and as such more gazes, leaving little attention to non-emotional fragments (Kensinger, 2009). Furthermore, viewers' moods were found to affect fixation durations similarly, resulting in longer fixations and shorter saccades when negatively primed. On the other hand, positive priming did not affect fixation durations, but however showed shorter saccades (Kaspar et al., 2013).

These search behaviours have been researched in the driving environment and found to result in similar patterns. Chapman and Underwood (1998a) highlight the importance of a good balance between fixation durations on different parts of the road. Too short fixations are unable to provide a driver with the necessary information and will most likely result in missing important parts of a whole scene. Too long fixations incur difficulties in the attentional switch from one object to another, and as a result a possibility of missing the appearance of another hazard, or prolonged reaction to this hazard. Konstantopoulos (2009) also argues that longer fixations indicate difficulties in attentional switch and longer information processing times. They collected evidence examining drivers' scene processing ability in low visibility conditions. Drivers fixated significantly longer during night driving and driving in the rain.

Nevertheless, researchers agree that glance measures well represent drivers' attention, and their visual and cognitive processing demands. These measures can be used to monitor changes in drivers' behaviour and in driving safety assessment.

3.4 Driving behaviour measures

3.4.1 Time headway

Time headway (TH) is defined as the time (measured in seconds) between the front bumpers of two vehicles travelling in the same direction at a constant speed (Evans, 1991). Based on TH data, several measurements can be calculated: minimum TH – which reflects the minimum following distance to a lead vehicle, and mean TH – which reflects a drivers' perception of a safety margin, and a drivers' ability to concentrate on a car following task (Saad et al., 2005). If TH is too short there is a risk that the following driver would not be able to react quickly enough should the lead vehicle stop (Knipling et al., 1993). For example in the UK, close car following has been associated with 7023 accidents in 2015, 469 of which were fatal or serious (Department for Transport, 2015). To address this, an upper limit of safe interaction, measured as TH has been proposed. This time varies from 1.5-3.5 seconds in good road and traffic conditions (Pasanen & Salmivaara, 1993; Piao & McDonald, 2003; Vogel, 2003; Wasielewski, 1979).

Maintaining a safe headway requires active interpretation of visual cues and rapid decision making (Brookhuis, Waard, & Mulder, 1994). The choice of TH can vary depending on different factors, such as risk tolerance, age, gender, perceived task difficulty and emotional involvement (Ranney, 1999; Y. Zhang & Kaber, 2013). Strong emotions provoked by these factors, such as frustration or anxiety could easily lead to dangerous behaviours (H. Summala, 2007). Summala also noted that the choice of TH is not always based on the law, it is directed by social norms as well. For example, in dense traffic conditions, many drivers are uncomfortable in following the legal TH due to this distance being outside the accustomed social norm. On the other hand, Brackstone and McDonald (1999) argued that drivers are inconsistent in their choice of TH, on day to day basis and even within a day. The choice of TH can also vary within individuals as a function of motivation or mood change (Y. Zhang & Kaber, 2013). They found that situations of urgency resulted in more aggressive driving with shorter TH and faster speeds. On an individual level, drivers modify TH to accommodate their performance ability, which in turn depend on task difficulty and driving skills, such as braking ability (Winsum & Heino, 1996). They argue that because of individual driving ability, preferred TH should remain consistent for individual drivers and vary only between individuals. On the other hand, there is considerable variability within individual performance, related to different individual emotion states. For example, Tasca (2000) found that aggressive drivers are more likely to 'tailgate', and Green (2000) found that drivers' stopping distance increases under cognitive load. The interaction between mood and load and their effect on following behaviour has been under-researched. Emotions may affect drivers by changing their of safety margins.

An increase in TH is a compensatory behaviour which occurs when drivers' cognitive load increases, for example, when interacting with other in-car devices (Jamson, Westerman, Hockey, & Carsten, 2004; Young et al., 2007). Some drivers prefer to sacrifice success in car following and allocate their attentional resources to in-car activities (Ranney, 1999). Nevertheless, this TH increase is not always enough to avoid a collision or accident (Jamson et al., 2004). Young et al. (2007) argue that this driving performance modification results from either too much attention allocated to a secondary task or inadequate attention to the primary task. Nevertheless, it is an indicator of an attentional deficit required to maintain safety.

TH also depends on drivers' trait characteristics and their momentary emotion (Garrity & Demick, 2001; Stephens & Groeger, 2011). Angry drivers are more likely to tailgate and drive close to a lead car (Stephens & Groeger, 2011). Garrity and Demick (2001) state that aggressive personality traits have a negative impact on driving behaviour. For example, hostility has been found highly correlate with traffic crashes, and high driver aggression was correlated with minor accident involvement. Furthermore, thrill-seeking correlates with risky driving behaviour, including close following distance (Jessor, 1987).

3.4.2 Speed and acceleration

Speed is a well-known factor associated with high accident risk. Societies enforce speed limits on roads to decrease the number of fatalities on the roads (Lajunen et al., 1997). Lajunen and colleagues report that the year following speed restriction introduction, the number of fatalities dropped by 25%. They also estimated that reduction of speed by 5 km/h could reduce the number of accidents involving injuries by 30%. Therefore speed choice is an important factor in driving safety. Too high speed can result in too long braking distance and not enough time to react to potential hazards. Speed limits are imposed to lower accident risk and consequences of accidents (Lajunen et al., 1997).

Speed measures, such as mean speed, speed variation and maximum speed are often used in driving safety research. Changes in mean speed have been recorded as a consequence of drivers' distraction. Patten, Kircher, Östlund, and Nilsson (2004) recorded speed reduction as a result of visual distraction. They argue that this decrease is a compensation for a reduced visual input. Similarly, Saad et al. (2005) explain speed reduction by necessity to gain more time for the road information processing in case of reduced visual road information. Speed decrease as a compensatory strategy for slower decision making was reported for elderly drivers (Brouwer & Ponds, 1994). Cognitive load, on the other hand, has been found to influence speed inconsistently, from having no effect on speed (Östlund et al., 2004), to speed increase while speaking on the hands-free mobile phone (Patten et al., 2004). Driving at higher speeds requires more attention, due to less time left to deal with unexpected situations. Drivers tend to compensate for this extra attention requirement by reducing speed if they have to perform additional tasks, such as talking on a mobile phone (Rakauskas, Gugerty, & Ward, 2004) or entering the destination in a navigator (Chiang, Brooks, & Weir, 2001).

Speed determines the time available for action in case a hazard occurs, as well as the severity of accident consequences (Rothengatter, 1988). However, although speed is a volitional drivers' choice, there are some problems in using it as a safety measure. First, drivers' speed choice is limited by speed restrictions and societal demands. For example, someone who prefers slow driving sometimes is forced to drive faster by pressure from other road users, or someone who likes fast driving is restricted by speed limits and busy traffic (Lajunen et al., 1997). Consequently, most of the time, drivers have to adapt a socially desirable driving speed. This makes it difficult, and under some circumstances almost impossible, to use mean or maximum speed to determine an influence of external factors on drivers' speed choice.

In experimental conditions, when drivers' speed choices are restricted, speed measures are not representative of driving performance (Saad et al., 2005). Acceleration, instead, is not restricted by traffic rules and regulations and can be freely chosen by drivers and adjusted according to their momentary wishes. Especially, this is evident at intersections; drivers can drive fast to the approach of the intersection and apply sharp braking just before it. After the intersection, drivers can accelerate to reach to the speed limit very fast. Therefore, the acceleration can be more representative of driving style than driving speed. Robertson, Winnett, and Herrod (1992) suggested using acceleration to characterise drivers' driving styles. They also argued that with experience drivers change their acceleration style, as gained experience helps in reading the road ahead and planning speed on the approach of obstacles. Thus, acceleration can be used as a measure of drivers' anticipation skills.

Lajunen et al. (1997) distinguish between lateral and longitudinal acceleration. Lateral acceleration is speed on road curves, where too high speed can result in activation of centrifugal forces and loss of control. It also can reflect lack of drivers' anticipation skills and experience. Longitudinal acceleration refers to drivers' style of acceleration and braking, and can reflect a drivers' thrill for fun and sensation seeking (Lajunen et al., 1997). Strong centrifugal forces can result in running off the road (Summala &

Merisalo, 1980), and strong longitudinal acceleration can result in rear-end collisions (West, 1993).

In driving related research, acceleration data has been used to predict fuel consumption (Murphey, Milton, & Kiliaris, 2009), determine ecological driving patterns (Ericsson, 2000), assess the likelihood of drivers being involved in accidents (Lajunen et al., 1997), and detecting drivers under the influence of alcohol (Bagdadi & Várhelyi, 2011).

Ericsson (2000) found that individual differences are one of the most influential factors capable of predicting driving style. Males accelerated harder at intersections as compared to females, as well as had a greater proportion of time in higher acceleration classes. Acceleration style has been used to detect drivers' vigilance and sleepiness (Desai & Haque, 2006), as well as classify driving styles (Di Lecce & Calabrese, 2008) and detect drunk drivers (Bagdadi & Várhelyi, 2011). Bagdadi and Várhelyi (2011) assumed that rapid acceleration and deceleration, as well as jerky stops, are good indicators of drivers having difficulties in maintaining a lane position and speed control, thus being evidence of driving under the influence of alcohol.

Murphey et al. (2009) state that the way drivers accelerate and brake determine fuel consumption and emissions. They define driving style as drivers' dynamic behaviour on the road. Sometimes drivers are calm, sometimes aggressive; these emotions determine driving style. They distinguished three driving styles;

- Calm – is the most fuel-efficient style, when a driver anticipates other road users and avoids hard acceleration.
- Normal – is when a driver adapts the moderate style of acceleration and braking.
- Aggressive- style assumes hard and abrupt acceleration and braking. This style is less fuel efficient.

This classification is based on a jerk profile. Murphey et al. (2009) define a jerk as the change in rate in acceleration and deceleration.

In summary:

Although driving speed and speed variation can be used as reliable measures to assess driving safety, they are not always representative of the real situation. In cases where drivers' choice of speed is restricted by speed limits, road layout (e.g. busy road with a lot of parked cars), or slow moving traffic, their acceleration style can determine their driving style. Driving style not only indicates driver's ability to maintain a lane position and speed control, but also can be an indicator of dangerous driving (e.g. aggressive style utilising abrupt braking).

3.4.3 Braking

There are a number of different brake metrics. Brake reaction time (BRT) is the time measured from the onset of a lead car's brake lights until the moment the brake pedal of the following vehicle is pressed (Winsum & Heino, 1996). BRT is the most commonly used driving performance measurement (Saad et al., 2005). BRT varies as a function of event expectancy. Shorter BRT was recorded for expected events compared to unexpected events (Johansson & Rumar, 1971) and for shorter headways compared to longer headways (Brookhuis et al., 1994; Schweitzer, Apter, Ben-David, Liebermann, & Parush, 1995). Green (2000) argues that fully alerted and ready drivers can react as fast as 0.7 – 0.75 seconds after spotting a brake light. Response to common but unexpected brake lights takes about 1.25 seconds, and response to unexpected signals takes 1.5 seconds. Green (2000) also states that these times are not an absolute value and depend on factors such as drivers' cognitive load, age and gender, as well as the urgency of a situation.

Brake reaction time components

To understand and interpret BRT, it is important to recognise that there are a number of components. Green (2000) offers a breakdown of BRT as follows;

- Mental processing time – the time needed to recognise that an action is needed. For example, a pedestrian steps into the road ahead. The driver should assess the situation and decide that braking is needed to avoid an accident. This component can be decomposed into three smaller units;

  - Sensation – object detection time ("There is an obstacle in the road.")
  - Perception – the time it takes to recognise the meaning of an obstacle ("This is a human".)
  - Response selection and programming – the time it takes to decide which action (if any) is the most appropriate and to plan the action ("If I brake, I would avoid a collision.")

- Movement time – the time needed to perform a pre-planned movement. For example, move the foot from the accelerator to the brake pedal. Green (2000) argues that for more complex actions longer time is needed to respond. He also states that the movement time is dependent on the arousal level and the amount of practice.
- Device response time – the time it takes for a mechanical response of the involved device to complete its response. For example, it could be the time for a car to stop after a brake pedal is pressed.

Green (2000) also states that reaction time (RT) should be referred to only as the first component – mental processing time. However, due to inconsistent use of terminology in the previous research, this term has been used as mental processing on its own and sometimes mixed with other components. In the desktop study of the present research the term 'response time' is used in relation to hazard response times. In this case, the term includes only the first component – mental processing. In the simulator study, for braking responses, all the components are included in the term BRT, as the measurements are taken from a hazard trigger time until a participant presses the brake pedal.

Research examining drivers' reaction has used different signals to induce braking: brake lights of the lead vehicle, traffic signals, the unexpected incursion of another car or pedestrian, auditory signals and slowing of a lead car without operating brake lights (Green, 2000). He concluded that the RTs are faster when hazards are present in foveal vision as compared to the peripheral presentation.

Braking time calculation

Another important aspect when analysing BRT is to determine how the pressure applied to the brake pedal is conceptualised and calculated. Many authors record only the time at which the brake pedal was first pressed (see Green 2000 for review). This metric can be considered as purely drivers' reaction time, as it calculates the time from the hazard onset until the drivers' first reaction. The disadvantage of such a measurement is that it does not take into account drivers' attitude to the presented stimuli. For example, as it was pointed out by Winsum and Heino (1996), individual differences, such as experience, age or gender, determine braking style. More experienced drivers and those who are more confident in their braking skills, engage in later braking and shorter headways. Consequently, the individual difference can be a determinant of brake initiation, and it is difficult to be sure whether these drivers have noticed an obstacle later, or they are just more confident in their braking skills. Other studies calculate braking time from an initial brake pedal press until its complete depression (McGehee, Mazzae, & Baldwin, 2000; Van Winsum & Brouwer, 1997). Barrett, Kobayashi, and Fox (1968) found individual differences in brake pedal using; drivers who reacted slower to stimulus appearance, were also slower in fully pressing the brake pedal (about 1 second), or the brake pedal was never fully pressed. Faster responders, instead, slammed on the brake pedal, so the pedal was fully pressed in about 0.5 seconds.

Expected, unexpected and surprise conditions

Green (2000) distinguishes between three types of studies examining braking times: expected, unexpected and surprising. Expected braking is when drivers are explicitly told that they would have to respond to a signal, which possibly would require deceleration or braking. These studies often report fast braking responses, from 0.5 to 0.75 seconds. He explains such fast responses by the application of ideal conditions; drivers knew what to look for, although some element of abruptness was applied.

Unexpected braking is considered to be more natural and described as drivers' reactions to unexpected events (Green, 2000). The reaction time in these studies varies from 0.13 to 1.35 seconds. Finally, he classifies the most unexpected braking as a surprise, where braking probability was very low. In such studies, objects suddenly moving into the drivers' path from a side road, were used as a stimulus. Most of these studies found very long braking times, 1.5 – 1.8 seconds, although they were dependent on time to collision (Hankey, 1997; Summala & Koivisto, 1990). Green concluded that surprised drivers take more time to brake, roughly twice as long. He explained this by drivers having to spend more time on all three mental-processing stages; detection – slower due to use of peripheral vision instead of foveal, perception – slower due to unusual nature of an obstacle and therefore, more time required to interpret it, and response is slower as a choice between braking and steering has to be made.

Other factors influencing brake reaction times

Brake reaction times are found to be influenced by many other factors besides expectancy (see Green, 2000 for review);

- Age has generally been found as a slowing factor for braking.
- Gender does not show consistent results, with males sometimes being faster and sometimes showing no difference. None of the studies found females to be faster.
- Urgency, defined as shorter time-to-collision has been found to facilitate braking times to some extent. Green explains this facilitation by higher arousal level in the cases of urgency. He also applies Yerkes and Dodson's law to this phenomenon, as urgency improves BRT only until certain extent; when conditions become too demanding, the performance does not improve.

Cognitive load is a robust predictor of prolonged braking times (Alm & Nilsson, 1994; Korteling, 1990). Attention is of limited capacity. Thus any factors requiring attentional resources would inevitably distract drivers from detecting sources of danger (Wickens, 1991). One of the most researched subjects in this area is the use of a mobile phone while driving. Simulator and on-road studies came to the same conclusion; mobile phone use decreases reaction times by about 0.5 seconds (Brookhuis et al., 1994; Green, 2000; Lamble, Kauranen, Laakso, & Summala, 1999), explaining their findings by drivers' overload during a phone conversation. In contrast to these findings, Alm and Nilsson (1994) found that drivers' reaction time could decrease under tricky road conditions, regardless of having a phone conversation at the same time. One explanation of these findings could be a malleable attentional resource theory (Young & Stanton, 2002). Drivers may have been mindful of their risky behaviour, so became more focused on the road.

Another source of cognitive distraction is the use of in-car devices (Summala, Lamble, & Laakso, 1998). However, operating in-car devices presumes looking at in-car objects, thus redirecting visual attention away from the road. Besides cognitive load, peripheral vision is used to detect sources of danger, which can determine slower reactions. Therefore it can be expected that emotions and cognitive load that take away the majority of drivers' attentional resources, would affect brake reaction time the most.

3.5 Hazard awareness

Drivers permanently have to update visual information during a drive by identifying relevant information in a fast-changing environment. This information includes anticipating hazards, judging their development and predicting the trajectory of this development (Wetton et al., 2010). Drivers' ability to anticipate dangerous road situations has been defined as hazard awareness (Horswill & McKenna, 1998).

Hazard awareness is a skill associated with the risk of car accidents in a number of studies (Darby, Murray, & Raeside, 2009; McKenna & Horswill, 1999; Wells, Tong, Grayson, & Jones, 2008). The idea of measuring drivers' hazard awareness ability was initiated by Pelz and Krupat (1974) and several times further developed (McKenna & Crick, 1991; Watts & Quimby, 1979). The introduction of the hazard perception test in the UK in the year 2002, resulted in a non-low-speed road crash rate reduction of 11.3% in the year following novice driver’s test (Horswill & McKenna, 1998). Moreover, a correlation between hazard perception skills and the crash rate has been recorded (McKenna & Horswill, 1999; Pelz & Krupat, 1974; Wells et al., 2008). Those who scored higher on hazard perception tests had lower crash rates.

The ability to detect and evaluate potentially dangerous road situations has been used as a measure of driver’s hazard perception and incorporated in the new driver assessment test in the UK. This test is a simplified version of driving reality, with hazards presented on a computer screen as videotaped scenes from a drivers’ perspective. Participants are required to watch these videos and imagine they are the driver of the car. Each video contains at least one potential hazard, which later develops into a critical situation requiring immediate action. The potential hazards vary and can include pedestrians stepping into the road, cars merging unexpectedly, cars braking suddenly or too rapidly, or road users violating traffic rules. As soon as a driver spots a potential hazard, he/she is required to indicate a response by pressing a button. Hazard perception skills are evaluated by computing the hazard response time (HRT) measured from the first indication of the hazard until the button is pressed (Chapman & Underwood, 1998a). The average time of responses is calculated and used as a measure to assess the driver’s hazard perception skills.

Hazard perception is an awareness of what can happen and action taken to be prepared for possible negative outcomes. Endsley (1995) proposed a theory of ‘situation awareness’ underlining three necessary abilities for situational awareness, which could be applied to hazard awareness: perception – hazard detection at an early stage of hazard development, comprehension – recognising that situation is a potential hazard and projection – prediction of possible situational development. The last stage, prediction, is based on the knowledge stored in declarative memory and ability to relate memory elements to the present situation (e.g. predict the driving trajectory of a possible hazard vehicle based on its speed and position in the scene).

For successful information processing, some mental effort is required (Shiffrin & Schneider, 1977). The authors state that, with experience and practice, controlled processing develops into automatic processing, which is less prone to errors and does not require mental effort (see section 2.4 for more information). Norman and Shallice (1986) introduced a concept of *schemata*, which is a mental representation of a sequence of well-learned actions. Each schemata consists of many schema (singular of schemata in Greek) representing a single action of possible choices of actions. Similarly in driving, when a driver is approaching a traffic light, which have been green for a while, the schemata for braking is activated and prepares the driver for performing a sequence of possible actions (Vlakveld, 2011). Although this process suggests some automaticity in this processing with experience, Vlakveld (2011) argues that some controlled processing is still required, as the action can have several possible outcomes and there is a need to decide when is the best time to intervene. This moment of decision making can compete for available attentional resources with drivers' other mental processes, such as mind wandering or efforts of the 'regulatory system' (Carver, 2003) to minimise the harm caused by negative emotions. Consequently, the process of hazard perception would be delayed in circumstances when the driver is disposed to negative emotions.

Hazard perception tests are widely used not only for the assessment of novice drivers, but also in a broad range of psychological research, and have been found to be a reliable measure of safety behaviour (Chapman, Underwood, & Roberts, 2002; Grayson & Sexton, 2002; McKenna & Horswill, 1999; Pradhan, Pollatsek, Knodler, & Fisher, 2009; Vlakveld, 2014). Therefore, hazard awareness can be used to determine the impact that emotions have on drivers' attention.

3.6 Coherence task

The coherence task was developed at the University of Groningen and is suitable for both field and simulator experiments (Brookhuis et al., 1994). Drivers are required to follow a car ahead keeping a constant distance from the lead car. The speed of the lead car fluctuates with an amplitude between

15 to 30 seconds, depending on task design (Brookhuis et al., 1994; De Waard, 1996; Rakauskas et al., 2008). Participants are asked to follow the lead car and adjust their car's speed, to keep a safe, close and constant distance from the lead car. Three metrics are derived from analysis;

- *Coherence:* a measure of squared correlation between the speeds of the participant's car and the lead car. Its value is similar to R^2, ranging from 0 to 1, with 1 being a perfect match between the two signals. If the correlation is < 0.3, car following has failed and further metrics (phase shift, modulus) should not be interpreted (Brookhuis et al., 1994).
- *Modulus:* is an amplification factor of the participant's speed with respect to the lead car. Modulus < 1 is interpreted as undershoot, and modulus > 1 is interpreted as an overshoot.
- *Phase shift:* also called a delay of a participants' response to the change of the lead car's speed.

Brookhuis et al. (1994) observed considerable delays in reaction when the participants were influenced by drugs or alcohol, and when they were talking on a phone. They calculate that a delay of 600 ms at 90 km/h requires 15 m extra braking distance should a car in front come to a stop. Therefore, depending on speed, 600 ms reaction delay could be an additional accident risk. They argue that being able to assess drivers' reaction delay is a reliable measurement tool to predict risk increase under certain conditions. Ward, Manser, De Waard, Kuge, and Boer (2003) manipulated driving task difficulty and driver's cognitive load in a driving simulator. They found that driving task difficulty increases coherence but decreases modulus, whereas cognitive load decreases both coherence and modulus. Phase shift was not affected. Heart rate significantly increased during both manipulation conditions, showing evidence of increased effort. The authors concluded that both tasks with low and high cognitive load, showed reduced performance as demonstrated by the decrease in modulus. The decrease in modulus was assigned to resource limitation which cannot be controlled. However, increase in coherence in a more difficult driving task somehow indicates performance improvement. Ward et al. (2003) concluded that when driving becomes more difficult, drivers invest more effort, whereas low demand is not motivating for investing resources in task performance.

3.7 Relating driving behaviour measures to theoretical framework

Negative and positive moods have different impacts on many types of behaviours. This thesis is particularly interested in the influence of mood on individuals' driving styles and their ability to respond in a safe and timely manner to the actions of other drivers. This section will summarise Chapter 3 with respect to drivers' ability to process traffic related information in different moods and the influence of mood on drivers' mind wandering, highlighted in Chapter 2. This section will also look at possible ways to minimise the negative effect of mood.

In a fast changing road environment the ability to update road related information and anticipate traffic behaviour are vitally important (Crundall et al., 2012). Understanding the factors influencing information processing can be a step towards predicting driving behaviour and developing interventions able to correct those behaviours were measured.

Positive moods broaden the scope of attention (Fredrickson & Branigan, 2005), free attentional resources (Carver, 2003) and encourage heuristic information processing (Schwarz, 2000). Negative moods, in contrast, requires a lot of energy to deal with, thus lowering attention to other things (Carver, 2003), and encourage systematic information processing style with attention to detail (Schwarz, 2000). It is important to understand how these theories can be implemented in a driving environment. A positive mood should facilitate drivers' hazard perception due to freed attentional resources and broader road side observation. Drivers in a positive mood should anticipate possible changes in the surrounding traffic and react in good time to avoid dangerous situations. A negative mood should facilitate focusing on one thing at a time, thus causing a delay in hazard perception and reacting to actions of other traffic (Luce et al., 1997). High arousal increases the amount of available cognitive resources (Humphreys & Revelle, 1984; Jamieson et al., 2010), thus should facilitate drivers' performance. Nevertheless, anger has been reported as having a negative impact on driving safety, for example, an angry driving style has been correlated with crash involvement (Wells-Parker et al., 2002). Happy moods (positive valence and high arousal) have not received much attention so far. In general researchers agree that happy drivers act similarly to those in negative mood valence and high arousal (e.g. angry) (Eherenfreund-Hager et al., 2017; Pêcher et al., 2009). However, these studies did not investigate drivers' hazard perception ability.

Another aspect, associated with drivers' distraction from the main task, is mind wandering. Mind wandering is a consequence of underload and mood related day dreaming (Smallwood et al., 2009; Smallwood & Schooler, 2006). He et al. (2011) found less speed variation and smaller horizontal dispersion of gazes while mind wandering compared to attentive driving. They associated these results with drivers' failure to scan and monitor the surroundings, thus increasing crash likelihood. Similarly, Yanko and Spalek (2013) found longer brake reaction times and higher speeds while mind wandering. Robertson et al. (1992) add that mind wandering negatively affects drivers' anticipation skills, resulting in jerkier driving styles, with higher acceleration and harder braking. Mood valence has a different impact on individuals, with deeper mind wandering and more difficult reengagement with the main task in a negative mood. However, the effects of mood induced mind wandering on drivers' attention and behaviour have not been investigated so far. Drivers in all moods should be affected by mind wandering, except drivers in the neutral mood. The positive valence of the neutral mood would not improve the performance, as according to Diener and Diener (1996), individuals by default feel more positive than negative. This effect should be evident through longer information processing times and attentional shift as indicated by duration of fixations and numbers of fixations. This effect should also be evident through driving performance related metrics, e.g. speed and braking (see hypothesis in section 3.8).

As mind wandering is not only a consequence of mood induced intrusive thoughts, but also a consequence of underload, adding some cognitive load should correct this problem, e.g. reduce underload and mind wandering. The influence of cognitive load on driving performance has been widely investigated, however, mainly with a purpose to learn the negative impact of additional load on driving performance (Engström, Markkula, Victor, & Merat, 2017). Young and Stanton (2002) argue that underload and overload both have a negative effect on driving safety. As underload is one of the main causes of mind wandering, adding some amount of cognitive load could fix this problem.

Cognitive load in the simulator study, reported in Section 5.4, was used to disconnect drivers' mind wandering and bring drivers' cognitive resources back to the driving task. Olivers and Nieuwenhuis (2006) observed that experimental manipulations facilitating divided attention, can be useful in activating attentional resources. An easy additional task not only does not disrupt performance in the main task, but can improve this performance (Olivers & Nieuwenhuis, 2006). Taking into account that executive function is involved in the information updating process, such as monitoring and evaluating current stimulus inputs of the task at hand (Baddeley 1992; Cohen et al. 1997), disruption from mind wandering should enhance the main task, thus improving driving performance. Two types of cognitive load were used in the simulator study: driving related load (DRL) and non-driving related load (NDRL). NDRL aims to disconnect drivers from mind wandering. DRL has a wider function: apart from disconnecting the drivers from their internal thoughts, it will direct drivers' attention to the road, thus enhancing driving performance, ability to switch attention, and road information processing. In addition a no-load (NONE) condition was added as the baseline to examine the effects of moods when no load is applied.

3.8 Hypotheses

3.8.1 The desktop study

The desktop study examined the influence of moods on drivers' ability to anticipate hazardous road situations. It was designed as a desktop experiment and measured participants' 'hazard response times' (HRT) to potentially dangerous situations. Based on previous research it was hypothesised that:

Hypothesis 1 – The sad drivers will have the longest HRT, fixation durations and the narrowest dispersion of fixations,

Hypothesis 2 – The happy drivers will have the shortest HRT and fixation durations and the widest dispersions of fixations.

3.8.2 The simulator study

The simulator study examined the influence of different moods on participants' ability to sustain attention for a period of time, their driving styles and how these driving styles affect driving safety. It also examined whether adding cognitive load, in the form of different types of questions, can disengage drivers' from mood-related intrusive thoughts.

Hypothesis 3 – neutral mood;

The driving related metrics, physiological measures and gaze measures in the neutral mood will not differ from the measures during the corresponding baseline drive.

Hypothesis 4 – physiological measures;

High arousal in the happy and the angry moods will be evident in higher heart rate and skin conductance. Cognitive load will not affect HR and EDA.

Hypothesis 5 – glance behaviour measures;

Mind wandering, as induced by mood, will prolong road related information processing as indicated by fixation durations (less in number and longer). Negative mood valence will result in longer processing as compared to positive mood valence due to the systematic mode of processing. The sad mood, being the most internal state with attentional self-focus of mind and passive attitude to surroundings, will result in a slower attentional shift as indicated by less but longer fixations. The high arousal in the angry mood will minimise the destructive effect of the negative valence. However, information processing will still be deteriorated, in comparison with the baseline, due to the influence of task unrelated, intrusive thoughts.

High arousal in the happy mood will affect drivers similarly to the angry mood with deterioration in performance in comparison to the baseline and will be inferior to the neutral mood.

With regards to the width of drivers' visual field of view, it is hypothesised that participants will concentrate their gaze more towards the road centre to compensate for mind wandering. In other words, drivers' visual field will be narrower while driving under the influence of mood, except the neutral mood.

Hypothesis 6 – car following;

Drivers in a positive mood will outperform drivers in a negative mood showing better attention and reaction to speed changes in the lead vehicle. The angry mood will facilitate overshooting similarly as it facilitates aggressive driving and tailgating. The tendency to tailgate will be represented by closer following distances. If the choice of TH is accounted for by arousal level, the happy drivers will prefer TH similar to the angry drivers. The sad drivers will show the slowest reactions as indicated by larger responses to the speed change of the lead vehicle. They also will compensate their attentional deficit by increasing TH.

Hypothesis 7 – hazard perception and anticipation of hazardous situations;

The propensity of the angry drivers to speed violation will be evident when the drivers' choice of speed is not restricted by the car following situation. They also will show less hazard anticipation and forward planning, which will be evident in higher acceleration and harder braking.

The happy drivers will employ similar driving styles, but the effect of arousal will be less evident due to a positive mood valence. Positive mood valence encourages exploration of the surrounding environment, thus wider visual field and better attentional shift will encourage better hazard perception and more proactive driving.

The most impaired hazard perception and anticipation is expected in the sad mood, with it being the most self-focused. This results in less interest in observing the surrounding environment and the biggest influence of mind wandering. There is no evidence for sad drivers violating the speed limits, or instead, driving too slowly. However, a self-centered character of the sad mood permits prediction that the sad drivers will drive slower and accelerate and brake smoother than the happy and the angry drivers. Nevertheless, if their visual fields are very narrow, they might have to brake sharper, due to the late reaction to appearing hazards.

Hypothesis 8 – the influence of cognitive load

It is hypothesised that non-driving related load will either disconnect the drivers from mind wandering, in which case driving performance will be the same as in the neutral mood, or add additional processing load, in which case the performance will deteriorate. Driving related load, on the other hand, will improve driving performance, as its function is to disconnect from mind wandering and direct drivers' attention towards road-related information. These changes will be indicated by both glance patterns and behavioural measures.

No-load condition will be the most representative of the mood influence on driving behaviour and glance patterns.

Chapter 4 – A desktop study to examine the effects of mood on glance behaviour and hazard response times

4.1 Background and justification of the study

Drivers' attention is an important component of road safety (Chapman et al., 2002; Crundall et al., 2002; Underwood, Chapman, Berger, et al., 2003). Attentional failure has been named as one of the most common factors causing accidents and near misses (Klauer et al., 2006; Lord & Mannering, 2010; Wang et al., 1996). Therefore, factors influencing drivers' attentional ability, or causing attentional lapses and failures, are widely investigated (Young et al., 2007). Drivers' mood is one of the factors that greatly influences drivers' behaviours (Dahlen, Martin, Ragan, & Kuhlman, 2005; Deffenbacher, Lynch, Filetti, Dahlen, & Oetting, 2003; Jallais et al., 2014; Pêcher et al., 2009). Emotions, feelings and moods are powerful and unique in their ability to capture and retain human minds, to overtake non-related information processing and influence human behaviours (Izard, 2002). Emotions can facilitate processing speed (Öhman, Flykt, & Esteves, 2001) and processing likelihood (Anderson, Christoff, Panitz, De Rosa, & Gabrieli, 2003) and, as such, facilitate safe driving. In contemporary society, driving becomes a usual everyday task. The Office for National Statistics (2016) reports a constant increase in a number of drivers and vehicles licensed every year. Cars are used for commuting to work, travelling, delivering goods, domestic, pleasure and many more. Such a wide and frequent use assumes that drivers have to operate cars in different moods and emotional states. These factors assume that influence of drivers' emotions on drivers' behaviours have an important impact on driving safety. Indeed, drivers with higher levels of sensation seeking, anxiety and aggression were more likely to adapt risky driving styles (Ulleberg, 2001), drive faster (Abdu et al., 2012), and even exceed speed limits (Arnett et al., 1997).

Ranney (1994) argues that individual predictors are less reliable than situation-specific factors in building drivers motivational models and identifying accident predictors. He named selective attention as one of the most consistent crash predictors. Rapidly switching attention from one subject to another is a required and necessary factor in complex task performance (Kahneman, 1973). For example, situational anger caused by road-rage can provoke different emotional responses, such as fear and anger (Britt & Garrity, 2006; Underwood, Chapman, Wright, & Crundall, 1999). These reactions divert attention towards a source of irritation and away from a primary task (Frijda, 1986).

Ellis and Moore (1999) argue that the emotional state influences attentional capacity by allocating some of the attentional resources to task-irrelevant emotion processing. The authors argue that negative emotions, such as sadness and depression are the most powerful in persuading mind wandering and attentional capture.

Influence of negative emotions on driving safety has been extensively investigated. They were found to affect lateral control, to influence on violating speed limits and red lights and processing too hard on gas or brake pedal (Jeon & Zhang, 2013). Positive emotions in relation to driving safety were investigated to a less extent. Research has merely reported that ‘happy drivers are better drivers’ (Eyben et al., 2010; Grimm et al., 2007) as they are less likely to be involved in accidents (James, 2000). Cognitive research is consistent in prioritising positive emotions in relation to various processes and performances (Carver, 2003; Fredrickson, 2001). Fredrickson states that positive emotions broaden attentional scope and Carver argues that attentional resources are merely used while experiencing happy emotions. Both of these qualities should sufficiently improve driving safety when possessed by drivers.

If positive emotions have a similar impact on drivers’ attention as it was recorded in other areas such as decision-making and information processing, happy drivers should be able to spot hazards earlier and be quicker in calculating possible situational outcomes. One way of assessing drivers’ ability to predict situational development is by checking their hazard perception skills. The traditional way of hazard assessment is done by using a computer: hazards are present on a computer screen, and the participant has to press a button as soon as a hazard is detected. The time from the first hazard appearance until the button press is recorded and called ‘reaction time’. Unfortunately, reaction time is a complex measurement including many segments (Green, 2013a). He decomposed the total reaction time into sequences of components (explained in more detail in chapter 3.4.5);

- Mental processing time – sensation, perception, situational awareness and response selection
- Movement time
- Device response time

As a result, one cannot be sure on what stage the response delay occurred. One way to overcome this ambiguity is by using an additional method to assess the influence of experimental variables on drivers’ reaction time. Borowsky, Shinar, and Oron-Gilad (2010) argue that using an eye tracker device to record drivers’ eye movements enriches the information about drivers’ ability to anticipate possible hazardous situations. Velichkovsky, Rothert, Kopf, Dornhöfer, and Joos (2002) argue that visual fixations are better predictors of hazard detection, as they do not involve the mechanical response factor, which could be a phase of delay in response time.

Hazard perception refers to the identification of traffic situations where possible danger can arise. Failure to identify such situations accurately and timely causes more than 50% of all collisions (Nagayama, 1978). For this purpose, time windows of 3 seconds were created around the experimental hazardous situations. The beginning of the time window was the trigger point of a hazard, which was set to 2.5 seconds to Time to Collision. This was done so drivers’ behaviours could be measured on the approach of the hazards as well as their reaction after the hazards were dealt with. This method was used to analyse four driving related hazards; ‘Single parked car’, ‘Parked car in group’, ‘Car merging from right’ and ‘Car merging from left’.

The hypotheses are outlined in Section 3.8.

4.2 Method

4.2.1 Mood induction and assessment

To date researchers have used a variety of mood induction techniques: Imagination, Film/Story, Music, Feedback and combinations of these. Westermann, Spies, Stahl, and Hesse (1996) reviewed the effectiveness of these techniques and suggested that combined methods are more effective for a mood induction than using single mood induction techniques. Therefore in the present study music was used in combination with corresponding pictures. The happy music was combined with coloured pictures containing images of weddings, running horses, smiling children and puppies. The neutral music was combined with images of peaceful nature, and the sad music was combined with images of natural disasters (Westermann, Stahl, & Hesse, 1996). Music used for the mood induction is represented in Table 1.

Table 1: Music used for mood induction

Mood	Music
Happy	Bach's Brandenberg Concerto No. 3, Allegro (played by Hubert Laws)
Neutral	1) Chopin's Waltz No. 11 in G flat 2) Chopin Waltz No. 12 in F minor
Sad	Prokofiev's Alexander Nevsky: Russia under the Mongolian Yoke

The choice of music was from Green, Sedikides, Saltzberg, Wood, and Forzano (2003) and Rowe, Hirsh, and Anderson (2007), with the difference that sad music was played at normal speed, unlike Row, Green and colleagues, who played the music at half speed.

It has been mentioned in Section 2.1 that, in the present research the terms 'mood' and 'emotion' are used interchangeably. Emotions are easier to manipulate due to their short lived nature: 10-15 minutes (Rauscher et al., 1993). This is an important feature, as in this study a repeated measures design was employed, requiring each participant to take part in all of the experimental conditions. All conditions were counterbalanced between the participants.

For mood assessment, the Brief Mood Introspection Scale (BMIS) was used (Mayer & Gaschke, 1988). This scale contains 16 mood adjectives and a 10-point subscale for overall mood assessment. The aim of Study 1 was to assess participant's mood valence. Therefore, only the pleasant-unpleasant subscale of the BMIS was used (Larsen & Ketelaar, 1991; Muraven et al., 1998). The mood assessment was completed four times: before each experiment, to assess baseline mood, and after each of the condition.

4.2.2 Hazard perception videos

The recording camera was fixed on the inside of the windscreen of the vehicle to record the forward view. The videos were recorded during one month in all weather conditions and on dual track roads and dual carriage ways in urban and suburban environments in the United Kingdom. All videos were screened for potential hazards, and very busy and empty roads were excluded. Videos twenty seconds in length were then created and divided into those with and those without hazards. All the initial screenings were carried out by a professional driving instructor. The videos were evaluated against the following criteria for inclusion: (1) the image was of acceptable quality, (2) the hazard was not in temporal proximity to other potential traffic hazards (i.e. before and after each hazardous situation there was a conflict-free driving), (3) there was evidence of action taken by the 'camera car' to avoid a collision.

Three driving instructors then rated the hazards regarding the amount of danger they could pose via a three-point scale: very dangerous, dangerous, and not very dangerous. This assessment was guided by the UK driving instructor training programme. The videos containing the most dangerous situations were selected for the experiment, with minimal repetition of the same hazards. The videos that did not include hazards were randomly selected from those available. These videos contained moderately busy traffic similar to the videos containing hazards. All videos were 20 seconds long. Ten videos with hazards and fifteen videos with no hazards were thus produced. The same videos were used for all conditions, only the order of presentation was changed. The no-hazard videos were different in all conditions. Each hazard had a starting point of development. These starting points were defined using Be-gaze software frame-by-frame technique from the moment when hazard started to develop. Two videos were excluded from the analysis, as many participants reported misunderstanding of the hazard onset time (HOT). Table 2 describes the remaining eight videos.

4.2.3 Apparatus

All music was converted to MP3 format and played using an HP laptop with Beats audio. The music was played through Beats by Dr. Dre Executive Over-Ear Headphones (MH6W2ZM-A). The videos were developed using an in-car camera (1080P full HD, high-definition, light source frequency 50 Hz/60 Hz) with the visual angle of the recording 130 degrees. The videos and the pictures were presented on a 3200 Samsung TV screen. Eye tracking data were recorded using SMI eye tracking glasses; 30 Hz binocular resolution, and 60 degrees horizontal and 46 degrees vertical field of view.

4.2.4 Participants

Twenty participants were recruited for the study (9 females and 11 males, age range 27–52 years). The inclusion criteria were driving experience of more than five years, more than 5000 miles driven each year, and normal or corrected to normal vision. The experiment received approval from the Faculties ethics committee (review reference AREA13-156) and accordingly participants gave informed consent to take part in the research.

4.2.5 Experimental design

For mood assessment and response time analysis, a repeated measures design was employed, with Mood as the main factor with three levels: neutral, happy and sad.

Gaze data were analysed using a mixed design with Mood as within-subject factor in three levels (neutral, happy, sad) and Hazard as a between-subject factor (with hazard and without hazard).

Table 2: Description of hazards from (Zimasa, Jamson, & Henson, 2017)

Hazard number	Hazard description
1	A ball suddenly appears from the side of the road, and a child appears after the ball. The HOT is set from the time the ball appears.
2	A car has stopped on the left side of the road and then moves off in front of the participants' car. The HOT is set from the moment the car starts moving.
3	A motorbike suddenly appears from behind parked vehicles. The HOT is set from the moment of its appearance.
4	A car was moving in the right hand lane and then, after indicating, moves into the left lane. It then suddenly brakes and turns left into a side road. The HOT is set from the moment the car started moving into participant's lane.
5	The same situation as in video two, but a car was stopped on the right side. The HOT is set from the moment the car starts moving.
6	When travelling towards a green traffic light, a pedestrian steps out from the right and causes the participant to brake. The HOT is set from the moment the pedestrian lifts their leg.
7	On turning left at a green traffic light, a cyclist crosses the road on the red traffic lights without giving way. The HOT is set from the moment when the cyclist starts moving across the road.
8	A car ahead moves into the central refuge area from the right, stops to give way and then suddenly accelerates to cut in front of the participant's car. The HOT was set from the moment the merging car accelerates.

4.2.6 Procedure

Participants were seated 70 cm from the screen and asked to complete a mood assessment questionnaire (referred to as baseline mood). They were given the opportunity to familiarise themselves with the hazard detection task. They were presented with 10 videos used only for practice runs and asked to press the space bar on the keyboard in response to a hazard.

The eye tracker glasses were then calibrated using three point calibration. The calibration was checked after each condition, in total three times for each participant. The first mood induction music was then played, accompanied by the mood relevant pictures for a total of 7 min. Participants were asked to adjust the volume of the music using volume adjuster on the lap-top, so it was loud but not harmful or disturbing. Immediately following the end of the music and pictures, participants were required to watch fifteen videos (ten with hazards and five without) and respond by pressing the space bar when they considered a hazard to be present. As soon as they pressed the space bar (or the end of the video was reached) the next video automatically commenced. When the fifteen videos had been played the participant was asked to complete a mood assessment questionnaire. After that, the same procedure was applied twice more for the remaining two mood induction conditions. The order of the three mood conditions was counterbalanced across participants, and the whole experiment took approximately 40–45 min and participants were then debriefed and paid £5 for their time.

4.3 Results

Repeated measures analysis of variance were performed on the data, after checking for normality and homogeneity of variance. Where the assumption of sphericity was violated, the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity. Main and interaction effects are reported, along with post hoc tests where appropriate. Bonferroni correction was used in all post hoc tests.

4.3.1 Mood assessment

Average scores were calculated for each of the four conditions (three moods plus baseline). The baseline and the neutral mood data were normally distributed. The data from the sad and the happy conditions were skewed.

Multilevel analysis of repeated measures with four levels (baseline, happy, neutral and sad) was performed to accommodate the skewed data. The analysis showed that the type of music played in combination with pictures presented had a significant effect on the participants' mood $F_{(3, 57)} = 23.49$, $p < 0.001$, $\eta_p^{\ 2} = 0.41$. Post hoc tests showed that the participants felt significantly more pleasant before the experiment (baseline) as well as in the happy and neutral moods compared to the sad mood ($p < 0.001$). There were no significant differences between any other moods (Figure 4).

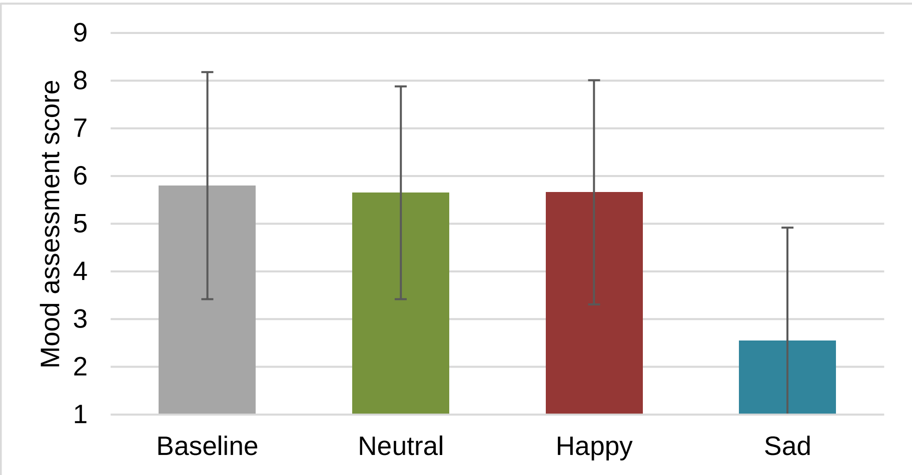


Figure 4: Mean mood scores from self-reported questionnaire

4.3.2 Hazard response times

Two of the ten videos containing hazards were excluded from the analysis as more that 50% of the hazard response times (HRT) were either less than 200 ms or exceeded 2000 ms, as this exceeded chance accuracy (Ratcliff, 1993; Swensson, 1972). Erroneous responses included late button presses and non-responses. The responses faster than 200 ms are considered to be faster than stimulus 'detection times', and responses longer than 2000 ms are associated with something unrelated to the particular stimulus. The response times were calculated from the hazard onset time till the button press. A 3 × 8 repeated-measures ANOVA with three levels of Mood (neutral, happy and sad) and eight Videos was conducted. There was a significant main effect of Mood on HRT, $F(2, 36) = 62.5$, $p < 0.01$, $\eta_p^2 = 0.78$. Post hoc tests showed significant differences between all pairs ($p < 0.05$), with the sad mood producing the longest HRTs and the neutral mood the shortest (Figure 5).

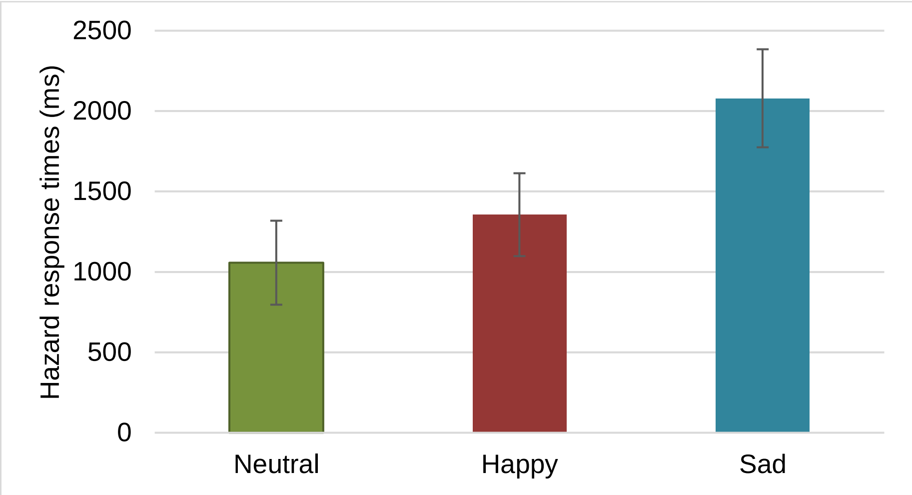


Figure 5: Hazard response times by Mood

There also was a significant main effect of Video on HRTs, $F(4.27, 76.86) = 102.13$, $p < 0.01$, $\eta_p^2 = 0.85$ and post hoc tests showed that the HRTs for videos 3, 5, 7 (means 824.23, 1063.96 and 1082 ms) were significantly faster than the others (mean range 1342.41–3287.39 ms, $p < 0.05$). Given that the mean HRT for video 4 was far in excess of 2 s (and thus considered an erroneous response) further examination of those data were carried out. It was found that in this video the behaviour of the ‘hazard vehicle’ was ambiguous. However, as the response times were consistent across the participants, the video remained in the data analysis.

A significant Mood × Video interaction was also found $F_{(6.86, 123.48)} = 3.29$, $p < 0.01$, $\eta_p^2 = 0.15$. Pairwise comparisons showed that the sad mood affected the HRTs in all videos. Moreover, videos 1, 3, 6, 7 and 8 were differentially affected by all three moods. Closer analysis of these videos showed that these videos featured vulnerable road users; video 1 contains a ball emerging from the side, which could be followed by children; video 3 contains a motorbike rapidly moving from behind a parked van; video 6 contains pedestrians stepping into the road; and video 7 contains cyclists crossing the road. Only video 8 contained a car. However, this scenario was filmed on a dual carriageway with a central refuge area, where the hazard car stopped and then proceeded. This double movement (from the side road to the central reservation and then further into the main road) could have caused a decision delay (Green, 2013b). These five videos were processed significantly longer in the sad mood than in the other moods, and significantly longer in the happy mood than in the neutral mood ($p < 0.05$)

Figure 6).

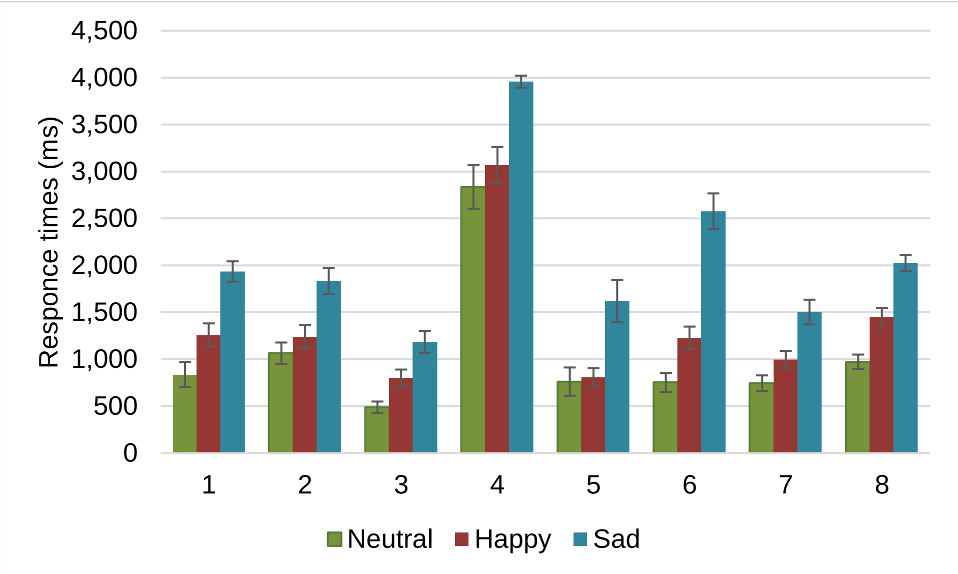


Figure 6: Mean HRTs (ms) in each video by Mood

4.3.3 Glance behaviour

The data from three participants were not recorded due to calibration difficulties. Fixation durations of eye movements were analysed using BeGaze software and data from videos that did not contain hazards were included in the analysis as a separate condition. For glance behaviour data analyses, factorial repeated measures design was used, with three levels of Mood (neutral, happy and sad), and two types of Video (with and without hazards).

There was a significant main effect of Mood on fixation duration, $F_{(1.26,\ 20.14)} = 11.28$, $p < 0.05$, $\eta_p{}^2 = 0.41$. Within-subject contrasts showed that participants fixated longer in the sad mood compared to the happy mood $F_{(1,\ 16)} = 12.73$, $p < 0.05$, $\eta_p{}^2 = 0.44$ and the neutral mood $F_{(1,\ 16)} = 11.54$, $p < 0.05$, $= 0.41$. There was no significant difference between the happy and the neutral moods. A significant main effect of Video was found, $F_{(1,\ 16)} = 14.36$, $p < 0.05$, $\eta_p{}^2 = 0.47$ with significantly longer fixations in the videos not containing hazards. No significant Mood by Video interaction was found (Figure 7).

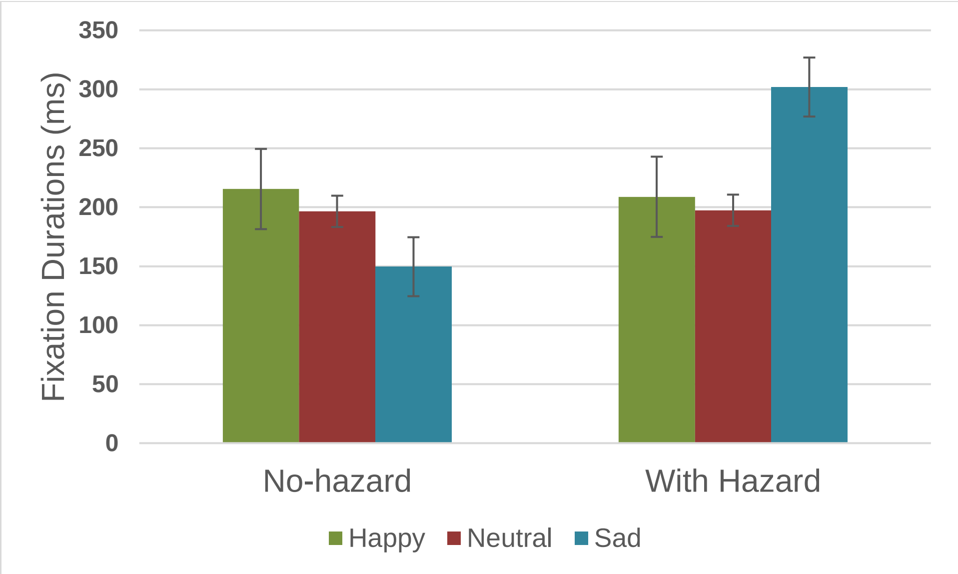


Figure 7: Fixation durations, by Mood and Video

Horizontal and vertical spread of fixations

No effect of mood on the spread of fixations was recorded, although, the dispersion was the widest in the neutral mood. Therefore, the results were in the predicted direction, but either there was not enough power due to the number of participants, or the difference could not be recorded due to small screen size.

4.4 Discussion

The desktop study was designed to investigate the relationship between drivers' mood and attention, via hazard perception. It was hypothesised that the happy drivers would have the shortest HRTs and fixation durations than the neutral and the sad drivers. Additionally, it was hypothesised that the sad mood would result in the longest HRTs and fixation durations compared to the neutral and the happy moods.

Carver (2003) proposed that individuals in the happy mood have additional attention resources available, which could be used to deal with problems or be attentive to sources of danger. The results of this study are partially in line with this model. Participants in the happy and the neutral moods reacted significantly faster to hazards than in the sad mood. This could be due to the different visual search patterns. According to Carver (2003) being in a sad mood does not encourage exploration of the environment; instead attentional resources are devoted to diminishing the cause of the sadness by producing a type of 'tunnel vision'.

However, the responses to the hazards were significantly faster in the neutral mood than the sad and the happy moods. The HRTs showed an inverted U shape. This does not fully support Carver's 'coasting' (gradual slowing caused by inertia, with no effort) prediction. Coasting would result in faster reactions in the happy mood than in the neutral mood. In addition, Carver (2003) proposed that 'the system' likes neither a sad nor a happy state; instead, it prefers a neutral state. In this case, the neutral mood (as the preferred one) and the happy mood (as the coasting) should have an advantage over the sad mood, but no difference between themselves, as they both represent an energy saving positive affect. However, HRTs were significantly different between the neutral and the happy moods and it is still not clear if and how the two positive conditions can significantly differ with regards to hazard response times.

This leads to the conclusion that, apart from mood valence, there is another aspect that could influence performance - mood arousal. A happy mood is considered to be a high-arousal physiological state (Gilet & Jallais, 2011;

Jefferies, Smilek, Eich, & Enns, 2008; Masmoudi, Dai, & Naceur, 2012). The level of arousal is an important characteristic of performance, first explained Yerkes and Dodson (1908b). The Yerkes-Dodson law states that arousal improves performance, but only up to a certain level. When arousal exceeds this level, performance deteriorates, creating an inverted U - shaped function, with the lowest performance at the edges. The hazard response data supports this model, the sad mood has the lowest arousal and the happy the highest, which caused performance deterioration in these conditions.

The questionnaire data in this study supports this model. There was no significant difference between the baseline, the happy and the neutral moods. Moreover, the participants reported feeling more positive at the beginning (mean 5.8 on a 10-point scale) compared to the neutral mood (mean 5.65). Although these numbers did not differ significantly, they represent a tendency in predicted direction, indicating that people are generally in a positive mood, as proposed by Diener and Diener (1996), which suggests that, by default, we feel a little bit better than neutral for the vast majority of time. Therefore, the neutral and the happy moods might be both considered as positive moods. However, it is still not clear how the two positive conditions can significantly differ with regards to hazard response times. According to the Broaden-and-Build theory (Fredrickson & Branigan, 2005) low (i.e. contentment) and high (i.e. excitement) emotional states broaden attentional scope by inducing different urges. For example, joy creates an urge to play, and contentment integrates the present life circumstances into new attitudes and representations. These different emotions are products of different arousal and result in different thought-action tendencies. The present research shows that the Yerkes–Dodson law can be applied to the mood-attention relationship in the driving environment. Consequently, these concepts permit us to refer to the neutral mood as a positive mood with low arousal and the happy mood as a positive mood with high arousal, although the present study did not find a significant difference between the happy and the neutral moods, which could be due to the questionnaire being not sensitive to arousal measurements. Therefore, when one conducts research investigating the impact of emotions on attention and performance, the level of arousal should also be taken into account.

Alternatively (Kahneman, 1973) suggests that attentional changes in high and low arousal depend on available cues. He states that in a low arousal condition there are many cues available to solve a problem. When arousal increases, the number of available cues diminishes. The more cues available, the longer the time required for processing and selecting the relevant ones, resulting in longer processing times in a low arousal state. However, a high arousal state implies more selectivity between relevant stimuli and concentration on fewer of them; this results in missing some of the important cues that could speed up the problem-solving process. Therefore, the most superior processing is observed in the midpoint of the arousal scale, resulting in an inverted U-shape. If access to the cues is restricted due to arousal, the limited available cues will slow down the processing times. In other words, positive affect with low arousal is the most optimal state of mind for driving. In this condition, drivers can spot hazards significantly earlier than in both negative affect and positive affect with high arousal. In other words, drivers' emotional involvement does not benefit drivers' attention and road safety, instead as less emotional involvement as possible encourages safe driving. This statement is also supported by Brodsky and Slor (2013) who found that elevated mood resulted in severely deficient driving behaviour.

The analysis also revealed that a number of videos were associated with significantly shorter HRTs. These videos contained 'unexpected hazards', which needed less time to process than 'expected hazards'. Unexpected hazards are those that appear suddenly; for example, a motorcycle moving out from behind a parked van. On the other hand, expected hazards are potential hazards that can be seen for a while and could or could not develop into real hazards. For example, when a car waiting to merge into the main road and giving way to oncoming traffic suddenly cuts in front of the participants car (Fig. 5). The reduced length of time required to process unexpected hazards implies a more automatic process as compared to expected hazards. The latter possibly required assessment and handling

(Shiffrin & Schneider, 1977). This leads to the conclusion that automatic and controlled processes are both affected by a participant's mood.

A significant interaction between Mood and Videos was found, with some videos showing faster responses. There is no definitive explanation for these results; however it could be speculatively assumed that the shorter responses were due to the presence of vulnerable road users in the videos. Yet, it equally could be that the 'time frame' (time needed for a hazard to develop into a critical event) was shorter for these videos. However, the sad mood resulted in longer response times to all the videos. This suggests that the introvert character of the sad mood prioritises personal emotions, therefore prolonging the reactions in this condition (Pêcher et al., 2009).

The current study presents both gaze data and the HRT measurement data, thus providing a possibility to investigate whether HRT could be related to longer processing, as indicated by the fixation durations. As for the glance measures, the findings are in line with previous research with the longest fixations in the sad mood (Kaspar et al., 2013). Driving safety research claims that fixation durations depend on driver experience with novice drivers fixating longer (Chapman & Underwood, 1998a), as well as road type with roads richer in road furniture generating shorter fixations (Chapman & Underwood, 1998b; Robinson et al., 1972) and driving conditions with low visibility resulting in longer fixations (Konstantopoulos, 2009). These studies relate longer fixations to longer cognitive processing time and failure to refocus attention (Underwood, Chapman, Brocklehurst, et al., 2003). Furthermore, (Huestegge, Skottke, Anders, Müsseler, & Debus, 2010) claim that these differences are due to faster processing among the experienced drivers. From the present study it can be concluded that the sad mood produces somehow similar outcomes. The sad drivers appear to need more time to switch their attention to different objects or they need more time for information processing.

Hazard response times, using computer-based tests, measuring the time from a hazard appearance till a button press, have been associated with road safety (Chou & Chuang, 2013). Well skilled drivers, with good ability of predicting the road ahead, detected more hazards and were quicker in responding to hazard detection tasks. The current study presents both glance behaviour measures and the computer-based data collection, thus providing evidence that HRTs could be related to the longer processing times as indicated by the fixation durations. However, the present research did not find a significant difference between fixation durations in the happy and the neutral moods, but did find a significant difference in the response latencies.

Figure 8: Examples of expected and unexpected hazards from Zimasa et al. (2017)

Another aspect that has been related to longer fixations is a reduced ability to refocus attention. For example, Mack and Rock (1998) referred to ‘inattentional blindness’ as a failure to recognise unexpected stimuli due to attention being focused on other aspects of the visual field. The present research brings combined evidence for both of these statements; longer eye fixations are mirrored in the longer HRTs. Both these factors are caused by reduced ability to switch attentional focus (Konstantopoulos, 2009). In this study longer fixations in the sad mood were accompanied by longer hazard response times, providing evidence that the reduced ability to refocus attention results in response delay. Longer fixations in videos without hazards were also found, which simply could be because the videos with hazards were interrupted by a button press after a hazard was detected. Videos without hazards, instead, required higher effort to search for hazards and, as a consequence, resulted in longer fixation durations. Nevertheless, positive conditions did not show the same effect. The reason for this is not clear- it could be that there was not enough power to pinpoint the differences in eye fixations, or that positive affect can influence only response latencies but not fixation durations. However, to be able to conclude with confidence which factor is the most influential, (attentional refocusing or prolonged processing time) one would need to manipulate attentional refocusing explicitly. For now it can be only taken as a preliminary result and a suggestion for further research.

4.5 Conclusions and implications for the next study

This study has found that the induced sad mood has a much stronger influence on HRT and drivers' attention, indicating that negative emotions have potentially greater effect on driving related skills compared to positive emotions. These findings are in line with the literature: showing that dealing with negative emotions is more costly in terms of demanding for more attentional resources. This study showed that sad drivers' hazard perception skills are impaired, as indicated by HRT and glance behaviours.

In driving safety research, the time taken to identify hazards and manually respond to them corresponds to a safety margin available to a driver. In this study, longer fixation durations are coupled with longer response times. Both these parameters are indicators of extensive processing potentially resulting in a higher likelihood of accidents and near misses. Thus, it can be concluded that sad drivers possess a reduced safety margin, and as a consequence higher accident involvement probability.

However, not all positive emotions lead to an improvement in performance. Simply dividing emotions into positive and negative affect is not sufficient.

Emotional arousal can act in a similar way as negative emotions, forcing the ‘system’ to make an effort towards emotional normalisation.

The results of this study indicate the importance of drivers’ mood for driving safety. However, clear evidence was provided only for differences between positive and negative mood valence. The differences between neutral and happy moods were also recorded, with drivers in a neutral mood reacting significantly faster to potential traffic hazards. The most obvious explanation for this is the difference in arousal between these two positive moods (Fredrickson, 2001). However, arousal was not explicitly manipulated and measured in this study. Therefore, it could only be assumed. With respect to emotional involvement, the next study should account for this shortcoming by employing a full design: positive and negative mood valence and high and low arousal.

Mood assessment: In addition, a self – report scale, capable of capturing drivers’ arousal should be used. Although self-report questionnaires have been proved to be a valuable and reliable measurement tool they demonstrate some substantial shortcomings (Section 3.2.1). For example, in this study it was difficult to distinguish between neutral and happy emotional states. It could be that the participants found it difficult to draw a borderline between neutral and happy emotions, with both of them being positive emotions. The use of physiological measurement together with self-reports could add to the emotional assessment reliability (Section 3.2.2). Moreover, physiological measurements should be collected, to support drivers’ self - reports of their mood valence and arousal.

Experimental setting: This study was a desktop experiment, having both advantages and disadvantages. This methodology permits the precise measurement of response times. However, desktop experiments permit only for data collection of a single metric, in this case – hazard response time, whereas driving is a complex task involving many sub – tasks and requiring simultaneous performance of all of them. For example, operating a vehicle, observing a road ahead, hazard perception and assessment (e.g. permanent hazards or developing hazards) (Driving test success, 2018). In real life, very rarely there is a situation when a driver is facing one hazard at a time. The fast changing road environment requires permanent concentration and situational updates. These conditions are difficult to implement in a desktop experiment, and a lot of useful information is missing. For example, whether drivers tend to drive faster or brake harder in a particular mood. These questions could be addressed by moving from low level behaviour to more complex level when many actions should be performed at the same time (e.g. operating car and observing environment). Hence the influence of drivers' emotions on driving behaviour and observational patterns was examined in the next study in a high – fidelity driving simulator.

Possible ways of reducing the negative impact of mood arousal and valence: Once such an impact is established, the next step is to minimise its harm and possible consequences. A methodology proficient in fulfilling this criterion should be developed. One of the solutions to this problem could be to add some cognitive load, to disconnect drivers from emotion induced mind wandering (see Section 2.7) This was done in the next study, in which not only was mood investigated, but so was cognitive load, in a form of a distractor task.

Chapter 5 – The simulator study to establish the effect of drivers’ mood and cognitive load on driving performance

5.1 Background and justification of the study

The desktop study examined whether positive mood theories can be equally applied to a driving environment. The results confirm that, at least with respect to hazard perception, a positive mood is superior for driving safety as compared to negative mood. The desktop experiment has shown that hazard perception and response times to hazardous events are dependent on drivers’ emotional valence. However, as Brookhuis et al. (1994) have argued, desktop laboratory tests have limited ecological validity. Besides, the relevance of such a delay in response to driving safety is difficult to establish. Similarly, it is not clear how conclusions drawn from the desktop study can apply to driving metrics, such as speed, following distance or braking metrics. Although the desktop study has shown some influence of emotion on response delay, this delay might be compensated for by increasing following distance or decreasing speed (Ranney et al., 2005). On the other hand, the response delay might be so minimal that it would have a little effect on drivers’ performance during a driving task.

Moreover, the results of the desktop study indicated that apart from emotional valence, some other variables affect performance. It is assumed that one of these variables could be arousal. Therefore, the simulator study was designed to control both aspects of emotion: valence and arousal. It was decided that negative valence would be represented by sad and angry emotions and positive valence would be represented by neutral and happy emotions. The emotions were the same as in the desktop study; only the angry emotion was added as a high arousal negative valence emotion to insure representation of all the bipolar dimensions.

One of the main aims of investigating the effects of external factors on driving safety is to establish the likelihood of accident involvement. Therefore the methodology should be maximally representative of real road situations (Brookhuis et al., 1994). Driving an instrumented vehicle in a field experiment provides richer information about the possible experimental outcomes. However this approach has two main disadvantages: lack of perceived risk and simulator sickness (De Winter, Van Leuween, & Happee, 2012). Nevertheless, the authors also named some advantages of using a driving simulator over field experiments, such as, experimental control, repetition, controlled interaction with other road users, possibility to design specific tasks (e.g. gap acceptance, car following), control of critical situations and advanced measurements. Often, lower risk perception is a less important factor than the possibility to control for the above named factors (De Winter et al., 2012). Similarly, a simulator experiment is more appropriate for addressing the research questions in this study.

Having found in the desktop study that drivers' emotional state affects their ability to react to expected hazards, the next step was to establish if these findings are replicated in traditional driving metrics, such as speed, acceleration, deceleration, lateral and longitudinal position, to name a few. These parameters are used to assess driving performance in research investigating the influence of various distracting factors on driving safety (Brookhuis et al., 1994; Greenberg et al., 2003; Jamson et al., 2004; Kountouriotis & Merat, 2016). These studies agree that the amount of information that drivers have to deal with at the same time cannot be wholly processed. Only some of the presented information receives attention and further processing. Drivers have to have enough attentional resources to deal with a fast-changing driving environment. If task demands exceed the available attentional resources, task performance is affected (Young et al., 2007). During driving, attention can be distracted away from the main task (driving) by such things as talking on a mobile phone (Organization, 2011), interaction with passengers (Heck & Carlos, 2008) or using in-car devices (K. Young, M. Regan, & M. Hammer, 2007).

The nature of these distractors implies that even hands-free tasks can significantly increase drivers' subjective workload (Matthews, Legg, & Charlton, 2003). Consequently, even when drivers' eyes are looking on the road, driver's mind can be occupied by driving unrelated thoughts. As demonstrated by Smallwood and Schooler (2006), often these lapses of attention are unrelated to driving, so-called *mind wandering.* Mind wandering is a default state of the human brain emerging during boring tasks with low processing demand (Forster & Lavie, 2009; Mason et al., 2007), which shifts attention away from the main task towards context irrelevant thoughts (Smallwood & Schooler, 2006).

This decreased attention may result in delays in registering the manoeuvres of other road users: cars, cyclists, pedestrians (Zimasa et al., 2017). This delay can be detrimental to road safety, for example, if travelling speed is too high to slow down or stop safely (Brookhuis et al., 1994). This could result in hasty braking or even too late braking, causing an accident (Young et al., 2007).

Apart from facing immobile and developing or expected hazards, one of the tasks that drivers have to perform every day is car following. In contemporary high volume traffic conditions, drivers have to possess skills permitting fast adaptation to the changes in speed or other manoeuvring of the traffic ahead. RTA Assistance Limited (2016) reported that each year in the UK approximately 400,000 rear-end bumps are registered, and for example, in the year 2010, 27% of all accident claims involved one car hitting another from behind. One way of measuring drivers' ability to respond to changes in lead vehicle's behaviour is a coherence task (see Section 3.6).

It is suggested by the developers of the coherence task (Brookhuis et al., 1994) that the distance that drivers keep between them and the lead vehicle is of major importance not only to avoid a crash; the outcome measurements of the coherence task are dependent on the following distance, chosen by the participating drivers. This dependency is caused by a driver's perception of the alteration of the lead car's speed which depends on the following distance (Janssen, Michon, & Harvey, 1976). However, Brookhuis and colleagues found that instructing the following distance to participants could lead to problems with the task validity. Indeed, this could lead to discomfort caused by unnatural, unusual and uncomfortable following distance. In the first experiments they tried to train the participants to keep a constant distance, but later decided in favour of drivers choosing their own following distances. One of the disadvantages of the latter is the variability in drivers' chosen distances in different conditions and the likelihood of this distance being different from the baseline.

A shorter TH leaves less time to respond to a potential hazard. This response is dependent on drivers’ emotions, cognitive load and their ability to switch attention from object to object (Crundall et al., 2003; Lee et al., 2007; Zimasa et al., 2017). For example, Tasca (2000) found that aggressive drivers are more likely to tailgate, and Green (2000) found that under cognitive load drivers’ stopping distance increases. However, the interaction between mood and load and their effect on the following behaviour has been under-researched.

Eye movement measures are reliable indicators of attentional shift (Underwood, Chapman, Berger, et al., 2003; Velichkovsky et al., 2003). The desktop study has shown that sad drivers are slower in attentional shift than happy and neutral drivers as indicated by longer hazard response times and eye fixation durations (Zimasa et al., 2017). However, the impacts of positive and negative mood valence and high and low arousal impacts on TH choice are not known.

The simulator study addresses both shortcomings: the validity issues resulting from controlled TH and the issues related to unnatural and uncomfortable following time. It is done by comparing changes in TH from baseline, as a reference point of a normal or usual driving style, to the driving style which occurs as a result of changes in drivers’ mood. It was hypothesised that the higher arousal moods would result in shorter THs. The lower arousal moods would elicit different behaviours: sad mood would result in slower attentional shift expressed by longer fixation durations and longer TH. The neutral mood should not bring any changes in TH and eye fixation durations.

Attention, as an important and necessary component of human life, has received extensive interest in many aspects of research (Driver, 2001), and in driving particularly (Trick, Enns, Mills, & Vavrik, 2004) (Sections 2.4 and 2.5). Trick and colleagues especially stressed the importance of visual and selective attention in a driving environment. Eye movement analysis helps to understand the practical application of visual and selective attention. The coherence task is largely based on drivers' ability to sustain their visual attention on a lead vehicle, mentally calculating, assessing and adjusting their following distance. Crundall, Shenton, and Underwood (2004) asked participants to drive through a simulated city with and without having to follow a lead vehicle. In the vehicle following condition participants fixated longer, and their fixations were less spread horizontally, they neglected pedestrians more and violated traffic rules. Crundall and colleagues concluded that car following has a negative impact on driving safety by narrowing drivers' attention. They attributed this deficit to inattentional blindness, a phenomenon occurring when the concentration on one of the aspects results in missing important information from other sources (Mack & Rock, 1998).

Chapman and Underwood (1998a) noted differences in the glance patterns of novice and experienced drivers. Experienced drivers' horizontal spread of visual search was much wider compared to novice drivers. However, the desktop study did not detect differences in the horizontal and vertical spread of fixations. The desktop study used a PC monitor to present drivers with video clips containing hazards. This could be one of the reasons why these differences were not detected. Hazard detection in a simulated driving differs from hazard detection on a desktop PC. Although Underwood, Crundall, and Chapman (2011) found similar outcomes on hazard perception experiments from desktop, naturalistic driving and driving simulator studies, simulator provides richer information.

Based on this literature review 6 hypotheses were proposed. The hypotheses are outlined in Section 3.8.

5.2 Method

5.2.1 The University of Leeds Driving Simulator

This study was performed at the University of Leeds Driving Simulator (UoLDS). The use of the simulator permitted examination of active driving behaviours in hazardous road situations. UoLDS is a motion-based simulator, therefore, driving scenarios could be tested in a more realistic environment. In addition, the car following task was performed, permitting examination of emotion-related changes in driving behaviours while following the lead vehicle. Rimini-Döring et al. (2005) describe this type of simulator as a highly immersive advanced system with dynamic motion and high levels of fidelity. It is based on a 2005 Jaguar S-type vehicle, equipped with fully operational controls, rear view and side mirrors, real steering wheel with force feedback and pedals. The vehicle is placed inside a dome (Figure 9). A spherical screen projection area provides the road environment at 60 Hz and a resolution of 3x1920x1200 to the front and 1024x768 in the peripheral and rear views. The field of view of the rear and side mirrors is 42°. The view is displayed on the mirrors. During the drives, a participant perceives braking and cornering forces as well as rough patches on roads and road 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 can move the dome in six orthogonal degrees-of-freedom (3 linear, 3 rotational). Additionally, for a better simulation, rails permit for a further 5 m of movement to the front and side in the longitudinal and lateral directions. The vehicle's software assumes an engine model from a 2002 Jaguar X-type and braking data from a Ford Mondeo. The simulator records data at 60 Hz from the driver's inputs, the vehicle movement and position, as well as data related to other vehicles on the simulated road.

The road layout for this study comprised rural and urban road sectors forming a single section for a 17.5 minutes' drive. The road setup comprised one lane in each direction and was appropriate for scenarios involving hazardous situations and a coherence task.

Figure 9: The University of Leeds Driving Simulator (University of Leeds, 2013)

5.2.2 Materials and Apparatus

5.2.2.1 Empatika E 4 wristband

Empatika E4 is a wearable wireless multi-sensor device used to collect physiological measurements during the experiment (Figure 10). This is a non-invasive, small (4cm x 4cm) and lightweight (25 grams) watch-like device for accurate real-time monitoring and recording physiological measurements for later analysis, using its internal flash memory. Measurements are taken using 4 sensors efficiently combined into a wristband:

1. Photoplethysmography sensor, which measures Blood Volume Pulse (BVP) from which Heart Rate Variability (HRV) and other measures can be calculated,
2. 3-axis Accelerometer, which captures motion-based activity,
3. Electro dermal activity sensor (EDA), which is used to measure sympathetic nervous system arousal,
4. Infrared Thermopile, which reads peripheral skin temperature.

Figure 10: Empatika E4 wristband. Front view on the left and sensors view on the right side

5.2.2.2 Glance behaviour measures

Eye movements were recorded using a Seeing Machines face LAB v5 eye-tracker fixed on a front panel in the driving simulator, enabling recording of drivers' gazes in real time with an accuracy of ±1° and frequency at 60 Hz.

5.2.2.3 Questionnaires

Demographic information

A questionnaire, collecting demographic information, was completed by participants before the experiment. The questionnaire included country of origin, years of driving experience in general and particularly in the UK and yearly mileage (see appendix 1).

Mood assessment

Each participant was asked to fill in two mood assessment grids (Russell, Weiss, & Mendelsohn, 1989) (Figure 11): one before the experiment, to assess the baseline mood valence and arousal, and the other at the end of the study, to assess their mood during the experiment. The participants had to mark one square for both valence and arousal. For example, Figure 11 shows a mark that indicates 7 for mood valence and 7 for arousal, both on scale from 1 to 9.

In addition, the participants were asked to answer some questions related their perception of task difficulty and whether cognitive load had an impact on their ability to concentrate on the driving task. The participants were asked to circle a number from 1 to 5 on Likert scale, with 1 meaning ‘not at all’ and 5 ‘totally apply’ (see Table 3 for example questions and Appendix 1).

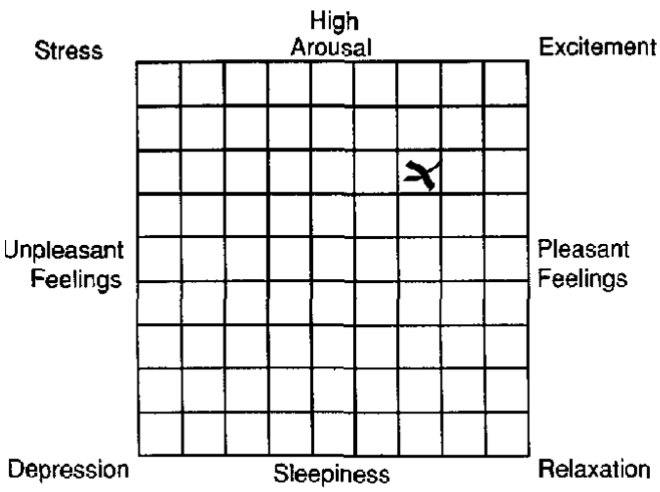


Figure 11: Mood - assessment grid (Russell et al., 1989)

Table 3: Mood - assessment questions

After experiment questions
1: ‘Did you feel calm (happy, sad, angry) during the drive?
2: ‘Was it difficult to concentrate on driving while feeling like this?’
3: ‘Did you feel distracted when asked driving-related questions?’
4: ‘Did you feel distracted when asked general questions?’

5.2.3 Experimental design

A (3x4) mixed design was employed with Load as the within-subject factor (3 levels – No-load (NONE), Non-driving related load (NDRL) and Driving related load (DRL)), and Mood as the between-subject factor (4 levels – Neutral, Happy, Sad and Angry).

The baseline measures were taken before each Mood induction and comprised of a normal drive, with the instruction ‘Drive as you would normally’. This condition was needed to establish participants’ normal driving style and to check whether there were individual differences between groups.

Within every Mood condition, participants performed three drives: NONE (when no-load was applied), NDRL and DRL. Each drive consisted of all the hazards, catch events and coherence task. The hazards and catch events where counterbalanced using pseudo counterbalancing. In each drive there were 8 scenarios: 3 catch events, 4 hazardous events and 1 coherence task. The coherence task, number 8, was always in the middle after the 4th event. Altogether there were 4 orders of hazard representation, and within each order, the hazards were represented in a different sequence. For an example of the experimental structure see Table 4 and Figure 12.

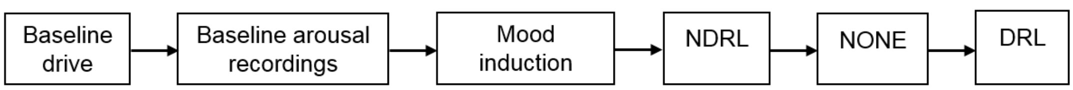


Figure 12: Example of the experimental run

Table 4: Hazard order numbers and hazard sequences within these orders, 8 indicates coherence task

Order	Scenario number
1	3, 5, 7, 4, 8, 2, 6, 1
2	1, 3, 2, 7, 8, 5, 6, 4
3	6, 1, 2, 5, 8, 4, 7, 3,
4	2, 7, 4, 6, 8, 1, 3, 5,

5.2.4 Driving scenarios

The experimental roads were 42.56 miles long, which provided for approximately 64 minutes of driving (16 minutes each driving). The road comprised one lane in each direction, leading through an urban area for the hazardous events and rural area for the coherence task. There was no traffic in the participant's lane, except in the coherence scenario and when cars merged into the lane in the hazardous events. The posted speed limits were 40 mph (64 km/h) for hazard scenarios and 60 mph (97 km/h) for the coherence task.

To assess the effects of different Mood and Load conditions on drivers' behaviour in dangerous situations, 4 hazardous events were developed. The coherence task permitted the evaluation of a driver's ability to follow a car. See (Figure 13, Figure 14, Figure 15, Table 5) for description.

Three catch scenarios were designed to prevent hazard anticipation on approach to each junction. In these scenarios, a vehicle passed across the junction, without merging in participant's path. In these scenarios participants could drive across the junctions without slowing down.

Table 5: Description of driving scenarios

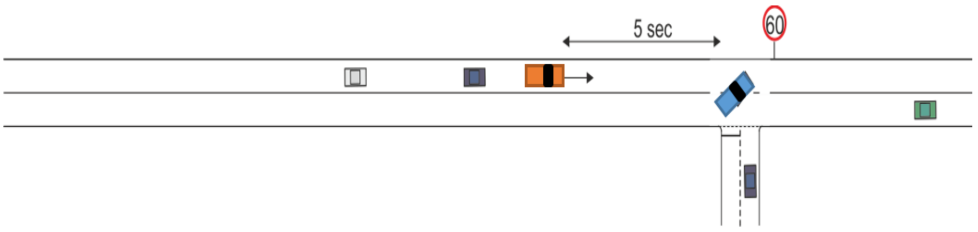
Scenario	Scenario description
1) Parked car in group of cars hazard	A parked car moving off from the left side of the road without having signalled when time to collision (TTC) of the participant's vehicle with the moving off vehicle was 2.5 seconds. The car was fourth in a row of cars. The participant had the choice to either brake or try to overtake it. The merging vehicle accelerated away and cleared the road by the next junction. TTC = 2.5 seconds.
2) Single parked car hazard	A similar scenario to scenario 1, the difference being that the merging vehicle was the only one that was parked on the roadside.
3) Car merging from left side junction hazard	A car merging from a side road on the left when TTC of the participant's vehicle with the stop line of the junction was 2.5 seconds. The merging car could be seen on approach, and the reaction of the participant would depend on how early it was perceived.
4) Car merging from right side junction hazard	A similar scenario to scenario 3, with the difference being that the merging vehicle came from the right side of the road.
5) Catch scenario – car from right junction	The participant's vehicle is approaching a junction when a vehicle crosses the road on the junction from the right side. The vehicle is not merging but just crossing it. TTC is 3 seconds,

	however, the participant could proceed without the braking.
6) Catch scenario – car from left junction	A similar scenario as scenario 6, with the difference that the merging vehicle crosses the road from the left.
7) Catch scenario – cars from two sides	A similar scenario as scenario 6, with the difference that there are two crossing vehicles from the left and the right side.
8) Coherence task	The participant follows a lead car that varies 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 reaches its minimum/maximum speed of 50/60 mph every 33.3 seconds and oscillates between them. The scenario was 2 minutes long.

Road layout – 'Coherence task'

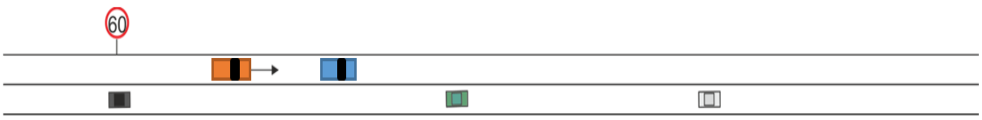
a) Beginning of 'Coherence task'

The participant's vehicle is approaching a crossroad while driving on a single carriageway (main road). The scenario begins 5 seconds from the junction. There are no traffic lights.



b) The task

The participant is following a lead vehicle, trying to match own car speed with the lead car speed.



c) End of 'Coherence task'

The lead car turns left at the junction.

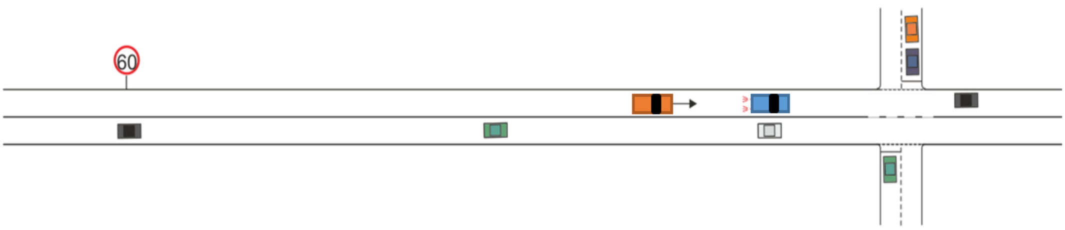


Figure 13: Road layout for the coherence task; a) beginning of the task, b) the task, c) end of the task (- participant's car, - lead car, - speed limit)

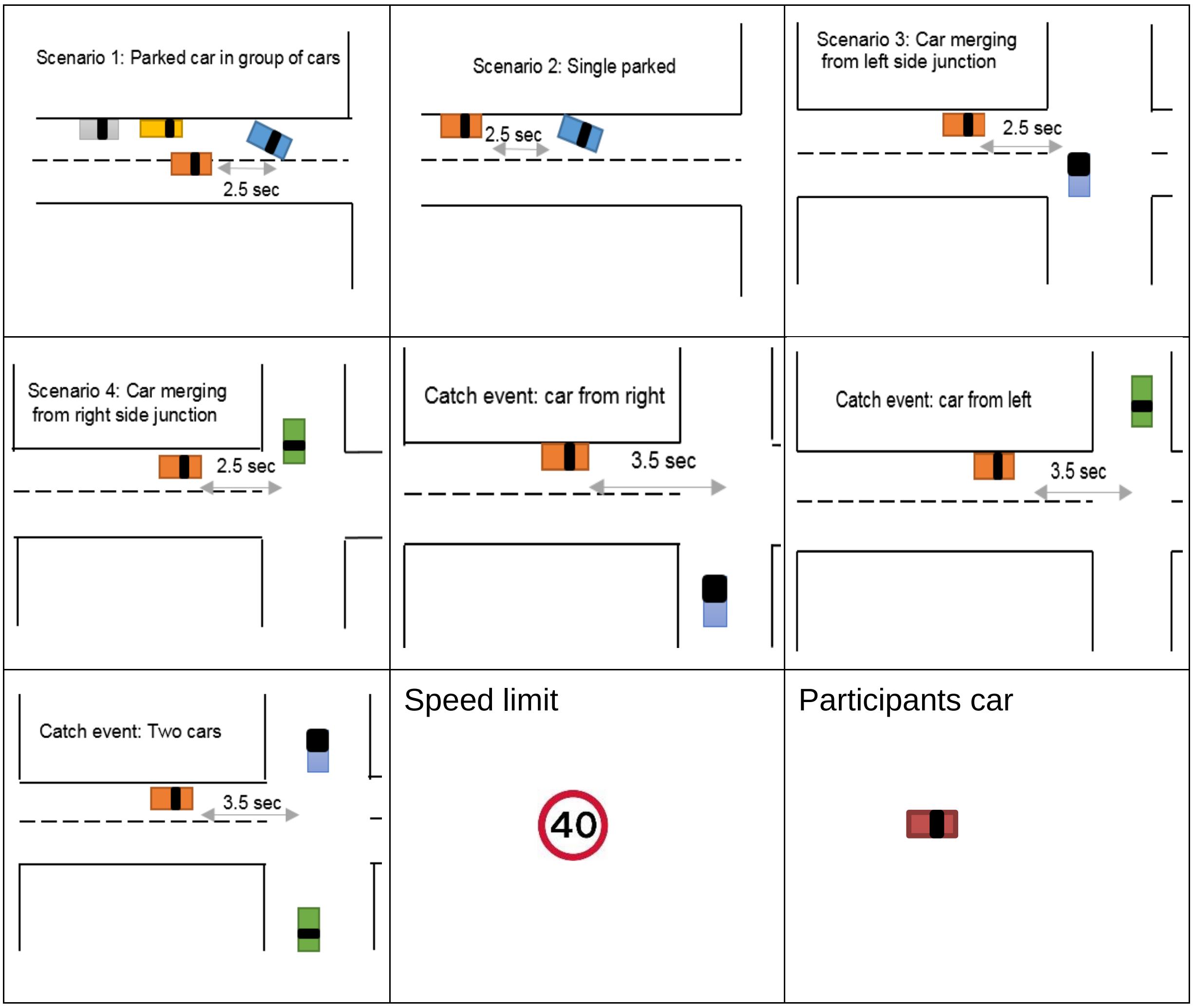


Figure 14: Examples of road layout of scenarios

Figure 15: Hazardous event – car from the right

5.2.5 Independent variables

5.2.5.1 Mood

Four moods were induced: neutral, happy, sad and angry. Similarly to the desktop study, this study used a mixed method for mood induction. The driving simulator does not have suitable facilities for the presentation of pictures, thus the music with corresponding pictures was changed for music with mental imagery (Table 6). Also, if pictures had been presented on a head-up display this might cause a visual distraction. The music excerpts were played continuously throughout the drives.

Table 6: Music used for mood induction

Mood	Music
Neutral	1) Chopin Waltz No. 12 in F minor, Op. 70, No.2 2) Chopin Waltz No. 11 in G flat, Op. posth, 70 No. 1
Happy	1) Delibs (1870), Mazurka from Coppelia 2) Bach (1721). Brandenburg Concerto #2
Sad	1) Chopin (1839). Opus 28,#6, from Preludes, Played by Alessandra Ammara, piano 2) Prokofiev (1938). Russia Under Mongolian Yoke from Alexander Nevsky
Angry	1) Mussorgsky (1867) – Night on Bald Mountain, played by symphonic orchestra. 2) Holst (1918). – The Planets – Mars, the Bringer of War

5.2.5.2 Cognitive Load

Three types of load were applied: no-load (NONE), non-driving related load (NDRL) and driving related load (DRL). Cognitive load was added as a disconnector from mood induced mind wandering, as Lavie (2010) suggests that internal forms of distraction, such as mind wandering, can be overcome by increasing perceptual or cognitive load. The purpose of the cognitive load in the present study was not to distract from the driving task but to redirect drivers' attention from the induced mood, and therefore acted as an intervention. In order for load not to interfere with driving, the questions were asked 2 seconds before a hazardous event occurred.

In NONE condition, when no questions were asked, drivers were the most affected by the mood induced mind wandering. NDRL was created by asking general questions. Whilst, DRL was created by asking questions about driving and road safety (Table 7).

All questions mainly required short, one or two word verbal answers. The participants were told that their answers would not be assessed, but they still have to vocalise the answers, as this would confirm that they were following the instructions. The experimenter observed the participants from the control room through monitors to ensure that the participants were answering. All the participants were asked the same questions at the same place. Some of the questions were repeated during the coherence task. For example, the question ‘what is the speed limit on this road?’ was repeated twice, before one of the hazardous events and during the coherence task. The nature of the questions implied that a participant might or might not be visually distracted from the point that they were looking at the moment of a question. For example, if the question was ‘what does it say on the road sign on your left’, this would direct a driver’s attention to that road sign. If the question was, ‘what is an appropriate speed limit for this particular road’, the driver would not have to look in any particular direction but would be able to answer based on existing knowledge. The questions were only mildly loading so as not to require too much processing that might distract drivers’ attention and demand compensatory mechanisms, such as speed reduction.

5.2.6 Dependent variables

The data collected in this study included:

- Questionnaire data, including mood self - report (valence and arousal) before and during the experiment, self - report on questions determining participants’ evaluation of cognitive load, induced moods and how much these factors interfered with their driving.
- Physiological measurements (EDA and HR), collected using Empatika E4 wristband, were used to assess participants’ arousal in different Mood and Load conditions.
- Glance behaviour data – number of fixations, fixation durations and spread of fixations were measured.
- The driving related measures, collected in driving simulator included: speed, brake force, time on the brake, acceleration. A separate analysis was performed on each hazardous event and on the coherence task. The coherence task also included an analysis of correlation, phase shift, modulus and time headway.

Table 7: Questions asked during the drives

Driving-related load	Non-driving related load
What is the speed limit on this road?	What did you have for breakfast today?
Do you think it would be safe to drive faster on this type of road?	Are you hungry now?
What does it say on the road sign on your left?	Would you like to be on a sunny beach now?
Is it safe to overtake these parked cars?	Do you have a dog?
What if a car emerges from a side road?	Do you like this music?
Are parked cars always hazards?	Do you consider yourself fit and active?
Could there be a hazard after a road bend?	Do you like cycling?
Could traffic lights suddenly change?	What is your name?
What is appropriate speed for this road bend?	Can you hear this question clearly?
Is it safe to overtake the car ahead?	Is my voice too loud in this question?

5.2.7 Participants

The participants were recruited using the University of Leeds simulator participant pool as well as personal contacts. The individuals who participated in the desktop study did not take part in the simulator study. The inclusion criteria were driving experience no less than 3 years and driving no less than 5000 miles per a year. As a gesture of appreciation, all participants were given £20.

Table 8: Participant demographic information

Mean age	SD	Maximum age	Minimum age	Male	Female
38.48	12.29	70	22	26	14

5.2.8 Procedure

After completing the consent forms and a standard safety briefing, participants were asked to complete a pre-study questionnaire. Then, the wristband for physiological measures was put on participant's wrist. After this, they were asked to perform a familiarisation drive with an experimenter present in the simulator. The hazard scenarios involved in the experiment were not used in the practice drive to prevent participants from expecting them.

After the practice drive and a short break, the participants were left in the simulator on their own. The first drive was completed without music and questions. This was to establish participants' normal driving style, to be able to measure changes induced by the experimental conditions. The participants were instructed to drive as they would normally, handle hazardous situations in their normal style and for the coherence scenario they were instructed as follows: "During the 'coherence task,' you have to follow the lead vehicle at a distance which you consider to be the safest and convenient. The speed of the lead vehicle will fluctuate. You have to try and keep this distance constant and try to do it smoothly, without rapidly braking and accelerating." The first drive lasted about 16 minutes, and is referred to as the baseline drive.

The baseline measurements for physiological arousal were then taken after a short break, after the baseline drive. This was done to insure that pre-study excitement or worries did not affect the measurements. The participants were asked to close their eyes sit calmly and relax, thinking about something that would keep them calm and as emotionless as possible for four minutes. Fishel, Muth and Hastrup (1986) suggest that approximately 3 minutes are needed to establish individual physiological baseline measures and another 1-2 minutes for adaptation before the measures are recorded. The adaptation time depends on experimental design. In the present study, 1 minute of adaptation was chosen, as participants already had been given time to accommodate to the experimental setting (e.g. practice drive and break).

After this, participants were asked to listen to one of the musical excerpts and think about events in their life that corresponded to the music. For example, when ‘happy’ music was played, they were asked to think about something very happy that happened to them previously and made them happy. The music was played through the simulator car speakers with a volume of 80dB, but the participants could ask to lower this if they felt uncomfortable. The music was continously played during the drives, but the volume was turned down to about 60dB, the volume of normal conversation.

Next, participants had to perform 3 more drives, approximately 16 minutes each, under different cognitive loads. These were: drive with no questions asked (NONE), drive when driving-related questions were asked (DRL) and drive when general questions were asked (NDRL). The order of the drives was counterbalanced. The questions were asked through the hands-free communication system in the vehicle at a volume of 65dB, so it was not too loud, but could be heard regardless of the music. The volume was measured using SPLnFFT Noise Meter. The participants were instructed to answer every question using one or two words maximum, and not thinking a lot. They were told that they would not be assessed on their answers and that the answers are needed to make sure that the participant engaged with the task.

Participants were offered short, 2 – 5 minutes breaks between the drives. During the breaks they could leave the simulator for should they need to do so. After the experiment, participants were seated in the room next to the simulator and asked to complete the last part of the questionnaire. This included: their mood assessment during the experiment and some questions that could help to assess the influence of mood and load on their driving (Table 3). Finally, participants were debriefed and their right to withdraw was repeated.

5.3. Data analysis

5.3.1 Overall approach

The data collected from the participants who withdrew from the study without fully completing it was excluded from the analysis. In cases when glance data were not possible to collect (e.g. calibration failure), the driving behaviour data was included in the analysis. For the coherence task there was missing data in the no-load neutral mood and NDRL in the happy mood. Multiple imputations were used to compensate for the missing data. Glance behaviour data analysis was not performed for the hazardous events due to a lot of missing data.

In the coherence task the driving behaviour data was missing for 2 participants in the angry and 1 participant in the happy mood. The data was missing due to participants overtaking the lead vehicle. The analysis was therefore performed on 37 participants. There was no behavioural data missing for the hazardous events.

EDA and HR data from 36 participants was used with four participants' data been lost due to a technical fault.

The driving related raw data collected in the driving simulator was processed in Matlab, and the data collected from the eye tracker was processed in R. For the baseline measures of behavioural and eye movement data, one-way ANOVAs were performed where the data were normally distributed and Kruskal–Wallis tests were used when the distribution was violated.

The eye tracking data and the simulator data were analysed in two ways. First, a comparison of differences between the four Mood and three Load conditions were assessed. This established whether the experimental manipulations had a significant impact on participants' driving behaviours and glance patterns. Second, the baseline data were subtracted from the data collected during driving under the corresponding experimental manipulations. For example, the data collected from the happy condition was subtracted from the corresponding baseline. The corresponding baseline was the baseline that relates to a particular mood for a particular participant, as mood was a between-subjects factor. This established changes in drivers' usual driving and glance behaviours as a result of mood induction. It permitted the assessment of whether the changes in Mood and Load conditions were due to an increase in one condition or decrease in the other. For example, if a significant difference in speed was found, it is not clear whether that difference is due to the significant increase in speed in the angry mood or a significant decrease in speed in the sad mood. Another example is when there are no significant differences in speed between the conditions, but analysis of changes shows that there is a significant difference in speed changes because of speed decrease in the sad mood and increase in the angry mood. This method permits the monitoring of mood-related changes in more detail and the drawing of more robust conclusions.

Repeated measures ANOVA was used to compare the differences between the conditions and the changes from baseline, with the within-subject factor Load (3 levels: NONE, NDRL and DRL) and the between-subject factor Mood (4 levels: neutral, happy, sad and angry). For the within-subject effect, Greenhouse-Geisser correction was used, if the assumption of sphericity was violated. In the following sections, the specific data analysis techniques are described.

Mixed ANOVA was used to determine whether significant differences between any of the variables can be merely explained by the main effects, or some of the findings should be attributed to the interaction between these variables (Stefan & Mats, 2016). To understand the meaning of these interactions, simple effects of post hoc tests were conducted. This frequently used procedure has two main weaknesses: it is ineffective in extracting the effects of central interest from the factorial ANOVA, and it is sensitive to an effect of sphericity (Boik, 1981). He argues that even small deviations from sphericity result in considerable biases in F-tests. Therefore f- tests should be avoided in repeated measures design.

Contrast analysis can be performed to overcome these weaknesses. Rosenthal, Rosnow, and Rubin (2000) define contrast analysis as an approach of comparing one set of means with another set of means. They state that asking focused research questions permits for a greater conceptual precision and greater statistical power in statistical analysis, hence, discovering an effect if it truly exists.

However, performing several statistical tests on the same data increases the probability of Type I error (e.g. accepting an alternative hypothesis when there is no experimental effect) (Abdi & Williams, 2010). There are several ways of controlling for this shortcoming, which can be divided into pre-study procedures and post-study procedures. For the post study procedures, post hoc tests with Bonferroni correction were used. The pre-study procedures, or planned comparisons, also were used as an alternative to post hoc procedures and to control for Type I errors (Stefan & Mats, 2016).

Thompson (1990) distinguishes between orthogonal and non-orthogonal contrasts. Orthogonal contrasts are statistically independent, meaning that the results of one contrast do not reveal information about the other contrast. Keppel (1982) states that the value of conclusions drawn from orthogonal contrasts is based on the independence of interferences in a way that any decision regarding the null hypothesis of a comparison is not influenced by the decisions regarding any other comparisons. However, besides all the advantages of orthogonal comparisons, there is one substantial shortcoming, that is a necessity for a balanced design or an equal number of data points in each condition (Winer, Brown, & Michels, 1971). However, Winer and colleagues argue that orthogonality is not an absolute must for planned comparisons. They state that comparisons should be constructed to have an experimental meaning, rather than be constrained by orthogonality. Interesting questions should be asked without worrying about redundancy. Similarly, Miller Jr (1977) states that there is no easy and straightforward way for deciding on contrasts. Researchers should be guided by their judgment and experimental design. Large experiments, with complicated mixed designs, cannot simply be treated as one ‘family’, as this can lead to a loss of sensitivity and poor explanation of the experimental results. Minium and Clarke (1982) also add that the protection of Type I error is too conservative, hence lowering the power of the tests. Overall, many researchers agree that planned comparisons should be performed even if F-tests are not significant (Kirk, 1982; Rosenthal et al., 2000; Stefan & Mats, 2016; Thompson, 1990; Winer et al., 1971).

The results of the desktop study provided some prior knowledge about the effects of drivers' mood on drivers' attention, thus permitting for more detailed hypothesis and consequently, for planned comparisons. Therefore both factorial ANOVA and planned comparisons are used to analyse the results of this study, permitting for deeper analysis and more detailed explanations.

Orthogonal tests could not be used in this study due to unequal participant numbers in each condition (Winer et al., 1971), thus non-orthogonal contrasts should be used instead. There are three types of non-orthogonal contrasts: repeated, simple and deviation. Repeated contrasts are usually used to analyse data which has a meaningful order, such as repeated measures after every month: month 1, month 2, month 3, or increased dose of medicine: 10 mg, 15 mg, 20 mg (Field, 2009). Therefore they could not be used to analyse discrete conditions. Simple contrasts are useful when there is a baseline condition. It compares the mean of each condition to the mean of the reference group. The first or the last group can be chosen as a reference (Field, 2009). This method would suit to this study to some extent. The load conditions had baseline level, which was the level when no load was applied. However, the Mood conditions did not have a true baseline level. Even the neutral mood is determined by low arousal and positive valence. Therefore, it cannot be considered a true baseline, and simple contrasts could not be used to analyse the Mood conditions. Deviation contrasts compare the mean of each condition (except the reference level) to the average of means of all the other levels (grand mean) (Field, 2009). This method is appropriate for the present study and permits for valuable statistical inferences about the effects of each mood on drivers' behaviour.

In summary:

Factorial ANOVA was used to assess main and interaction effects in the experiment, and post hoc tests with Bonferroni correction. SPSS software was used for the analysis. Deviation contrasts were used to obtain a more detailed picture of these effects and to establish whether there were any trends in the data. JASP software was used for the contrast analysis. General linear model (GLM) regression tables (parameter estimates) were used to predict changes in dependent variables. For parameter estimates *t* – values, *p* – values and h_p^2 – partial eta squared are reported. The neutral mood is always the reference condition (redundant variable or intercept), it is calculated with all other variables held constant. The other parameters are calculated with reference to the neutral mood.

5.3.2 Glance behaviour patterns

In visual search activities, the human eyes move two to five times per second (Rayner, 1998). This process brings environmental information into a foveal information processing region. The point between eye movements, when an eye is still, and a fovea is directed to an information processing point, is called a fixation. For the present study, the 'Dispersion-Based-Algorithm' was used to identify the eye fixations (Salvucci & Goldberg, 2000). This method utilises the fact that fixation points tend to cluster closely together. There is no agreement in the literature about the length of a fixation needed to be able to process information. The time dispersion is wide – between 100 to 300 milliseconds (Salthouse & Ellis, 1980). Moreover, Duchowski (2002) suggests an even bigger interval 150ms – 600ms. Some research claims that to detect an object only a few milliseconds are needed and other 250 milliseconds are needed to process this information (Holmqvist et al., 2011). Nevertheless, others state that for simple processing only 100 milliseconds are needed (Rayner, 1998). Salthouse and Ellis (1980) also concluded that the time needed for a stimulus identification is 80-100 milliseconds; however, normally fixation durations are 250 milliseconds while processing information. A temporal threshold of 200 milliseconds is considered to be a standard in studies of normal and psychiatric groups (Manor & Gordon, 2003) and therefore was adapted as a suitable measure for the present study. Widdel (1984) also stated that a 200 milliseconds threshold permits capturing a minimum pose of an eye without much stimulus processing, which is an important component in driving for early detection.

5.3.3 Questionnaires

For the analysis of the questionnaires and grids, one-way independent ANOVAs were used where the data were normally distributed, and the Kruskal-Wallis non-parametric equivalent to ANOVA was used if the data were not normally distributed. For follow up studies Dunn-Bonferroni corrections were applied.

5.3.4 Physiological measurements

Physiological data measurements were assessed separately for mood induction and during the driving. For mood induction the physiological measurements were assessed by subtracting the data obtained during the mood induction from the data obtained during the rest (baseline). This was done to eliminate any individual differences in the measurements (Boucsein, 2012). To calculate tonic EDA and HR during the drives, the data collected during a drive under a particular mood was subtracted from the data recorded during the drive without mood induction for the same individual. This method permitted the calculation of only mood induced changes in individuals' skin conductance and heart rate. The results of mood induction were analysed using between-groups ANOVA for the parametric data and Kruskal–Wallis test if the data were not normally distributed. The results gained from recordings during the drives were analysed using mixed ANOVA, with Greenhouse-Geisser correction, if the assumption of sphericity was violated.

The effect of Mood and Load on EDA and HR during the coherence task was investigated similarly. The data collected during the experimental drives was subtracted from the baseline drives, to account for individual differences. As the baseline was always the first drive, it was expected that EDA and HR would be higher during the baselines, due to task novelty. They were expected to decrease as the drivers became more familiarised during subsequent drives.

5.3.5 Coherence task

The coherence task included 2 cycles, 1 minute each. Each of the cycles was analysed separately, as the second cycle could induce some repetition effect. Driving performance assessed using several metrics:

- Coherence, phase shift, modulus (Brookhuis et al., 1994). The description of these parameters are provided in Section 3.6
- Time headway (TH)

First, any THs longer than 6 seconds were excluded from the analysis, as they were considered to be too long to be following (Vogel, 2002). Then, all THs less than 6 seconds were divided into 6 one second intervals: 0-1, 1-2, 2-3, 3-4, 4-5, and 5-6[1]. For each time segment, the proportion of time participants drove in each time segment as a proportion of all time spent following was calculated and compared across conditions. These times were calculated separately for each Mood and each Load.

In addition, physiological and glance metrics were analysed during the coherence task.

5.3.6 Hazardous events

For this analysis, time windows of 3 seconds were created around the hazardous situations. The beginning of the time window was a trigger point of a hazard, which was set to 2.5 seconds to time to collision (TTC) between the participant’s car and the hazard. The 2.5 seconds trigger point forced the drivers to actively react to the hazards in a way that the reaction would depend on the drivers’ observational patterns and driving parameters (speed, acceleration, brake) on the approach to the hazard (Lee, 1976). The 3 seconds window was chosen so the drivers’ behaviours could be measured

[1] The times are calculated from 0 to less than 1 (1 not included), from 1 to less than 2 (2 not included), and so on.

on the approach to the hazards as well as their reaction after the hazards were dealt with. This method was used to analyse four hazardous events: 'Single parked car', 'Parked car in group', 'Car merging from right' (CFR) and 'Car merging from left' (CFL). The hazards were designed so 'expected hazards' and 'unexpected hazards' would be included. The desktop experiment found that drivers reacted differently to expected and unexpected hazards. These differences were further explored in the simulator study. CFL hazard was classified as unexpected hazard, as it could not be seen on approach to the junction, and merged unexpectedly straight in front of the participants' car. CFR was seen on approach to the junction, thus permitting more time for assessment and action. Parked cars could be seen on approach and thus could be anticipated as hazards.

For all hazardous events several measures were recorded and compared: mean speed, speed variation, acceleration and deceleration, time actively braking, braking force and maximum brake. **The time actively braking** included all time when a driver actively pressed the brake pedal during the hazardous event. **Braking force** is the power with which a driver presses the brake pedal (measured in Newtons).

For the braking data analysis, all the data containing braking information was extracted from the data files, and all the data that did not represent active braking (zeros in the data files) were excluded from the analysis. Braking force was calculated as the average of all braking force during the hazardous event. For braking time, the number of rows was divided by 60 (60 Hz data collection). This enabled the comparisson of the time actively braking in each condition.

ANOVAS, post hoc tests and contrasts were performed the same as for the car following task.

5.4 Results

5.4.1 Self-reported emotions

The analysis of the pre-study questionnaires showed that there were no significant differences in mood valence between the participants assigned to the different conditions (mean-6.63, standard deviation SD-0.42 on a 9-point scale). There also was no significant difference in arousal levels between the groups prior the experiment (mean-6.13, SD-0.19 on a 9-point scale). This indicates that the participants in each group were in approximately the same positive mood and similarly aroused prior to the experiment.

The analysis of the post-study questionnaires revealed significant differences in the participants' mood valence between the four groups, $F_{(3, 35)} = 7.43$, $p < 0.05$, $\eta^2 = 0.39$ (Figure 16). Pairwise comparisons showed higher scores in valence in the happy mood compared to the sad mood, $t = -2.85$, $p < 0.05$, and compared to the angry mood, $t = 3.5$, $p < 0.05$, and higher scores in the neutral mood compared to the sad mood, $t = -3.11$, $p < 0.05$, and. There were no differences between the sad and the angry moods and between the happy and the neutral moods, both $p > 0.05$.

There also were significant differences in arousal between the groups, $F_{(3, 35)} = 7.04$, $p < 0.05$, $\eta^2 = 0.38$. Pairwise comparisons showed higher arousal in the angry mood compared to the sad mood, $t = -3.61$, $p < 0.05$, and compared to the neutral mood, $t = -3.68$, $p < 0.05$, and the happy and the neutral moods, $p < 0.05$. There were no differences between the sad and the happy, the sad and the neutral, and the happy and the angry moods, all $p > 0.05$.

These results indicate that the participants rated their mood as more positive after the positive valence conditions as compared to the negative valence conditions. The participants also considered their arousal being significantly higher after the high arousal conditions (happy, angry) as compared to the low arousal conditions (sad, neutral). However, it must be noted that the difference between the sad (low arousal) and the happy (high arousal) moods was only marginally significant $p = 0.053$.

Means and standard deviations for post study self-reported valence and arousal are displayed in Table 1 of Appendix 2.

Changes in the mood valence and arousal from the baseline:

The changes in mood valence and arousal from the baseline to the corresponding Mood condition were also analysed (Figure 16). There was a significant difference in the changes of the reported mood valence between the pre and post-test study questionnaires, χ^2 (3) = 15.82, $p < 0.001$, η^2 = 0.42, with a mean rank score of 28.2 for the sad, 12.7 for the happy, 12.67 for the neutral and 25.7 for the angry moods. The results show that the most mood valence changes have occurred in the sad and the angry moods. This result was expected, as prior to the study participants mostly scored high on mood valence, indicating that they were in a positive mood prior to the study. There also was a significant difference in the changes of the reported pre and post-study arousal, χ^2 (3) = 14.87, $p < 0.001$, η^2 = 0.24, with a mean rank score of 27.7 for the sad, 14.15 for the happy, 26.39 for the neutral and 12.4 for the angry moods. The results show that the most changes in arousal occurred in the sad and the neutral moods. This result was expected, as prior to the study the participants mostly scored high on arousal, indicating that they were energetic and aroused prior to the study. The sad and the neutral mood inductions appear to have a calming effect on the participants.

In summary:

The valence and arousal assessment grid reliably distinguished between the induced moods, with high arousal moods showing an increase in arousal from the baseline and low arousal moods not inducing a significant change. The participants assigned to the happy group even indicated lower arousal level compared to their baseline arousal. This could be due to the participants feeling more tired after the study.

Participants assigned to the negative valence groups indicated a significant change in their mood valence after the experiment. Whereas participants in the positive valence groups did not report mood changes.

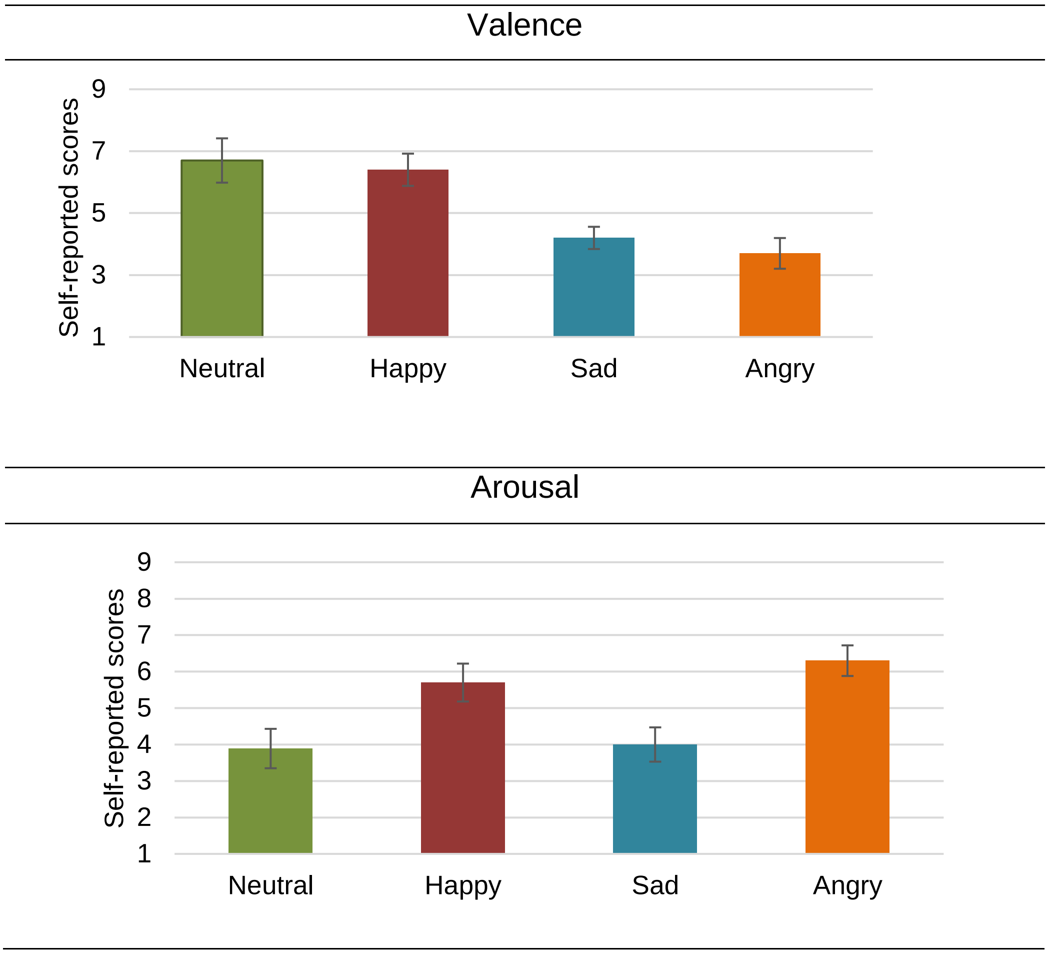


Figure 16: Mood valence and arousal - post-study assessment[2]

2 Self-rated on an assessment-grid from 1-not at all to 9-felt a lot

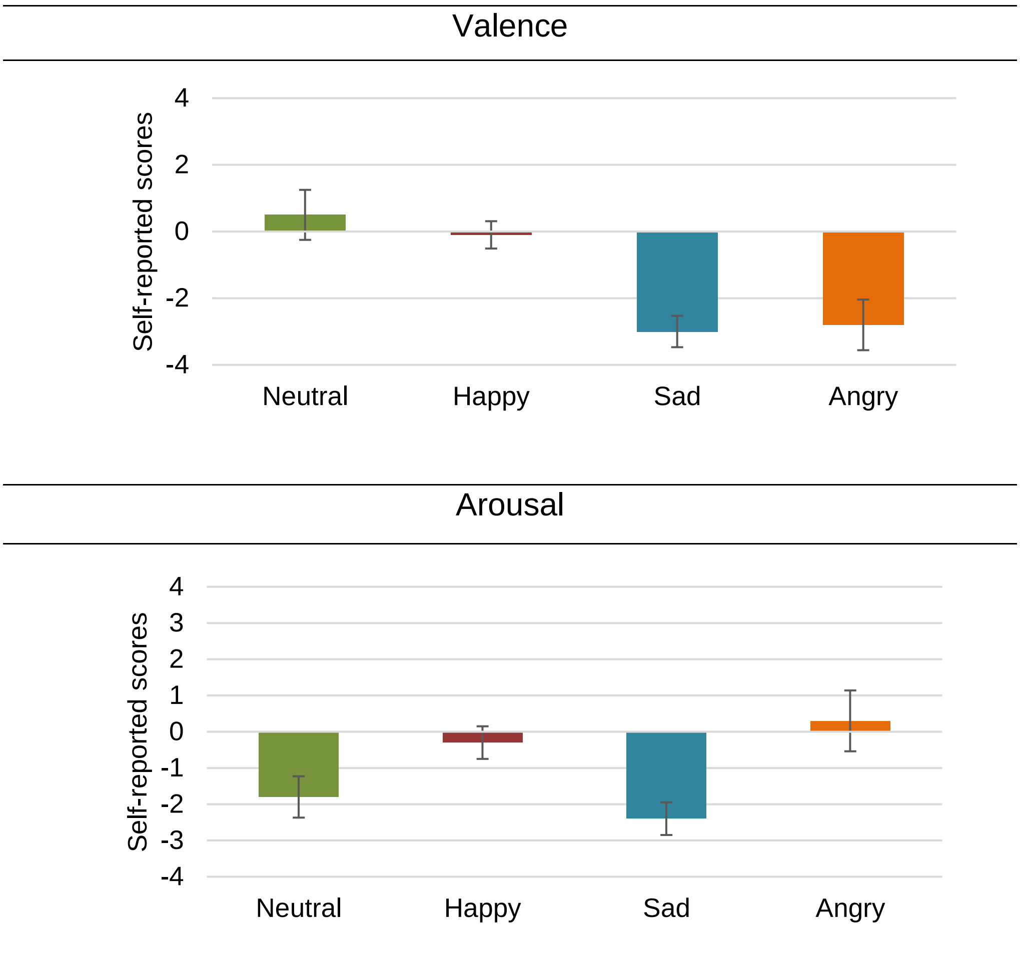


Figure 17: Changes in mood valence and arousal between the pre and post-study self-reports

5.4.2 Post-study questionnaire

5.4.2.1 Driving related load

There was a significant difference in the self-rated difficulty in concentrating on driving when DRL was applied, χ^2 (3) = 8.97, p < 0.01, η^2 = 0.24, with a mean rank load score of 22.45 for the sad, 23.85 for the happy, 10.44 for the neutral and 22.30 for the angry moods. Pairwise comparisons showed the happy drivers perceived DRL as more disturbing than the neutral drivers, U = 13.41, *p* < 0.05. The participants did not feel that responding to the driving-related questions in the neutral mood would significantly disturb them from driving (Figure 18).

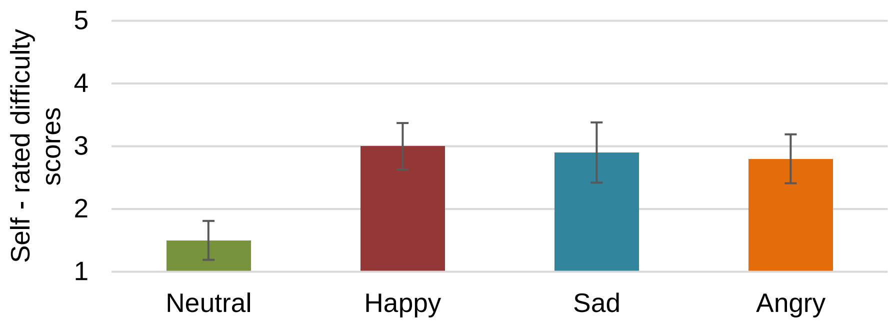


Figure 18: Perceived difficulty in concentrating on driving while answering driving-related questions[3]

5.4.2.2 Non-driving related load

There was no significant difference in the perceived load between the different Moods, χ^2 (3) = 4.55, p = 0.21, with a mean rank score of 23.06 for the sad, 20.6 for the happy, 13.17 for the neutral and 20.9 for the angry moods. The results show that the participants perceived NDRL similarly distracting in all the moods. The perceived load was scored lower in the neutral mood. However, this value did not reach significance (Figure 19).

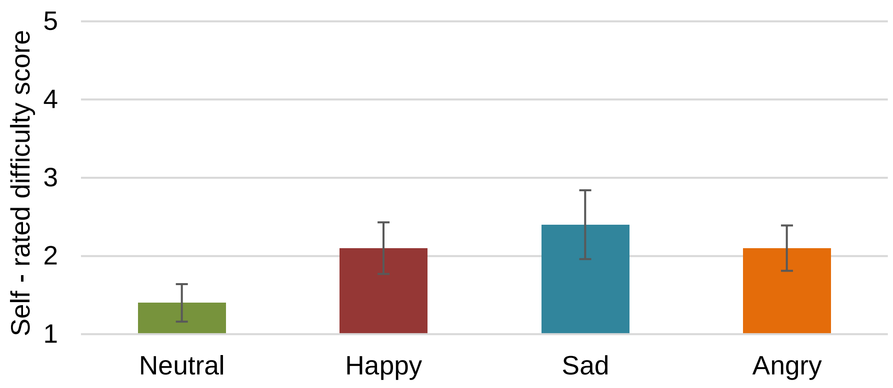


Figure 19: Perceived difficulty in concentrating on driving while answering non-driving related questions

[3] Self-rated on an assessment scale from 1-not at all to 5-felt a lot

5.4.2.3 Perceived ability to concentrate on driving

There was a significant difference in perceived ability to concentrate on driving while in different Moods, χ^2 (3) = 8.94, $p < 0.03$, $\eta^2 = 0.24$ with the mean rank score of 20.85 for the sad, 22.6 for the happy, 10.78 for the neutral and 24.85 for the angry moods (Figure 20). Pairwise comparisons showed the angry drivers experienced more difficulties in concentrating on driving than the neutral drivers, U = 13.41, $p < 0.05$.

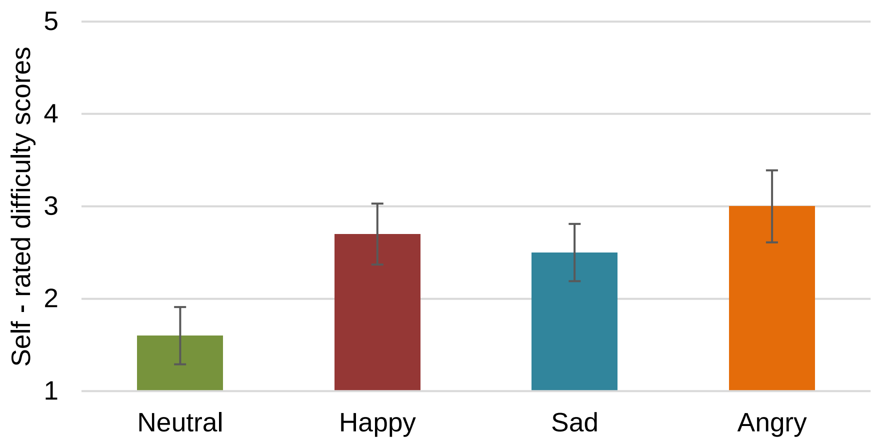


Figure 20: Perceived difficulty in concentrating on driving while in a particular mood

In summary:

It was hypothesised [H8] that driving related and non-driving related questions would disconnect participants from their mind wandering. The results showed that the participants considered NDRL as not distracting from the driving task, thus perceived as easy secondary task. DRL, on the other hand, have been distracting in all moods, except the neutral, indicating that it had an influence on drivers' attention. However, it is not clear whether the attention was directed to the road. These results can be explained by the mind wandering theory. Participants, after mood induction, were engaged in mind wandering, without fully acknowledging it. When questions were asked, it disconnected them from mind wandering, and this disconnection was as disturbing from driving. However, non-driving related questions were too easy and did not have this disconnection effect. The results also show that the participants' perceived significantly less difficulty in concentrating on driving in the neutral mood compared to the other moods. The participants felt that their concentration on driving in the neutral mood was not disrupted by their emotions.

5.4.3 Physiological measures

5.4.3.1 Effects of mood induction on physiological measures

There was a significant difference in EDA between the Mood conditions χ^2 (3) = 21.76, $p < 0.001$, $\eta^2 = 41.3$, with mean ranks of 29.55 for the sad, 12 for the happy, 25.83 for the neutral and 10.5 for the angry moods (

Table 9, Figure 21, Table 2 in Appendix 2). Pairwise comparisons showed the significant differences between the low (neutral, sad) and the high (happy, angry) arousal conditions.

There was a significant difference in HR between the Mood conditions χ^2 (3) = 23.2, $p < 0.001$, $\eta^2 = 37.5$, with mean ranks of 24 for the sad, 12.9 for the happy, 29.63 for the neutral and 7.5 for the angry moods. Pairwise comparisons showed the significant differences between the low (neutral, sad) and the high (happy, angry) arousal conditions (Table 10, Figure 22).

Table 9: Test statistics and p values for follow up comparisons of EDA

Mood comparison	U- test	Significance
Angry v Happy	0.46	1
Angry v Neutral	11.82	0.004**
Angry v Sad	12.8	0.002**
Happy v Neutral	10.89	0.006**
Happy v Sad	9.02	0.02*
Neutral v Sad	4.34	0.22

*Significant at 0.05 level

**Significant at 0.01 level

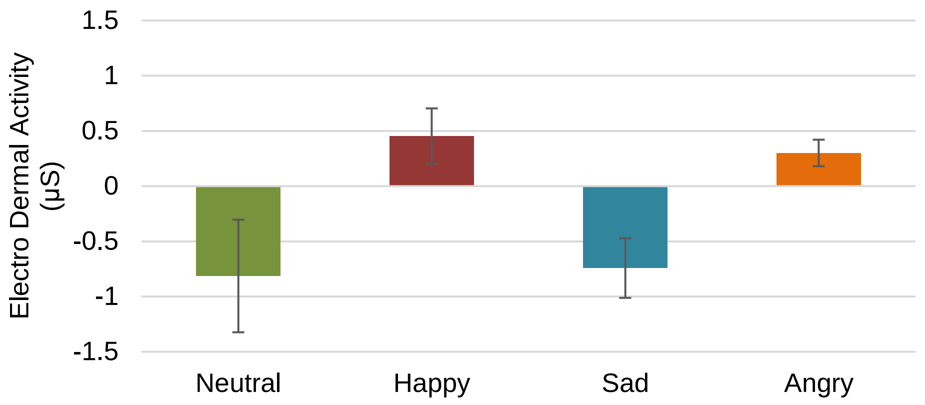


Figure 21: Changes in EDA between pre and post Mood induction

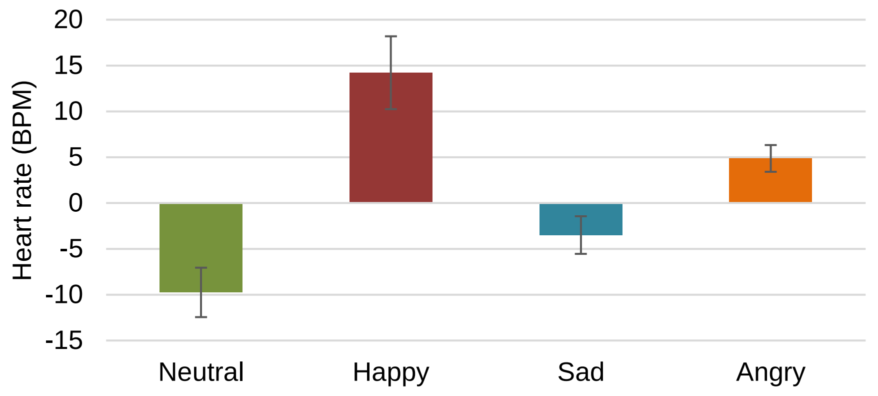


Figure 22: Changes in HR between pre and post Mood induction

Table 10: Test statistics and p values (adjusted) for post- comparisons of HR data

Mood comparison	U - test	Significance
Angry v Happy	5.4	1
Angry v Neutral	22.13	0.00**
Angry v Sad	16.5	0.006**
Happy v Neutral	-16.73	0.005**
Happy v Sad	11.1	0.11
Neutral v Sad	-5.63	1

*Significant at 0.05 level

**Significant at 0.01 level

In summary:

The analysis of EDA and HR showed the increase in HR and EDA in the high arousal conditions (happy, angry) and the decrease in the low arousal conditions (neutral, sad). The results showed that EDA and HR are sensitive to changes in participants' arousal initiated by mood induction. EDA and HR of the angry and the happy individuals increased after the mood induction, the sad and the neutral individuals' EDA and HR showed lower levels of arousal.

5.4.3.2 Effects of mood induction on the coherence task

Heart rate

There was a main effect of Mood, $F_{(3,\ 31)} = 3.72$, $p < 0.05$, $\eta_p^{\ 2} = 0.23$ (Figure 23). Post hoc tests showed that the drivers in the angry mood had higher HR compared to the drivers in the sad mood, $t = -2.88$, $p < 0.05$ and higher than the drivers in the neutral mood, $t = -2.88$, $p < 0.05$.

There was no main effect of Load and no interactions.

In summary:

HR measures can be used to differentiate the effort caused by the angry mood.

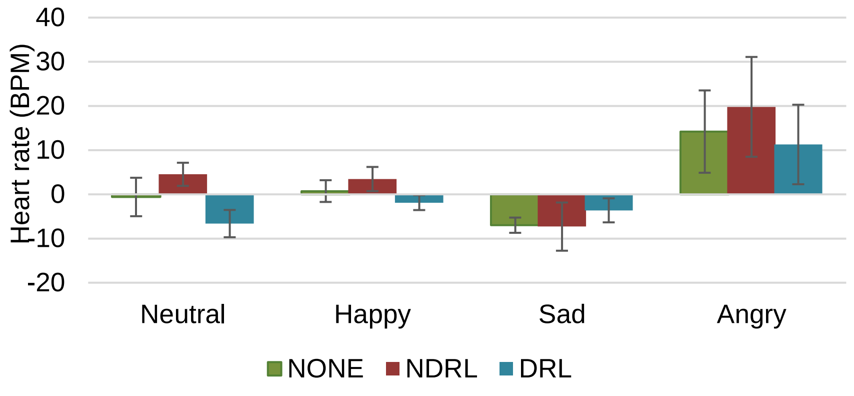


Figure 23: Heart rate by Mood and Load

Electro dermal activity

There were no main effects of Mood and Load and no interactions in EDA, although EDA showed the lowest habituation effect in the angry moos, with conductance close to the baseline, and hjighest habituation effect in the neutral mood (Figure 24, Table 3 in Appendix 2).

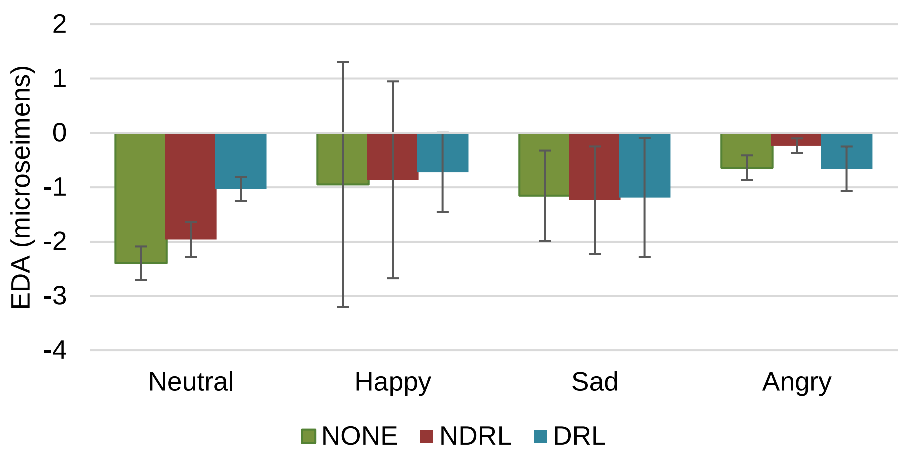


Figure 24: Electro dermal activity by Mood and Load

In summary:

EDA did not have enough power to reliably distinguish between drivers' emotion.

5.4.3.3 Effects of mood induction on unexpected and expected hazards

Electro dermal activity

The data from 5 participants had to be discarded due to weak signal.

Heart rate

There were no main effects of Mood and Load and no interaction in HR (Figure 25).

Car from left

There was a significant main effect of Mood, $F_{(3, 31)} = 4.23$, $p = 0.013$, $\eta_p^2 = 0.3$ (Table 19 in Appendix 2). Post hoc tests showed that the angry drivers' EDA was higher than the neutral drivers' EDA, $t = -2.81$, $p = .05$, the happy drivers' EDA higher than the neutral drivers' EDA, $t = 2.96$, $p = .03$, and the neutral drivers EDA lower than the sad drivers EDA, $t = -3.13$, $p = .02$ pairs.

Deviation contrasts showed that EDA in the neutral mood was lower, $t = 2.8$, $p = 0.009$.

Parameter estimates showed that the neutral mood is a significant predictor of EDA regardless of Load, and other moods often are predictors of EDA in relation to neutral mood (see Table 11).

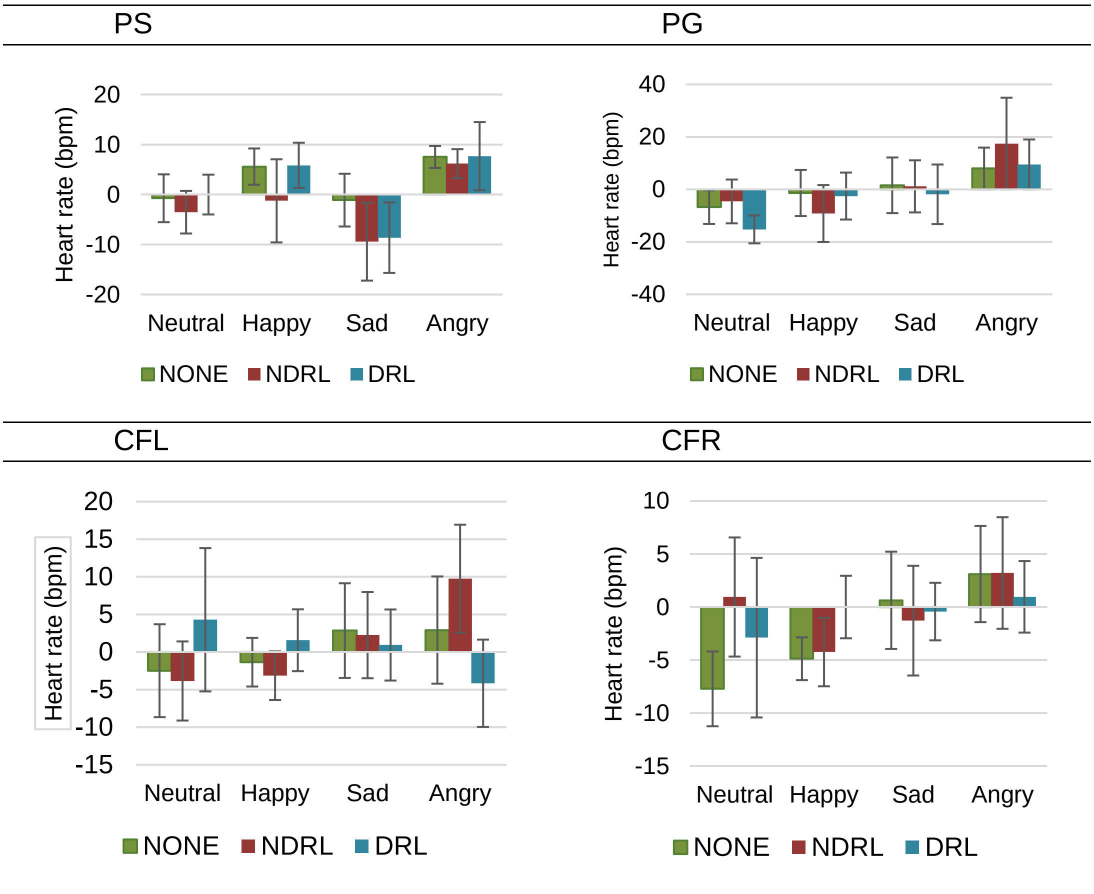


Figure 25: Heart rate by Mood and Load for four hazards

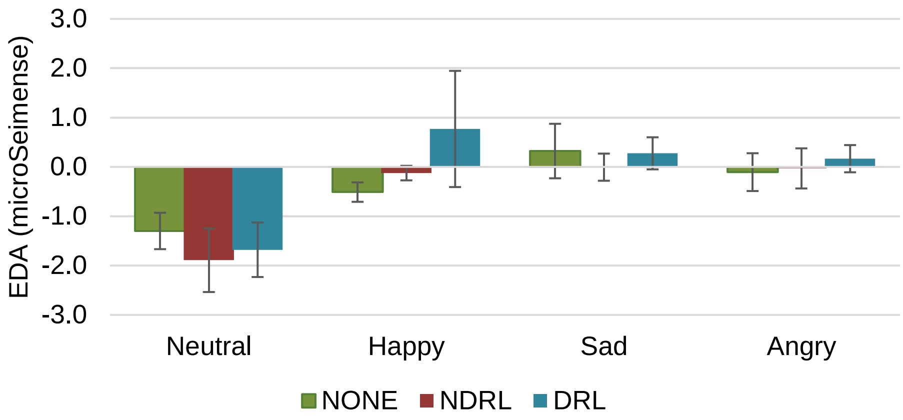


Figure 26: Electro dermal activity on approach to CFL hazard

Table 11: Parameter estimates for electro dermal activity during CFL hazard

Load	**Conditions**	**t**	**p**	**η_p^2**
NONE	Intercept	-3.31	.002**	0.27
	Angry	2.08	.046*	0.13
	Happy	1.4	.17	0.06
	Sad	2.84	.008**	0.21
	Neutral	-	-	-
NDRL	Intercept	-4.42	.001***	0.39
	Angry	2.99	.006**	0.23
	Happy	2.93	.007**	0.22
	Sad	3.02	.005**	0.23
	Neutral	-	-	-
DRL	Intercept	-2.37	.02*	0.16
	Angry	1.79	.08	0.09
	Happy	2.44	.02*	0.17
	Sad	1.89	.06	0.11
	Neutral	-	-	-

There was no significant main effect of Load and no interaction in EDA on approach to CFL hazard.

Car from right

There was a significant main effect of Mood, $F_{(3, 31)} = 3.16$, $p < 0.05$, $\eta_p{}^2 = 0.23$ (**Error! Reference source not found.**, Table 20 in Appendix 2). Post hoc tests showed that the happy drivers' EDA was higher than the neutral drivers' EDA, $t = 3.02$, $p < 0.05$. Deviation contrasts did not reveal significant differences (Table 12).

Table 12: Parameter estimates for electro dermal activity during CFR hazard

Load	**Conditions**	**t**	**p**	**$\eta_p{}^2$**
NONE	Intercept	-3.6	.001**	0.29
	Angry	0.98	.33	0.03
	Happy	1.56	.13	0.07
	Sad	1.04	.31	0.03
	Neutral	-	-	-
NDRL	Intercept	-4.43	.001***	0.39
	Angry	2.24	.03*	0.14
	Happy	3.24	.003**	0.25
	Sad	2.42	.02*	0.16
	Neutral	-	-	-
DRL	Intercept	-2.77	.009**	0.2
	Angry	1.17	.25	0.04
	Happy	2.64	.01*	0.18
	Sad	1.3	.2	0.05
	Neutral	-	-	-

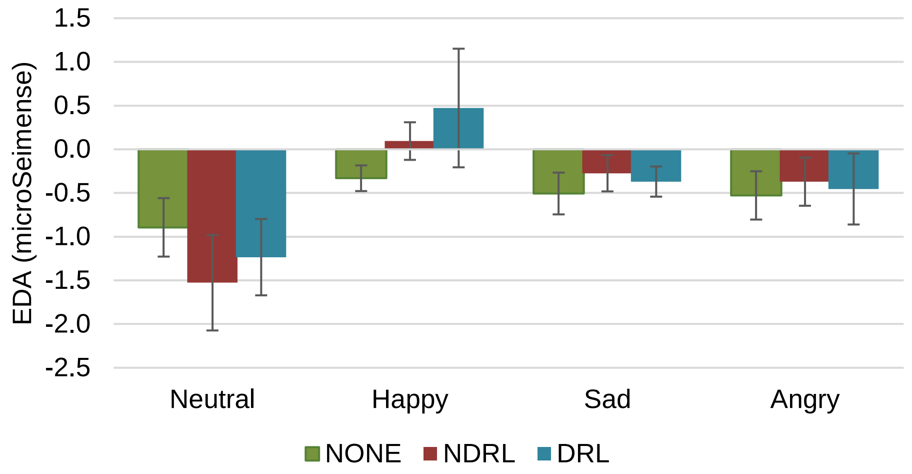


Figure 27: Electro dermal activity on approach to CFR hazard

There was no main effect of EDA in Load and no interaction during CFR hazard.

<u>Combined data for single parked car and parked car in group</u>

There were no significant differences between Mood and Load conditions and no interactions in EDA during PS and PG (Figure 28, Table 21 in Appendix 2). However, the data had a clear trend, so, to improve the statistical power the events were combined.

There was a significant main effect of Mood in combined data, $F_{(3, 66)} = 3.16$, $p < 0.05$, $\eta_p{}^2 = 0.12$ (Figure 29). Post hoc tests showed that the happy drivers' EDA was higher compared to the neutral drivers' EDA, $t = 2.94$, $p < 0.05$. Deviation contrasts revealed no differences.

Parameter estimates showed that the neutral mood is a significant predictor of EDA regardless of Load: NONE - $t = -2.77$, $p < 0.01$, $\eta_p{}^2 = 0.1$, NDRL - $t = -4.03$, $p < 0.001$, $\eta_p{}^2 = 0.2$, and DRL - $t = -2.62$, $p < 0.01$, $\eta_p{}^2 = 0.1$. The happy mood is a significant predictor of EDA only if some kind of Load is applied, NDRL - $t = 3.28$, $p < 0.01$, $\eta_p{}^2 = 0.14$, and DRL - $t = 2.96$, $p < 0.01$, $\eta_p{}^2 = 0.12$.

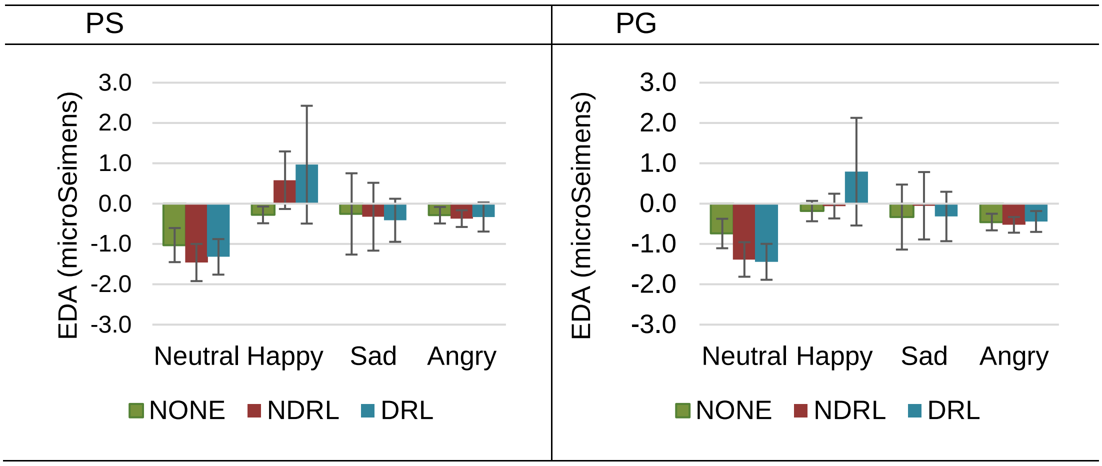


Figure 28: EDA while passing parked car hazards

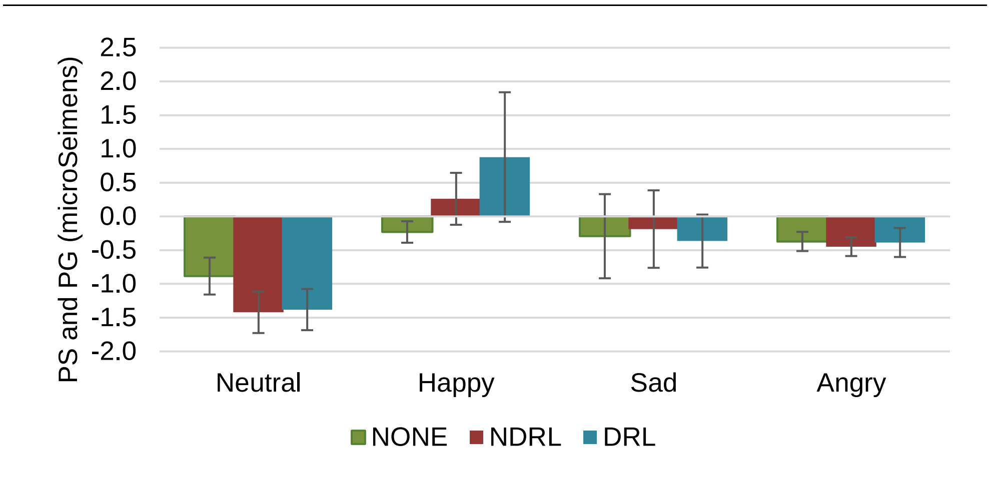


Figure 29: Combined EDA while passing parked car hazards

There was no main effect of Load and no interaction in combined data.

5.4.5 Coherence task

5.4.5.1 Coherence

There were no main effects of Mood and Load on coherence and no interaction effect between the conditions and no significant changes from the baseline to the corresponding condition. This was true for both cycles. Minimum and maximum correlations are displayed in Table 13 along with means and medians. The minimum correlation was higher than 0.3 indicating that the car following was successful throughout the task, thus phase shift and modulus could be reliably analysed.

Table 13: Correlation means, minimums, maximums and medians for both cycles

Period	Mean	Minimum	Maximum	Median
Cycle 1	0.7	0.35	0.9	0.68
Cycle 2	0.83	0.67	0.92	0.88

5.4.5.2 Phase shift

Cycle 1

Comparison between conditions:

There was a significant main effect of Mood on phase shift, $F_{(3, 33)} = 8.31$, $p < 0.01$, $\eta^2 = 0.43$. Deviation contrasts showed that the differences were in the happy mood, $t = -3.41$, $p < 0.01$, and the sad mood, $t = -4.59$, $p < 0.01$ (Figure 30, Table 6 in Appendix 2).

There was no main effect of Load and no interactions in phase shift in cycle 1.

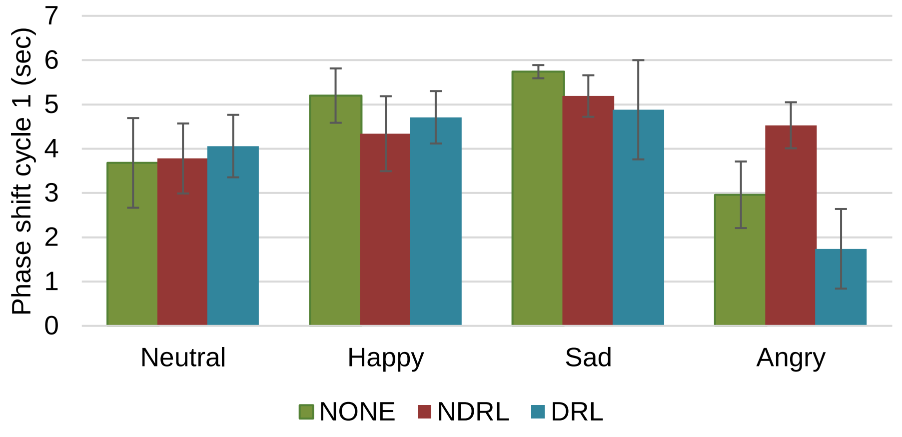


Figure 30: Phase shift in cycle 1

Parameter estimates show that the neutral mood is a significant predictor of phase shift, regardless of Load. The sad mood is a significant predictor of phase shift only when no load is applied (Table 14).

Changes from the baseline to the corresponding condition:

There was a significant main effect of Mood, $F_{(3, 33)} = 3.4$, $p < 0.05$, $\eta^2 = 0.24$ (Figure 31). Deviation contrasts showed that the sad mood initiated the biggest changes in phase shift from the baseline, $t = 3.09$, $p < 0.05$. Parameter estimates did not show any significant predictions in phase shift changes from the baseline to the corresponding Mood condition.

There was no main effect of Load and no interactions in changes in phase shift from the baseline to the condition.

Table 14: Parameter estimates for phase shift by Mood and Load

Load	**Mood**	**t**	**p**	**h_p^2**
NONE	Intercept	4.97	0.001***	0.43
	Angry	-0.45	0.65	0.006
	Happy	1.83	0.08	0.1
	Sad	2.45	0.02*	0.16
	Neutral	-	-	-
NDRL	Intercept	6.66	0.001***	0.58
	Angry	0.52	0.6	0.008
	Happy	0.32	0.75	0.003
	Sad	1.34	0.19	0.05
	Neutral	-	-	-
DRL	Intercept	4.48	0.001***	0.39
	Angry	-1.75	0.09	0.09
	Happy	0.54	0.59	0.009
	Sad	0.7	0.49	0.02
	Neutral		-	-

Cycle 2

There were no main effects of Mood and Load and no interactions in cycle 2 neither between the conditions nor in the changes from the baseline to the corresponding condition.

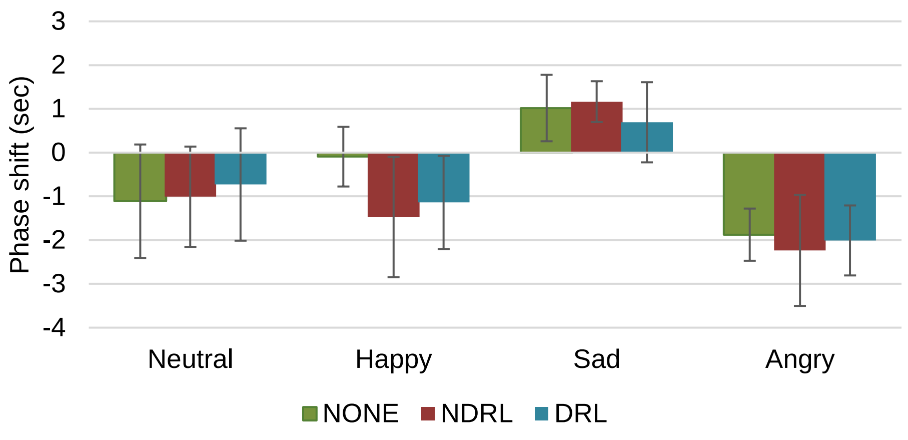


Figure 31: Changes in phase shift from the baseline to the corresponding condition in cycle 1

5.4.5.3 Modulus

Cycle 1

Comparison between conditions:

There was a significant main effect of Mood, $F_{(3, 33)} = 3.25$, $p < 0.05$, $\eta^2 = 0.23$ (Figure 32, Table 7 in Appendix 2). Post hoc tests showed that the difference was between the happy and the sad moods, $t = -3.02$, $p < 0.05$. Deviation contrast showed that this difference was due to the happy mood being different to all the other moods, $t = 2.01$, $p < 0.05$.

There was no main effect of Load and no interactions.

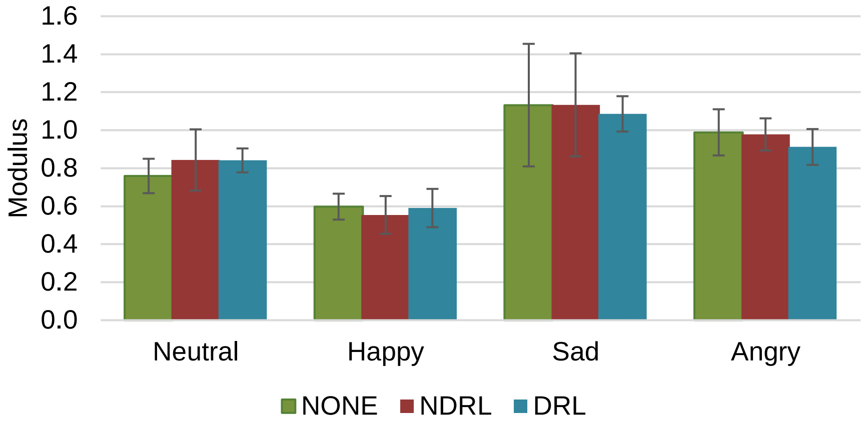


Figure 32: Modulus in cycle 1

Parameter estimates showed that the neutral mood is a significant predictor of modulus, regardless of Load. NONE and NDRL did not interact with any of the moods. DRL, however, significantly affected modulus in the sad and the happy moods (Table 15).

Table 15: Parameter estimates for modulus by Mood and Load

Load	**Mood**	**t**	**p**	**h_p^2**
NONE	Intercept	4.11	0.001***	0.34
	Angry	0.83	0.41	0.02
	Happy	-0.60	0.55	0.01
	Sad	1.43	0.16	0.06
	Neutral	-	-	-
NDRL	Intercept	4.83	0.001***	0.41
	Angry	0.51	0.61	0.01
	Happy	-1.14	0.26	0.04
	Sad	1.17	0.25	0.04
	Neutral	-	-	-
DRL	Intercept	9.94	0.001***	0.75
	Angry	0.56	0.58	0.01

Happy	-2.04	0.049*	0.11
Sad	2.05	0.049*	0.11
Neutral	-	-	-

Changes from the baseline to the corresponding condition:

There was a significant main effect of Mood, $F_{(3, 33)} = 3.63$, $p < 0.05$, $\eta^2 = 0.25$. Post hoc tests showed that the difference was between the happy and the sad moods, $t = -3.3$, $p < 0.01$ (Figure 33). Deviation contrasts did not reveal any significant differences.

There was no main effect of Load and no interaction.

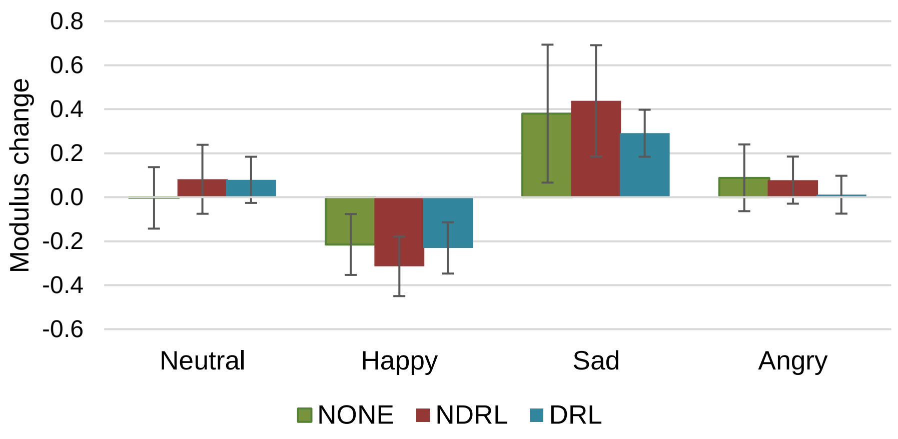


Figure 33: Changes in modulus from the baseline to the corresponding condition in cycle 1

Parameter estimates showed that DRL in the happy mood is a significant predictor of modulus changes from baseline driving, $t = -2.14$, $p < 0.05$ (Table 16).

Cycle 2

Comparison between conditions:

There was a marginally significant main effect of Mood, $F_{(3, 32)} = 2.64$, $p = 0.06$, $\eta^2 = 0.2$ (Table 8 in Appendix 2). Deviation contrasts showed that there was a significant difference between the sad and all the other moods, $t = -2.51$, $p < 0.01$.

There was no main effect of Load and no interaction in changes from the baseline to the corresponding condition in cycle 2.

Table 16: Parameter estimates for changes in modulus from the baseline to the corresponding conditions

Load	**Mood**	**t**	**p**	**h_p^2**
NONE	Intercept	-0.02	0.98	0.00
	Angry	0.33	0.75	0.003
	Happy	-0.78	0.44	0.02
	Sad	1.35	0.19	0.05
	Neutral	-	-	-
NDRL	Intercept	0.5	0.62	0.01
	Angry	-0.02	0.99	0.00
	Happy	-1.66	0.11	0.08
	Sad	1.43	0.16	0.06
	Neutral	-	-	-
DRL	Intercept	0.79	0.43	0.02
	Angry	-0.45	0.65	0.01
	Happy	-2.14	0.04*	0.12
	Sad	1.31	0.2	0.05
	Neutral	-	-	-

5.4.5.4 Time headway (TH)

Comparison between conditions:

There were no significant differences in the TH segments of 0-1, 2-3, 4-5 and 5-6 in any of the conditions.

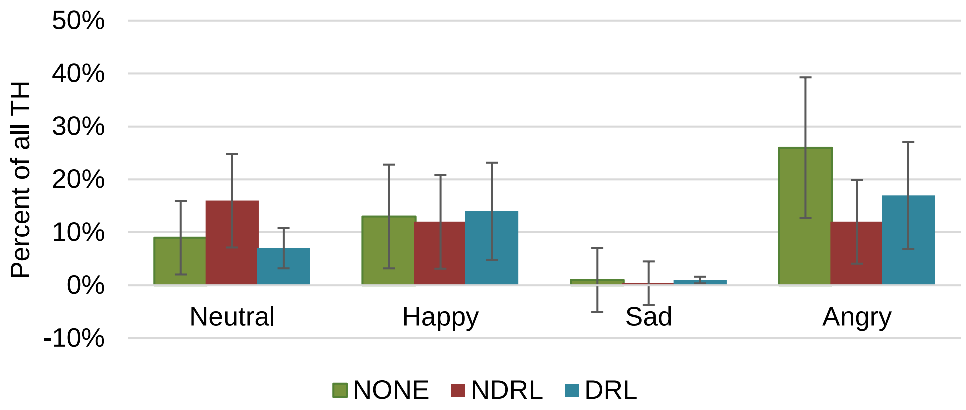
There was a main effect of Mood on TH in the 1-2 seconds time segment, $F_{(3, 35)} = 3.72$, $p < 0.05$, $\eta^2 = 0.24$ (Figure 34, Table 9 in Appendix 2). Post hoc tests showed that this difference was between the sad and the angry moods, with the sad drivers spending significantly less time in this TH, $t = -3.09$, $p < 0.05$. Deviation contrasts showed that the difference was between the sad and all the other moods, $t = 2.13$, $p < 0.05$, demonstrating that, regardless of Load, the happy, the neutral and the angry drivers preferred travelling at this time headway significantly more compared to the sad drivers.

In the time segment of 3-4 seconds, there was a significant main effect of Mood, F (3, 35) = 3.22, $p < 0.05$, $\eta^2 = 0.21$. Post hoc tests showed that this difference was between the sad and the angry moods, $t = 3.08$, $p < 0.05$, with the sad drivers spending significantly more time in this TH.

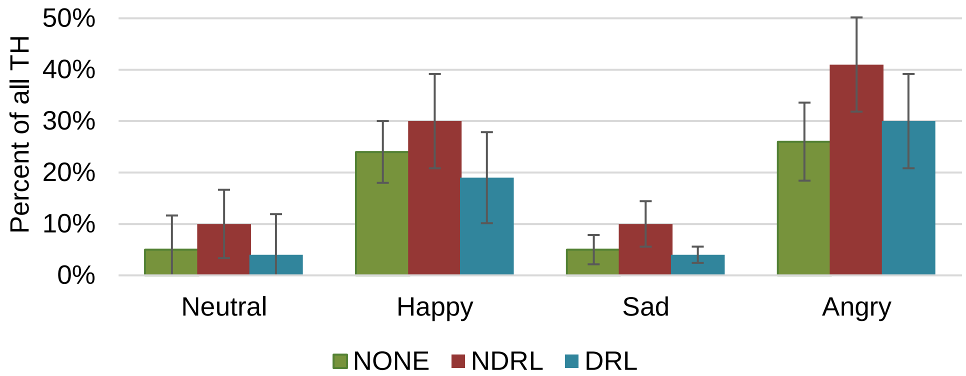
There also was a significant main effect of Load, F (1.59, 55.48) = 3.5, $p < 0.05$, $\eta^2 = 0.1$. Post hoc tests showed that in the NDRL condition drivers preferred to spend less time in 3-4 seconds time segment compared to the NONE condition, $t = 2.66$, $p < 0.05$. Deviation contrasts showed NDRL was different from other Load conditions, $t = 2.62$, $p < 0.05$, indicating that regardless of Mood when asked non-driving related questions, drivers preferred to spend less time at this TH.

There were no significant interactions between Mood and Load in 3-4 seconds segment (Figure 34).

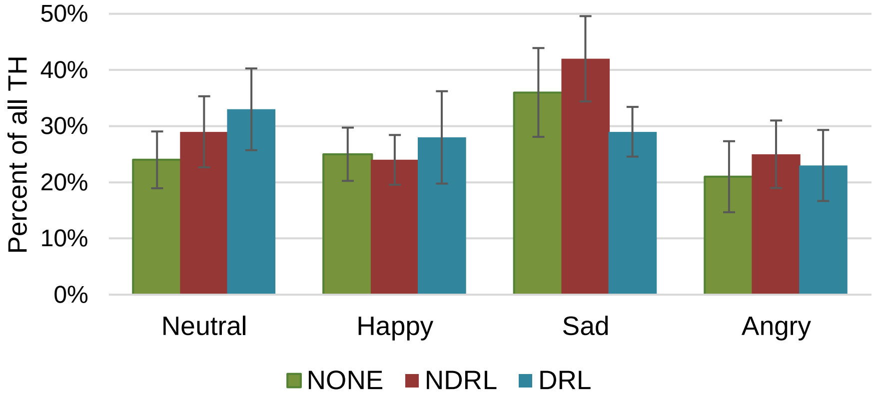
TH 1 second



TH between 1 and 2 seconds



TH between 2 and 3 seconds



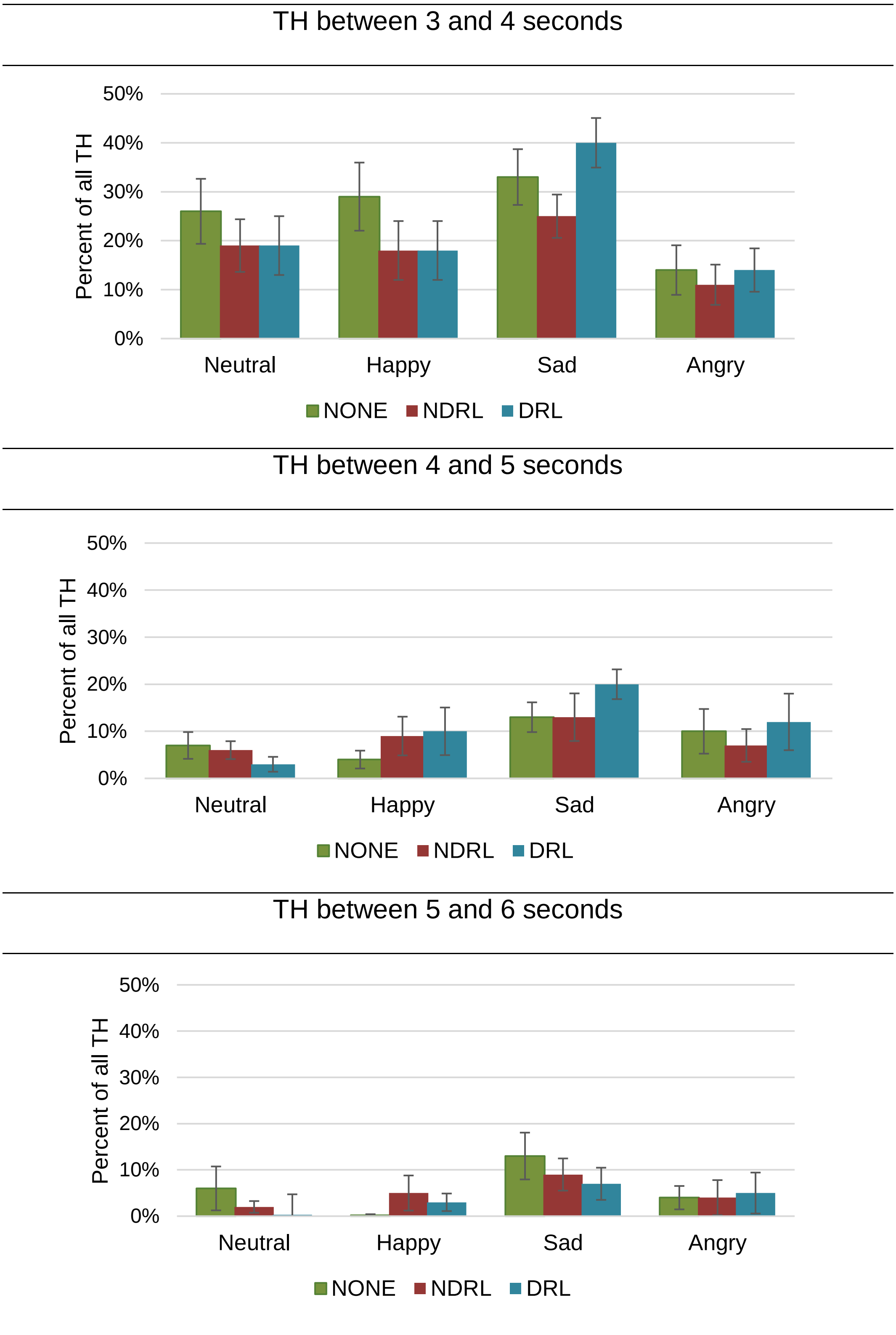


Figure 34: Percent time spent at different time headways by Mood and Load

<u>Comparison of changes from the baseline to the corresponding condition:</u>

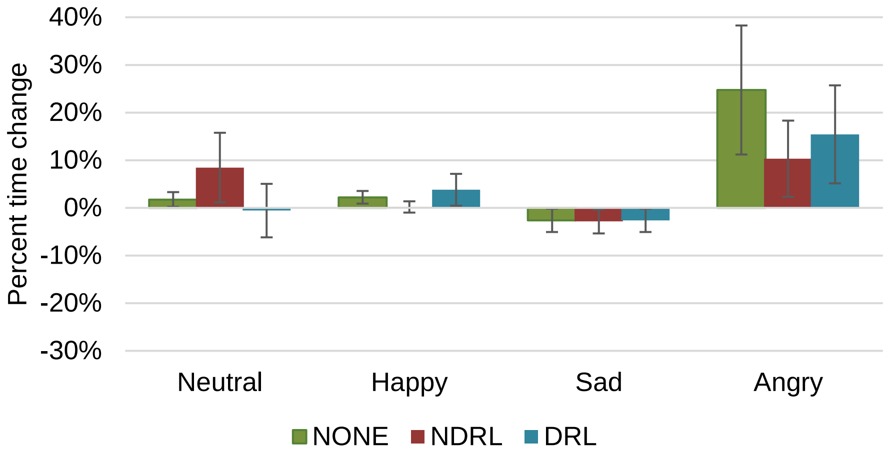
There were no significant differences in the TH changes from the baseline in the time segments 0-1 second, 1-2 seconds and 2-3 seconds. Figure 35 shows that the sad drivers reduced the time spent in 0-1, 1-2 and 2-3 time segments, and increased time spent in the 3-4 segment. The drivers in the neutral mood remained similar to their baseline TH, and only decreased it for 2-3 seconds TH. The happy drivers did not show meaningful changes and kept their THs close to the baseline. The angry drivers decreased time in the time segments more than 2 seconds, thus increasing time in closer than 2 seconds THs. However, not all of these changes reached a significance level.

There was a significant main effect of Mood, $F_{(3, 36)} = 3.2$, $p < 0.05$, $\eta^2 = 0.21$ (Figure 35, Table 10 in Appendix 2). Post hoc tests showed that that this effect was due to the angry drivers reducing time in this time segment more compared to the sad drivers, $t = 2.8$, $p < 0.05$. Deviation contrasts showed the difference between the angry and all other drivers, $t = 2.46$, $p < 0.05$, indicating that drivers in the angry mood spent significantly less time in this time segment compared to their driving when not affected by angry mood. (Figure 35).

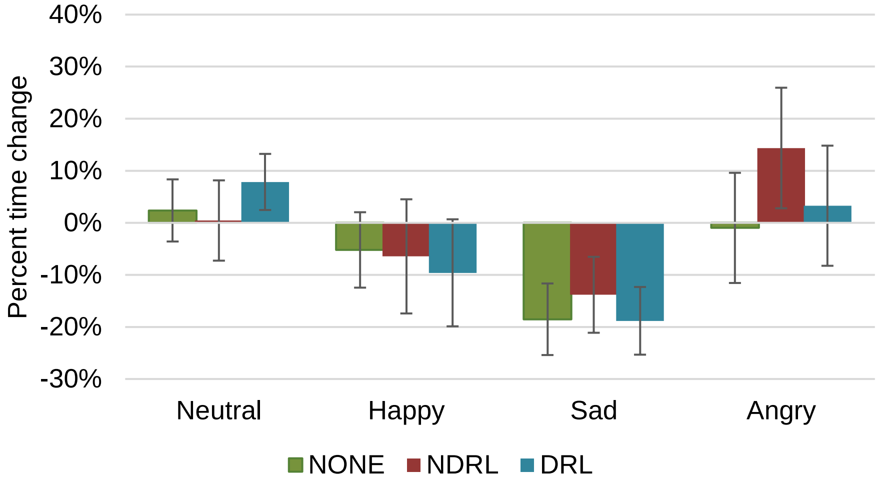
There was a significant main effect of Load in the 3-4 seconds time segment, $F_{(1.59, 57.27)} = 3.95$, $p < 0.05$, $\eta^2 = 0.1$. Post hoc tests showed that in the NONE condition drivers spent significantly more time in this time segment compared to the NDRL condition, $t = 2.81$, $p < 0.05$. Deviation contrasts showed that different was NDRL condition, $t = 2.74$, $p < 0.05$, indicating that regardless of Mood, drivers' reduced the time spent in this segment in the NDRL condition (mean = -0.02, SE = 0.03) compared to the DRL (mean = 0.31, SE = 0.03) and NONE (mean = 0.06, SE = 0.06) conditions.

There were no significant interactions.

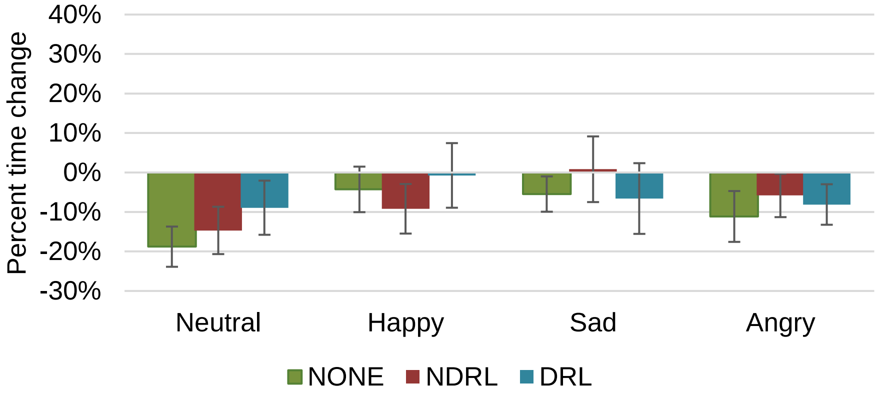
Time headway 1 second



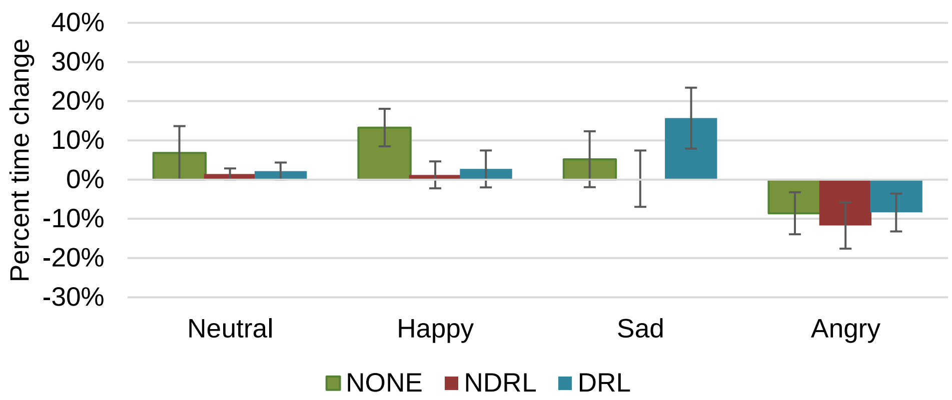
Time headway between 1 and 2 seconds



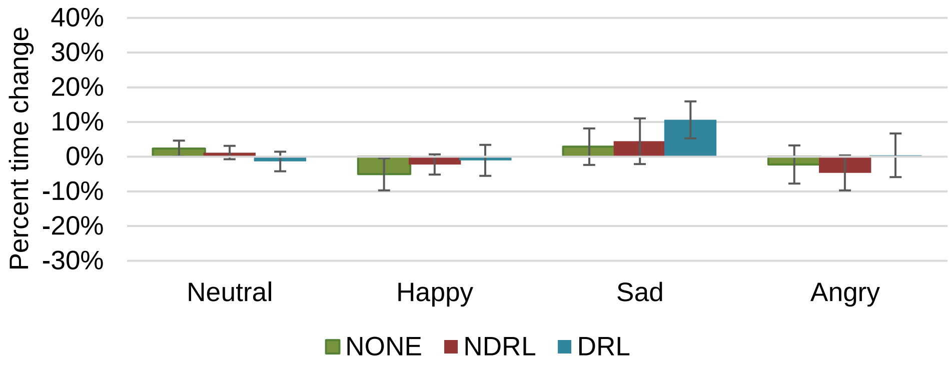
Time headway between 2 and 3 seconds



Time headway between 3 and 4 seconds



Time headway between 4 and 5 seconds



Time headway between 5 and 6 seconds

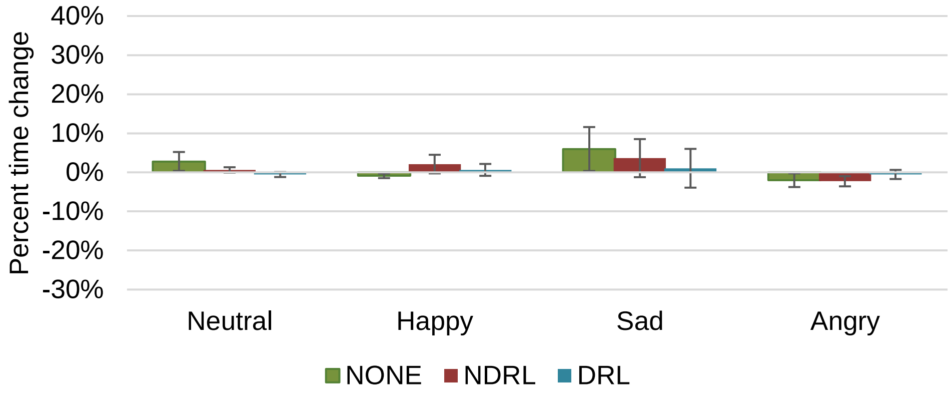


Figure 35: Changes in percent time spent at different time headways between the baseline and the corresponding condition

5.4.5.3 Glance behaviour

Glance data were analysed with respect to number of fixations, fixation durations and spread of fixations.

5.4.5.3.1 Number of fixations

Means and standard deviations for all glance behaviour measures are displayed in Tables 4 and 5 in Appendix 2.

Comparison between Mood and Load conditions. There were no significant main effects of Mood and Load on the number of fixations. However, there was a significant interaction, $F_{(6, 72)} = 2.5$, p < 0.05, $\eta_p^{2} = 0.17$. Within-subject contrasts showed that this difference was between the NDRL and DRL in the sad mood, $p < 0.01$ (Figure 36).

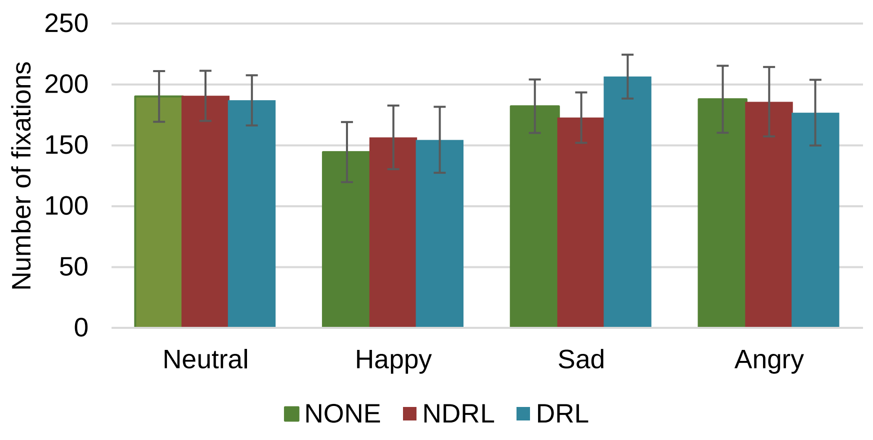


Figure 36: Number of fixations by Mood and Load

Comparison of changes from the baseline to the corresponding condition. There was a significant main effect of Mood in the change in number of fixations from the baseline, $F_{(3, 36)} = 3.2$, p < 0.05, $\eta_p^{2} = 0.21$, the difference being between the neutral and all other conditions, $t = 2.74$, $p < 0.05$ with a significant increase in the number of fixations in the neutral mood. There also was a significant interaction between the Mood and Load, $F_{(6, 72)} = 2.5$, p < 0.05, $\eta_p^{2} = 0.17$, with difference being between the NDRL and DRL in the sad mood, $p < 0.01$ (Figure 37).

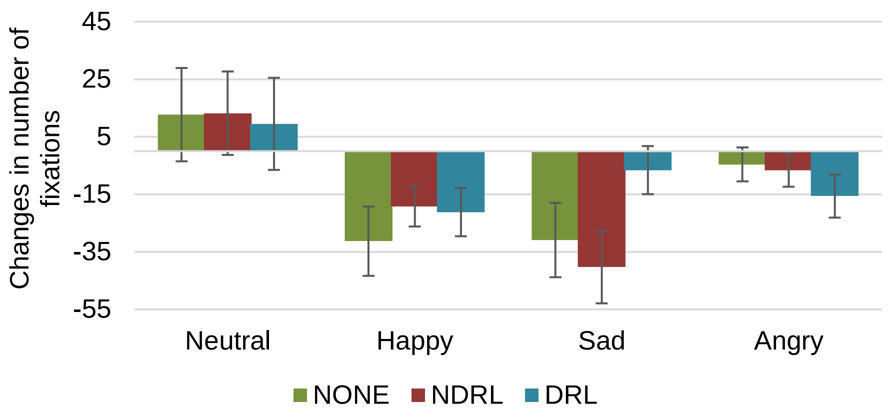


Figure 37: Changes in number of fixations between the baseline and the corresponding condition

5.4.5.3.2 Duration of fixations

Comparison between conditions. There was a marginally significant main effect of Mood, $F\ (3, 36) = 2.84$, $p = 0.05$, $\eta_p^2 = 0.19$ (Figure 38). Post hoc tests showed longer fixation durations in the sad mood compared to the neutral mood, $t = 2.86$, $p < 0.05$. Deviation contrasts showed that the sad mood was different from other conditions, $t = 2.55$, $p < 0.05$.

There was a significant main effect of Load, $F_{(1.71,\ 61.52)} = 9.23$, $p < 0.001$, $\eta_p^2 = 0.20$. Post hoc tests showed that fixation durations were significantly longer in the NONE compared to the NDRL condition, $t = 4.13$, $p < 0.01$, and in the DRL being significantly longer compared to the NDRL condition, $t = -3.1$, $p < 0.01$. There also was a significant interaction, $F_{(5.13,\ 61.52)} = 3.86$, $p < 0.01$, $\eta_p^2 = 0.24$. Within subjects contrast showed that fixation durations were significantly longer in NONE compared to NDRL in the sad mood, $p < 0.01$; and marginally longer in DRL compared to NDRL in the sad mood, $p = 0.08$.

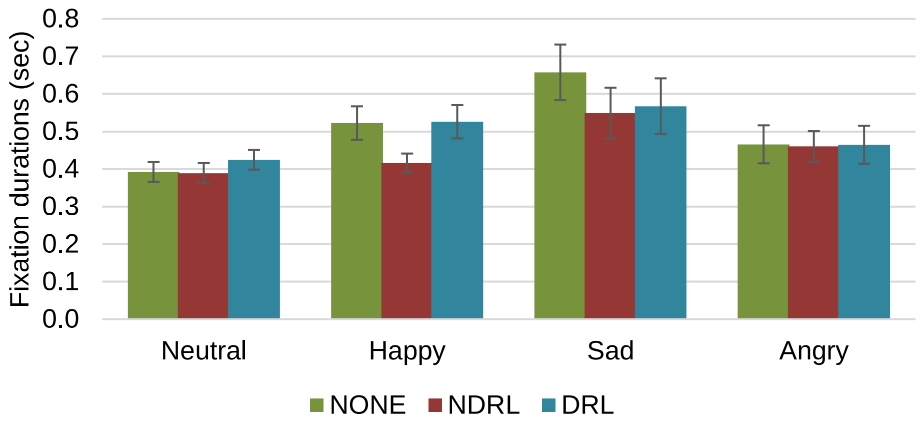


Figure 38: Fixation durations by Mood and Load

Comparison of changes from the baseline to the corresponding condition.

There was a significant main effect of Mood, $F_{(3, 36)} = 4.75$, $p < 0.01$ $\eta_p^2 = 0.28$ (Figure 39). Post hoc tests showed longer fixations in the sad mood compared to the happy mood, $t = -2.98$, $p = 0.05$, and compared to the neutral mood, $t = -3.34$, $p = 0.01$. Deviation contrasts showed that the difference was between the neutral mood and all other moods, $t = -4.13$, $p < 0.001$.

There was a significant main effect of Load on the changes in duration of fixations from the baseline, $F_{(1.71, 61.52)} = 9.23$, $p < 0.001$ $\eta_p^2 = 0.16$. Post hoc tests showed longer fixation duration of fixations in the NONE compared to the NDRL conditions, $t = -3.42$, $p < 0.001$ and in the NDRL significantly more than the DRL condition, $t = 3.1$, $p < 0.01$. Deviation contrasts showed longer fixations in the NDRL compared to other conditions, $t = 2.98$, $p < 0.001$.

There also was a significant interaction, $F_{(5.13, 61.52)} = 3.86$, $p < 0.01$, $\eta_p^2 = 0.24$. Within subjects contrast showed that the difference was between NONE (mean -0.08 sec) and NDRL (mean 0.03 sec) in the sad mood. Between NDRL (mean 0.14 sec) and DRL (0.03 sec) in the happy mood there was a marginally significant effect $p = 0.08$.

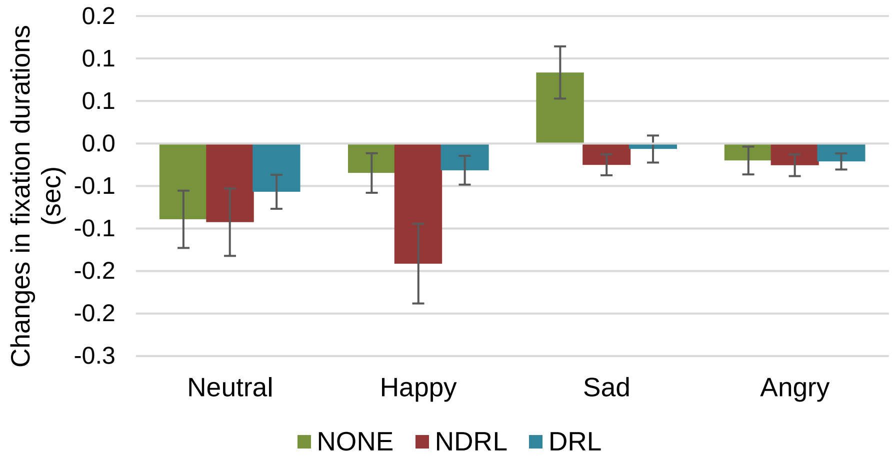


Figure 39: Changes in fixation durations between the baseline and the corresponding condition

5.4.5.3.3 Horizontal spread of fixations

Comparison between conditions.

There was a significant main effect of Mood, $F_{(3, 36)} = 6.3$, $p < 0.01$, $\eta_p^2 = 0.34$ (Figure 40). Post hoc tests showed that the neutral mood resulted in wider spread of fixations compared to the angry mood, $t = -3.7$, $p < 0.01$, and the happy mood, $t = -3.18$, $p < 0.05$, and neutral – sad, $t = 3.67$, $p < 0.01$ moods. Deviation contrasts showed that the neutral mood was different from all the other moods, $t = -3.7$, $p < 0.001$. Parameter estimates showed that the neutral mood is a significant predictor of fixation spread Table 17. All other Mood are significant predictors of fixation spread with the reference to the neutral mood in every Load condition, except NDRL in the happy and the sad mood.

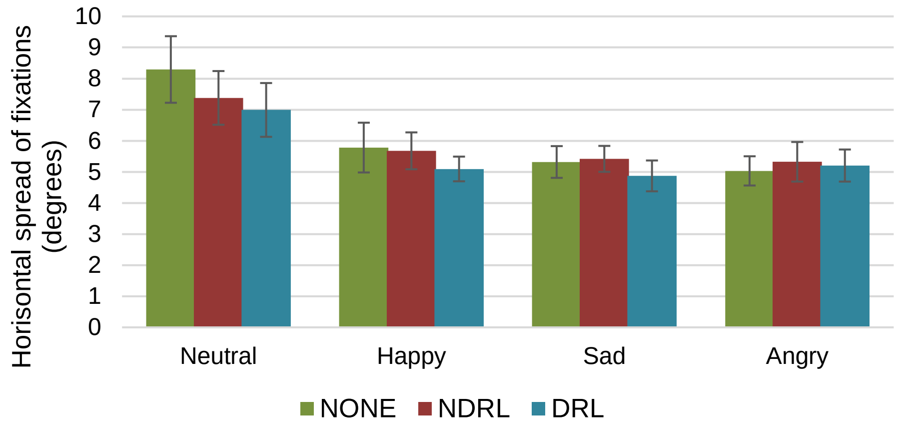


Figure 40: Horizontal spread of fixations by Mood and Load

Table 17: Parameter estimates for spread of fixations by Mood and Load

Load	**Conditions**	**t**	**p**	$\eta_p{}^2$
NONE	Intercept	11.01	.001***	0.77
	Angry	-3.06	.004**	0.21
	Happy	-2.36	.024*	0.13
	Sad	-2.79	.008**	0.18
	Neutral	-		
NDRL	Intercept	11.39	.001***	0.78
	Angry	-2.43	.03*	0.12
	Happy	-1.86	.07	0.09
	Sad	-2.14	.39	0.11
	Neutral	-		
DRL	Intercept	11.75	.001***	0.079
	Angry	-2.12	.04*	0.11
	Happy	-2.26	.03*	0.12
	Sad	2.5-2.52	0.2*	0.15
	Neutral	-	-	-

There was no significant main effect of Load and no interactions in the horizontal spread of fixations

Comparison of changes from the baseline to the corresponding condition.

There was a marginally significant effect of Mood, $F_{(3, 36)} = 2.52$, $p = 0.07$, $\eta_p^2 = 0.17$ (Figure 41). Deviation contrasts showed that the difference was between neutral mood and all the other moods, $t = -2.09$, $p < 0.05$. Parameter estimates showed that the neutral mood is a significant predictor of spread of fixations only when no questions are asked, $t = 2.51$, $p < 0.05$. The angry mood is a significant predictor changes in spread of fixations only when no questions are asked, $t = -2.14$, $p < 0.05$, $\eta_p^2 = 0.11$, and the sad mood, when no questions are asked, $t = -2.55$, $p < 0.05$, $\eta_p^2 = 0.15$ and when driving related questions are asked, $t = -2.34$, $p < 0.05$, $\eta_p^2 = 0.13$.

There was no significant main effect of Load and no interactions in changes from the baseline to the corresponding Load conditions.

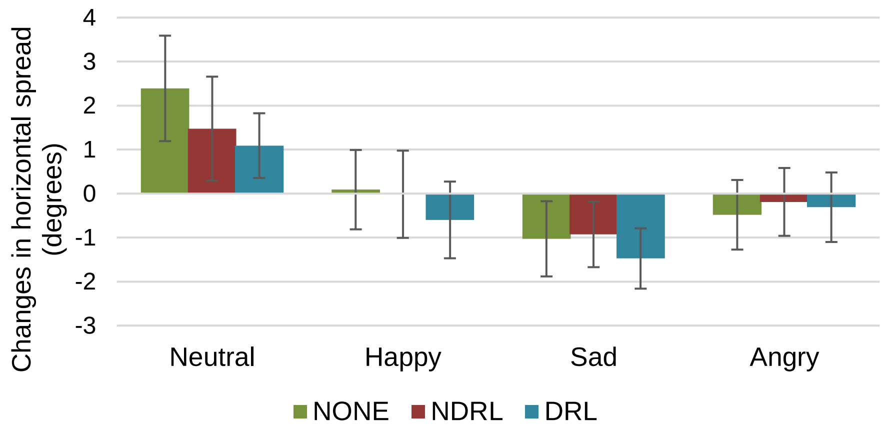


Figure 41: Changes in spread of fixations from the baseline to the corresponding condition

5.4.6 Unexpected hazard, car from the left side junction

There were no main effects of Mood and Load and no interactions between the conditions and on changes from the baseline to the corresponding condition in average speed, acceleration and deceleration.

5.4.6.1 Speed variation

Comparison between conditions:

There were no main effects of Mood and Load and no interactions in mean speed on approach to CFL hazard between conditions, and no differences in changes from the baseline to the corresponding condition.

There was a significant main effect of Mood on the speed variation, $F_{(3, 36)}$ = 3.2, $p < 0.05$, $\eta_p^2 = 0.21$, with significantly higher variation in the happy mood compared to the sad mood, $t = 2.61$, $p < 0.05$, and higher in the happy mood compared to the neutral moods, $t = 2.72$, $p < 0.05$ (Figure 42, Table 11 in Appendix 2). Deviation contrasts showed that the neutral mood has lower speed deviation, compared to other moods, $t = 2.28$, $p < 0.05$.

Parameter estimates for CFL showed that the neutral mood is a significant predictor of speed variation (intercept): NONE - $t = 3.01$, $p < 0.01$, NDRL - $t = 3.01$, $p = 0.059$, DRL - $t = 3.54$, $p < 0.01$. The happy mood is a significant predictor only when NDRL is applied, $t = 2.84$, $p < 0.01$.

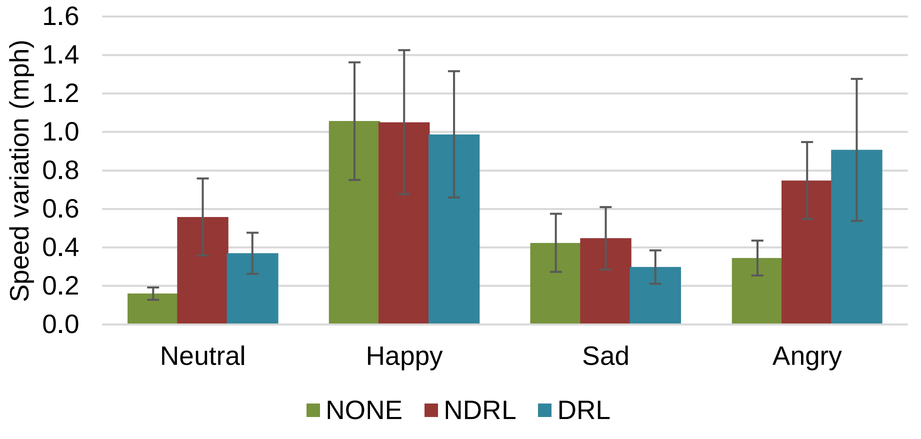


Figure 42: Speed variation by Mood and Load

There was no significant main effect of Load and no interactions in speed variation.

<u>*Comparison of changes from the baseline to the corresponding mood:*</u>

There was a significant main effect of Mood on speed variation in changes from the baseline to the corresponding mood, $F_{(3, 36)} = 3.02$, $p < 0.05$, $\eta_p{}^2 = 0.2$, with significantly higher speed variation increase after the angry mood induction compared to the neutral mood, $t = 2.64$, $p < 0.05$ (Figure 43, Table 11 in Appendix 2). Deviation contrasts showed that the sad drivers decreased speed variation the most, compared to the drivers in other moods, $t = 2.06$, $p < 0.05$, and the drivers in the neutral mood decreased speed variation the most, compared to other moods, $t = 2.38$, $p < 0.05$.

Parameter estimates for CFL showed that the neutral mood is a significant predictor of speed variation: NONE - $t = 3.01$, $p < 0.01$, NDRL - $t = 3.01$, $p = 0.059$, DRL - $t = 3.54$, $p < 0.01$. The happy mood is a significant predictor only when NDRL is applied, $t = 2.84$, $p < 0.01$.

There were no significant main effect of Load and no interactions in speed variation.

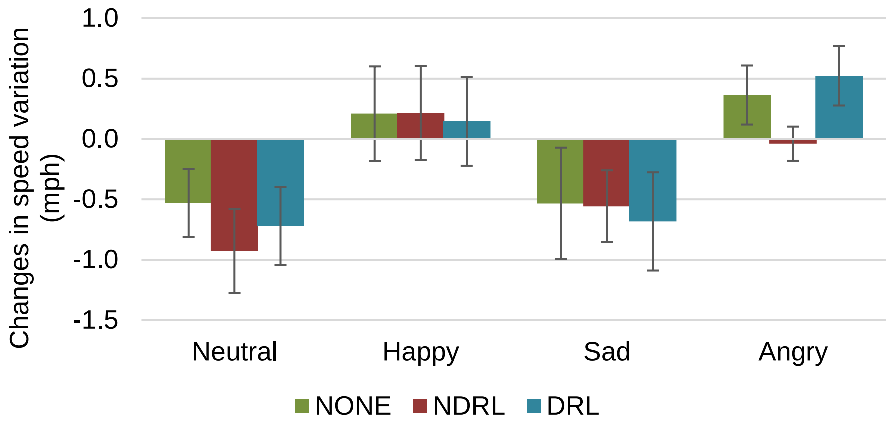


Figure 43: Changes in speed variation from the baseline to the corresponding condition

5.4.6.2 Braking force

<u>*Comparison between conditions:*</u>

There was a significant main effect of Mood, $F_{(3, 36)} = 3.09$, $p < 0.05$, $\eta_p{}^2 = 0.21$ (Figure 44, Table 14 in Appendix 2). Deviation contrast showed that the difference was between the neutral and all the other conditions, with participants in the neutral mood braking milder, $t = 2.25$, $p < 0.05$. Parameter estimates showed that the neutral mood is a significant predictor of milder brake force applied regardless of cognitive load: NONE – $t = 4.24$, $p < 0.001$, NDRL – $t = 3.56$, $p < 0.001$, DRL – $t = 4.32$, $p < 0.001$. The angry mood is a significant predictor of more braking force applied if no questions are asked and when driving related questions are asked: NONE - $t = -2.085$, $p < 0.05$, DRL – $t = -2.13$, $p < 0.05$.

There was no main effect of Load and no interactions in braking force during CFL hazardous event.

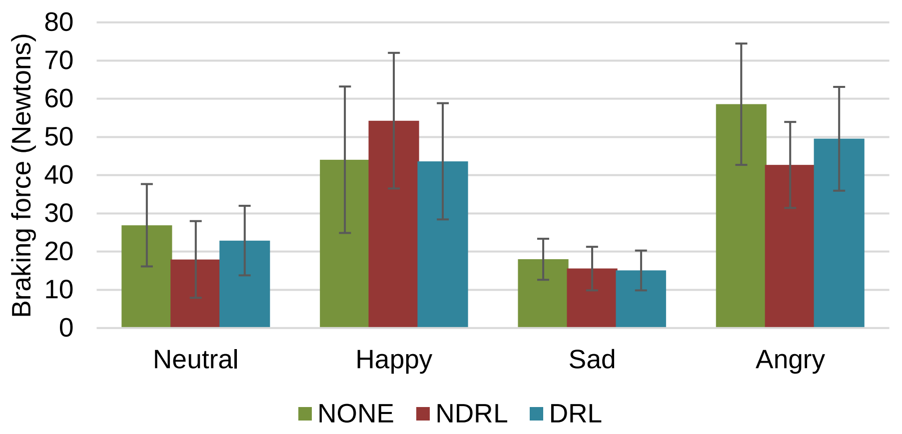


Figure 44: Braking force by Mood and Load

<u>Comparison of changes from the baseline to the corresponding mood:</u>

There were no significant main effects of Mood and Load and no interaction in braking force in changes from the baseline to the corresponding conditions. Deviation contrasts showed that the braking force in the happy mood is significantly higher than in the other moods, $t = 2.21$, $p = 0.03$ (Figure 45). Parameter estimates showed that none of the moods can be a significant predictor of braking force.

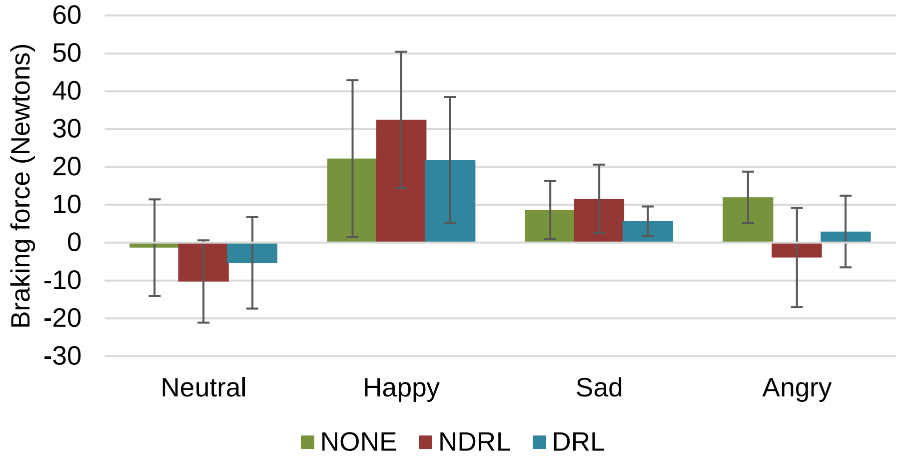


Figure 45: Changes in braking force from the baseline to the corresponding condition

5.4.6.3 Maximum braking

There were no significant differences in the maximum braking force between Mood and Load conditions and no interaction for CFL hazard. There also were no significant differences in changes in maximum braking force from the baseline to the corresponding conditions and no interactions. All the drivers, except the angry drivers and happy drivers, tend to brake more gently in the experimental drives compared to the baseline. However, these differences did not reach significance level (Figure 46).

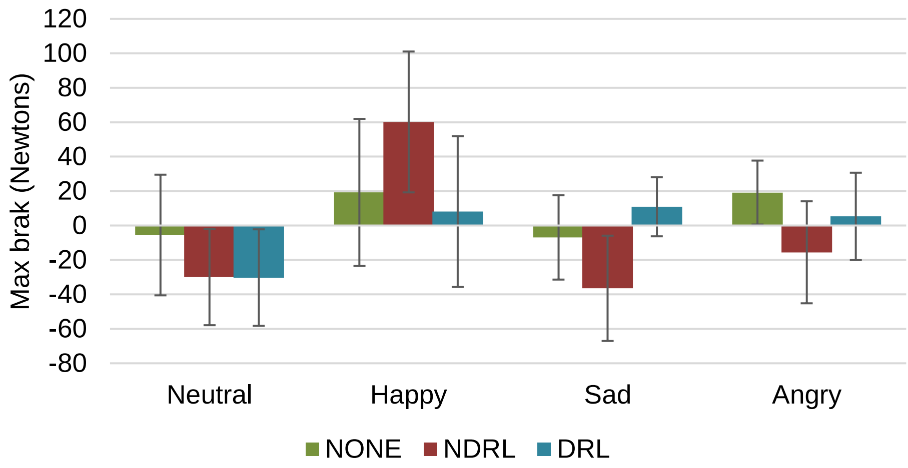


Figure 46: Changes in maximum braking force from the baseline to the corresponding condition

5.4.7 Expected hazards

5.4.7.1 Car from the right side junction

There were no main effects of Mood and Load and no interactions between the conditions and on the changes from the baseline to the corresponding condition in average speed and acceleration. In deceleration, there were no main effects of Mood and Load and no interactions between the conditions, but was a main effect of Mood on the changes from the baseline to the condition.

5.4.7.1.1 Speed variation

Comparison between conditions:

There were no main effects of Mood and Load and no interactions in average speed on approach to CFR hazard between conditions, and differences in changes from the baseline to the corresponding condition.

There was a significant main effect of Mood on speed variation, $F_{(3, 36)} = 5.16$, $p < 0.01$, $\eta_p^2 = 0.3$, with significantly higher variation in the happy mood compared to the sad mood, $t = 3.52$, $p < 0.01$ (Figure 47). Deviation contrasts showed that the happy mood has higher speed variation compared to other moods, $t = -1.97$, $p < 0.05$.

Parameter estimates for CFR showed that the neutral mood is a significant predictor of speed variation when no-load is applied: NONE - $t = 2.46$, $p < 0.05$. The happy mood is a significant predictor against neutral mood only when NDRL is applied, $t = 4.29$, $p < 0.001$.

There was no significant main effect of Load and no interactions in speed variation.

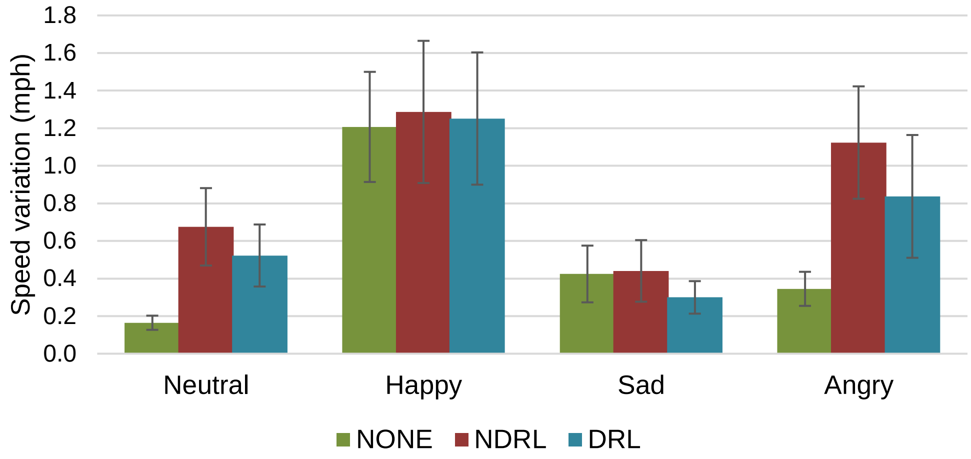


Figure 47: Speed variation by Mood and Load

Comparison of changes from the baseline to the corresponding mood:

There were no significant main effects of Mood, Load and no interactions (Figure 48).

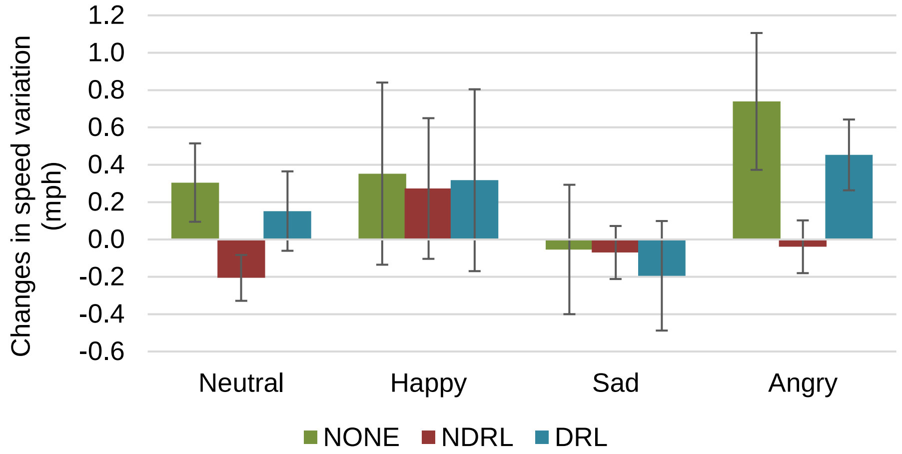


Figure 48: Changes in speed variation from the baseline to the corresponding condition

5.4.7.1.2 Deceleration

Comparison of changes from the baseline to the corresponding mood:

There was a significant main effect of Mood on deceleration changes from the baseline to the corresponding Mood condition in CFR hazard, $F_{(3, 36)}$ =

3.3, $p < 0.05$, $\eta_p^2 = 0.22$ (Figure 49, Table 12 in Appendix 2). Post hoc tests showed that the angry drivers decelerated less after the mood induction. This difference was significant compared to the neutral drivers, who increased the amount of deceleration after the mood induction, $t = -2.99$, $p < 0.05$. Deviation contrasts showed that the happy drivers decelerated significantly less after the mood induction compared to all other drivers, $t = 2.17$, $p < 0.05$.

Parameter estimates showed that when no-questions are asked, the neutral mood is a significant predictor of deceleration, $t = 2.08$, $p < 0.05$. It also showed that, the happy mood is a significant predictor when no-questions are asked, $t = -3.34$, $p < 0.01$, and when non-driving related questions are asked, $t = -2.74$, $p < 0.01$.

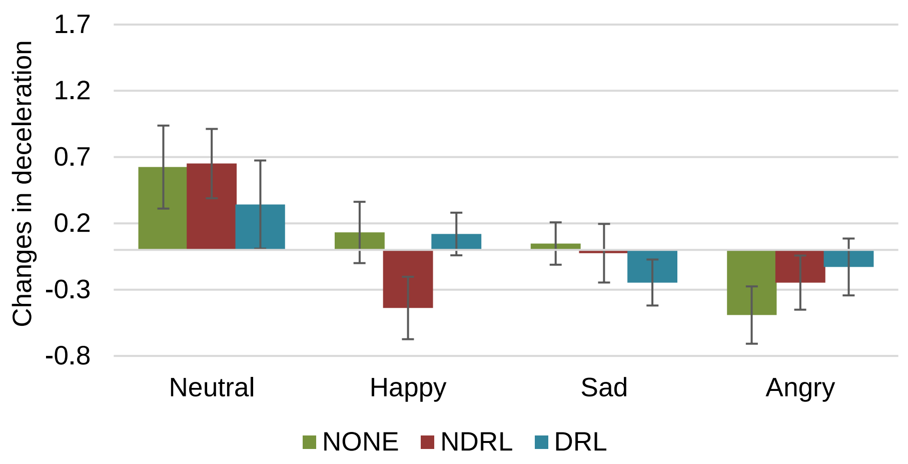


Figure 49: Changes in deceleration from the baseline to the corresponding condition

5.4.7.1.3 Time actively braking

There were no main effects in Mood and Load and no interactions in the time actively braking between different conditions and between changes from the baseline to the corresponding condition in CFR hazard.

Deviation contrasts showed that the happy drivers during CFR hazardous event spent significantly more time actively braking compared to the drivers in other conditions, $t = 2.06$, $p < 0.05$ (Figure 50, Table 13 in Appendix 2).

Parameter estimates for CFR hazardous event showed that, when no questions are asked, the happy mood is a significant predictor of time spent actively braking, $t = 2.03$, $p < 0.05$.

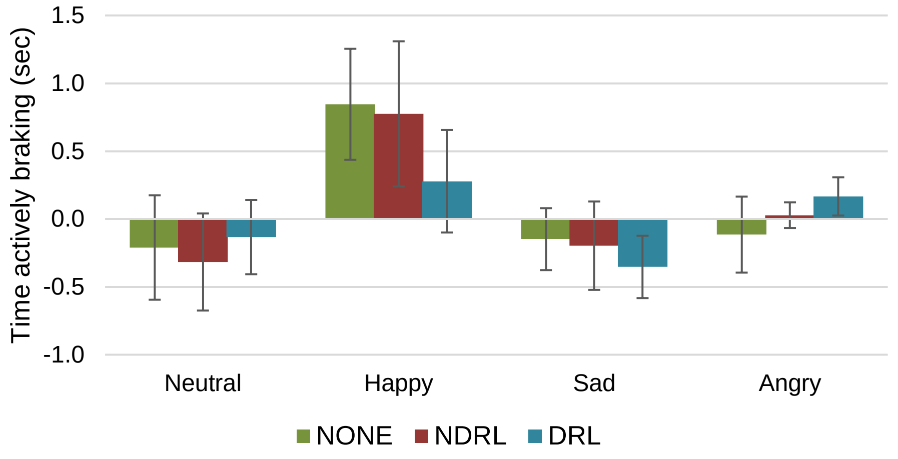


Figure 50: Changes in time actively braking from the baseline to the corresponding condition

5.4.7.1.4 Braking force and maximum braking

There were no significant main effects of Mood and Load and no interaction in braking force during CFR hazardous event and in the changes from the baseline to the corresponding Mood and Load conditions.

However, the angry drivers tend to brake harder compared to the baseline (Figure 51).

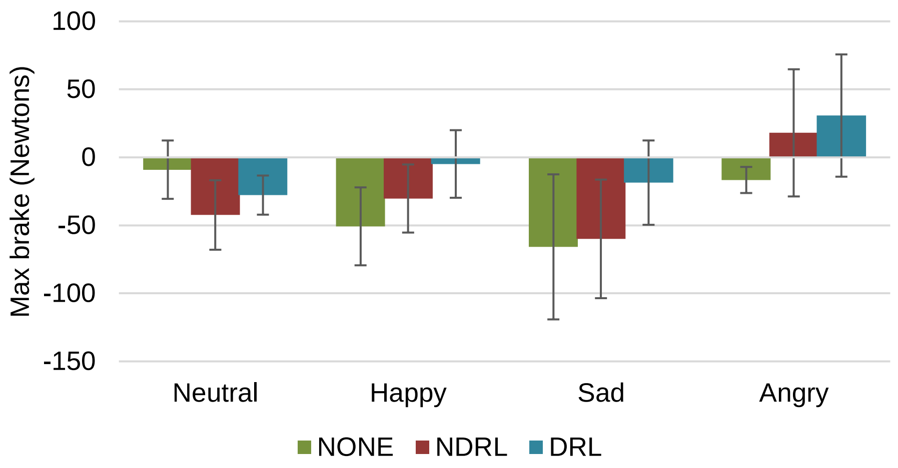


Figure 51: Changes in maximum braking force from the baseline to the corresponding condition

5.4.7.2 Single parked car suddenly moving off

There were no main effects of Mood and Load and no interactions between the conditions and on the changes from the baseline to the corresponding condition in speed variation, acceleration, deceleration and time actively braking.

5.4.7.2.1 Average speed

<u>*Comparison between conditions:*</u>

There was a significant main effect of Mood, $F_{(3, 36)} = 15.16$, $p < 0.001$, $\eta_p^2 = 0.99$, with significantly higher speed in the high arousal conditions compared to low arousal conditions (Table 18, Figure 52, Table 15 in Appendix 2). Deviation contrasts showed that this difference was due to the speed being slower in the low arousal conditions compared to all other conditions: neutral, $t = 5.58$, $p < 0.001$, sad, $t = 4.36$, $p < 0.001$.

Table 18: Post hoc tests for average speed

Moods	*t* - value	*P* - value
Angry v Neutral	5.58	.001***
Angry v Sad	4.36	.001***
Happy v Neutral	4.99	.001***
Happy v Sad	3.8	.01**

Parameter estimates for PS hazard showed that drivers' mood is a significant predictor of drivers' speed choice when driving on not busy roads, with occasionally parked cars, regardless of cognitive load, except the sad mood with the reference to the neutral mood (Table 19).

Table 19: Parameter estimates for average speed

Load	Mood	*t*	*p*
NONE	Neutral (intercept)	30.73	.001***
	Angry	4.96	.001***
	Happy	4.01	.001***
NDRL	Neutral (intercept)	27.65	.001***
	Angry	3.13	.01**
	Happy	3.12	.01**
DRL	Neutral (intercept)	28.72	.001***
	Angry	5.12	.001***
	Happy	4.59	.001***

There was no main effect of Load and no interactions in mean speed in PS hazardous event.

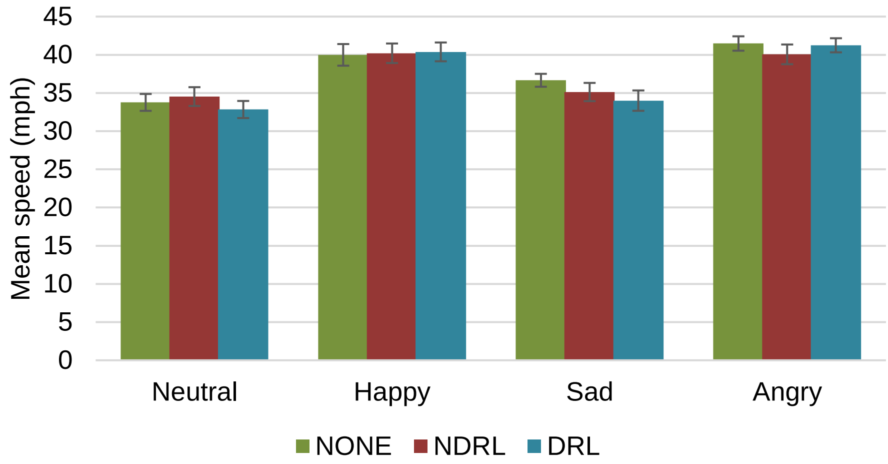


Figure 52: Average speed by Mood and Load

There was no significant main effect of Load and no interaction in speed during PS hazard.

Comparison of changes from the baseline to the corresponding condition:

There was a significant main effect of Mood, $F_{(3, 36)} = 4.77$, $p < 0.01$, $\eta_p^2 = 0.29$, with significantly lower speed in the neutral mood compared to the happy mood, $t = 2.82$, $p < 0.05$, and significantly lower speed in the sad mood compared to the happy mood, $t = 2.91$, $p < 0.05$ (Figure 53). However, deviation contrasts showed that this difference was due to the speed being slower in the low arousal conditions compared to all other conditions: neutral, $t = 5.58$, $p < 0.001$, sad, $t = 4.36$, $p < 0.001$. Deviation contrasts showed that the neutral mood was different from all the other conditions, $t = 2.42$, $p < 0.05$, and the sad mood was different from all the others, $t = 2.51$, $p < 0.05$.

Parameter estimates show that the neutral mood is significant predictor of speed regardless of cognitive load, and the happy and the angry moods are significant predictors of speed against the neutral mood regardless of cognitive load, except the angry mood, which is not significant predictor when NDRL questions are asked (Table 20). The sad mood is not a predictor of the speed changes with the references to the neutral mood, regardless of the type of load.

Table 20: Parameter estimates for changes in speed from the baselines to the corresponding condition

Load	Mood	*t*	*p*
NONE	Neutral (intercept)	-3.61	$.001^{***}$
	Angry	2.74	$.01^{**}$
	Happy	2.76	$.01^{**}$
NDRL	Neutral (intercept)	-2.57	$.01^{**}$
	Happy	2.09	$.05^{*}$
DRL	Neutral (intercept)	-3.38	$.002^{**}$
	Angry	2.44	$.02^{**}$
	Happy	2.71	$.02^{**}$

There was no main effect of Load and no interactions in mean speed changes from the baseline to the corresponding condition in PS hazardous event.

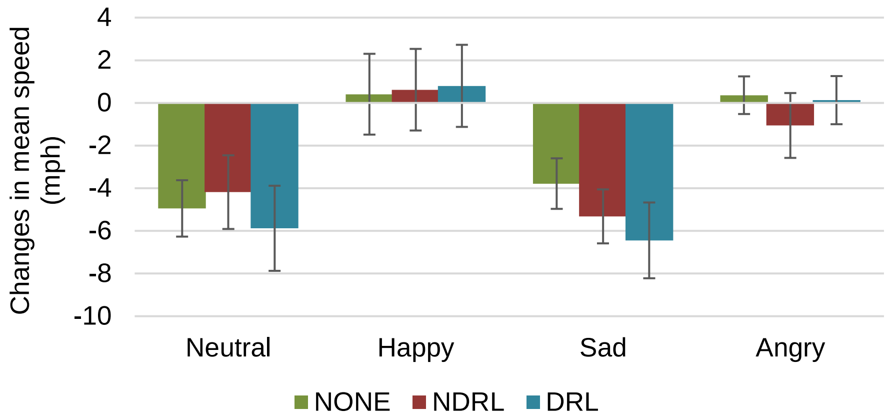


Figure 53: Changes in average speed from the baseline to the corresponding condition

5.4.7.2.2 Braking force

Comparison between conditions:

There was a significant main effect of Mood in braking force, $F_{(3, 36)} = 3.78$, $p < 0.05$, $\eta_p^2 = 0.24$ (Figure 54, Table 17 in Appendix 2). Post hoc tests showed that the angry drivers applied significantly more braking force compared to the sad drivers, $t = 2.9$, $p < 0.05$. Deviation contrasts showed that both low arousal conditions were different, neutral, $t = 2.62$, $p < 0.01$, and sad, $t = 2.9$, $p < 0.01$. Parameter estimates showed that angry mood is a significant predictor of braking force in NONE, $t = 2.94$, $p < 0.01$, and NDRL, $t = 2.51$, $p < 0.05$ Load conditions.

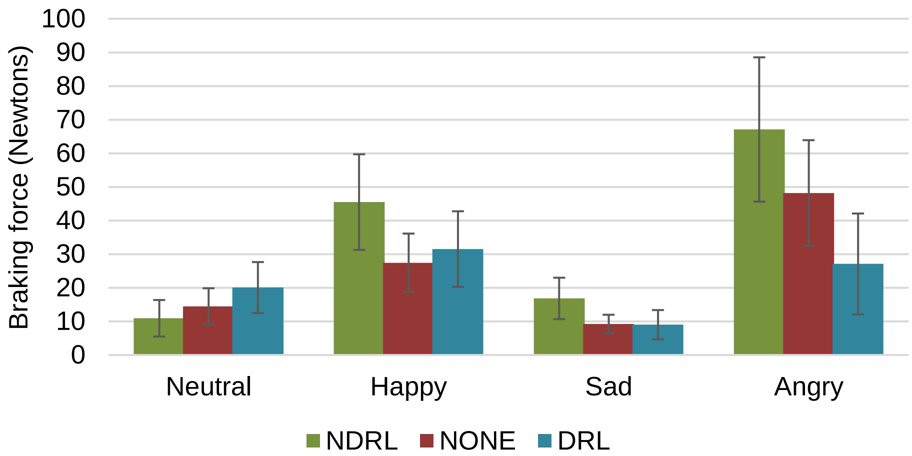


Figure 54: Mean braking force by Mood and Load

There was no significant main effect of Load and no interactions in braking force in PS hazard.

Comparison of changes from the baseline to the corresponding condition:

There was a significant main effect of Mood in braking force changes from the baseline to the corresponding Mood, $F_{(3, 36)} = 5.17$, $p = 0.01$, $\eta_p{}^2 = 0.30$ (Figure 55, Table 17 in Appendix 2). Post hoc tests showed that the angry drivers pressed the brake pedal significantly harder than the happy drivers, $t = 3.5$, $p < 0.001$, the drivers in the neutral mood, $t = 2.84$, $p < 0.05$ and the sad drivers, $t = 3.17$, $p < 0.05$. Deviation contrasts showed that the happy, the neutral and the sad moods differed from the grand mean (Table 21).

Parameter estimates showed that angry mood is a significant predictor of braking force in NONE, $t = 3.19$, $p < 0.01$, and NDRL, $t = 3.01$, $p < 0.01$ Load conditions.

Table 21: Deviation contrasts for changes in braking force from the baseline to the corresponding condition

Moods	***t* value**	***P* value**
Happy – Angry, Happy, Neutral, Sad	3.5	.001***
Neutral – Angry, Happy, Neutral, Sad	2.84	.007**
Sad – Angry, Happy, Neutral, Sad	3.17	.003**

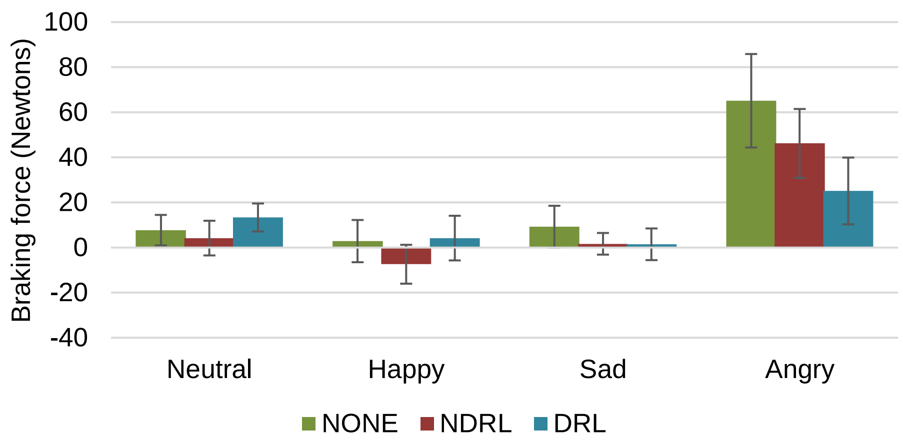


Figure 55: Changes in mean braking force from the baseline to the corresponding condition

There was no significant main effect of Load and no interactions in braking force changes from the baseline to the corresponding Load condition in PS hazardous event.

5.4.7.2.3 Maximum braking

Comparison between conditions:

There was a marginally significant main effect of Mood, $F_{(3, 36)} = 2.78$, $p = 0.055$, $\eta_p^2 = 0.19$ (Figure 56, Table 18 in Appendix 2). Deviation contrasts showed that the difference was between neutral and other means, $t = 2.5$, $p < 0.05$, and sad and grand mean, $t = 2.25$, $p < 0.05$.

Parameter estimates showed significant prediction only in the angry mood when no questions were asked, $t = 2.51$, $p < 0.05$.

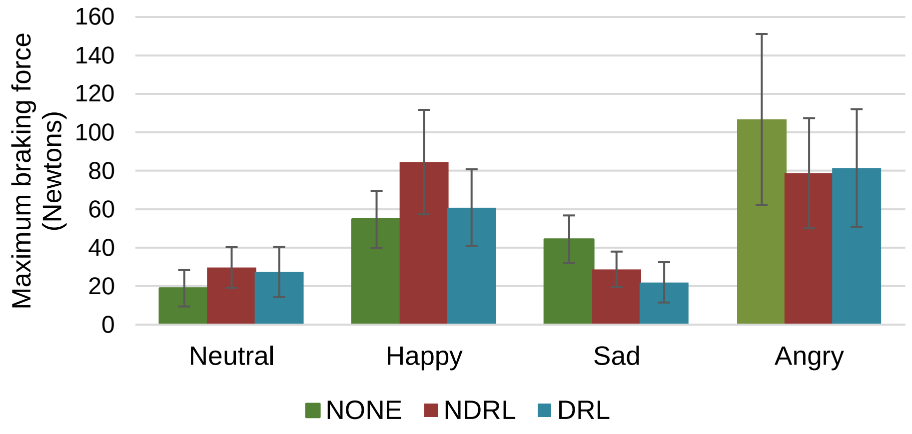


Figure 56: Maximum braking force by Mood and Load

There were no significant differences in Load and no interaction in maximum braking force in PS hazard.

Comparison of changes from the baseline to the corresponding condition:

There was a significant main effect of Mood, $F_{(3, 36)} = 3.55$, $p < 0.05$, $\eta_p^2 = 0.23$ (Figure 57, Table 18 in Appendix 2). Post hoc tests showed that the angry drivers pressed the brake pedal significantly harder compared to the drivers in the neutral mood, $t = 3.09$, $p < 0.05$. Deviation contrasts showed that different were the neutral mood, $t = 3.09$, $p < 0.01$, and the sad mood, $t = 2.39$, $p < 0.05$.

Parameter estimates showed that the angry mood, regardless of cognitive load, significantly predicts maximum braking force: NONE - $t = 2.99$, $p < 0.01$, NDRL - $t = 2.38$, $p < 0.05$, DRL - $t = 2.49$, $p < 0.05$.

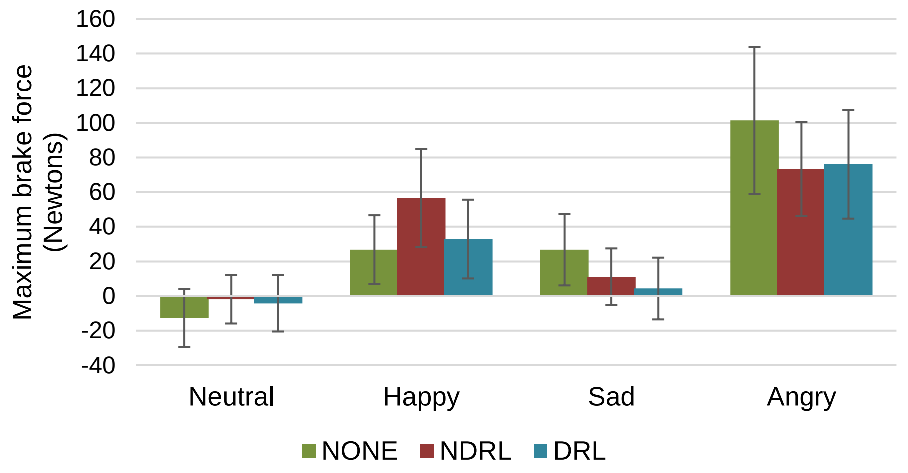


Figure 57: Changes in maximum braking force from the baseline to the corresponding condition

There were no significant differences in changes from the baselines to the corresponding conditions in maximum braking force in Load and no interaction.

5.4.7.3 Parked car in group suddenly moving off

There were no main effects of Mood and Load and no interactions between the conditions and on the changes from the baseline to the corresponding condition in speed variation, acceleration, deceleration, braking force and maximum braking.

5.4.7.3.1 Average speed

Comparison between conditions:

There was a significant main effect of Mood, $F_{(3, 36)} = 5.31$, $p < 0.01$, $\eta_p^2 = 0.31$, with significantly higher speed in the angry mood compared to the neutral mood, $t = 2.98$, $p < 0.05$, and significantly higher speed in the happy mood compared to the neutral mood, $t = 3.14$, $p < 0.05$ (Figure 58, Table 15 in Appendix 2). Deviation contrasts showed that the differences were between the neutral mood and all other moods, $t = 2.98$, $p < 0.01$, and between the sad mood and all other moods, $t = 2.41$, $p < 0.05$.

Parameter estimates for PG hazard showed that the neutral mood is a significant predictor of speed regardless of cognitive load: NONE, $t = 24.53$, $p < 0.001$, NDRL, $t = 28.62$, $p < 0.001$, DRL, $t = 25.31$, $p < 0.001$. The angry mood is a significant predictor of speed in relation to the neutral mood only when no questions are asked, $t = 2.33$, $p < 0.05$, and the happy mood is a significant predictor of speed when no questions are asked, $t = 2.16$, $p < 0.05$, and when driving related questions are asked, $t = 3.2$, $p < 0.01$.

There was no main effect of Load and no interactions in mean speed between the conditions during PG hazardous event.

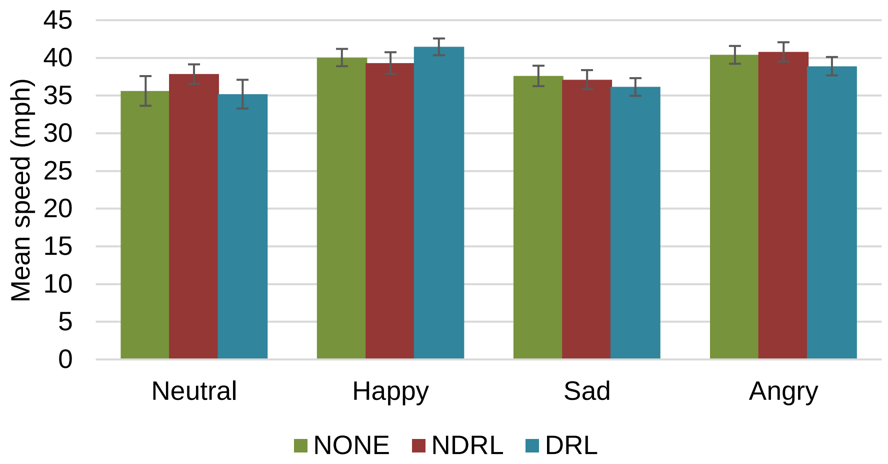


Figure 58: Mean speed by Mood and Load

<u>Changes from the baseline to the corresponding mood:</u>

There was a significant main effect of Mood, $F_{(3, 36)} = 4.25$, $p < 0.01$, $\eta_p^2 = 0.26$, with significantly higher changes in speed in the happy mood compared to the neutral mood, $t = 3.08$, $p < 0.05$ (Figure 59). Deviation contrasts showed that the speed increase in the happy mood was significantly higher than in all other moods, $t = -2.02$, $p < 0.05$.

Parameter estimates for changes in speed when approaching PG hazard showed, the neutral mood is a significant predictor of speed only when driving related load is applied, t = -2.05, $p < 0.05$. The happy mood is a significant predictor of speed changes in relation to the neutral mood when no questions are asked, t = 2.67, $p < 0.01$, and when driving-related questions are asked, t = 3.41, $p < 0.01$.

There was no main effect of Load and no interactions in mean speed changes from the baseline to the corresponding condition in PG hazardous event.

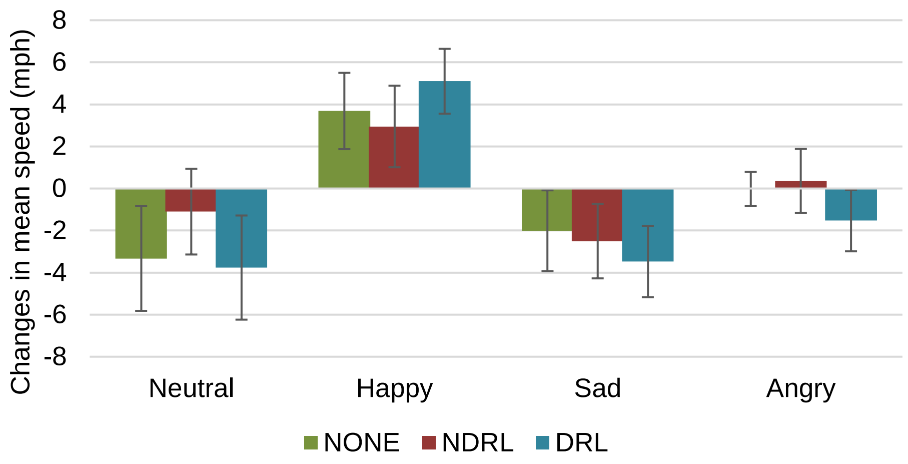


Figure 59: Changes in mean speed from the baseline to the corresponding condition

5.4.7.3.2 Time actively braking

Comparison between conditions:

There was a marginally significant main effect of Mood in time actively braking, $F_{(3, 36)} = 2.36$, $p = 0.08$, $\eta_p^{2} = 0.16$ (Figure 60, Table 16 in Appendix 2). Deviation contrasts showed that the angry drivers actively pressed the brake pedal for significantly shorter period of time compared to the other conditions, t = 1.93, $p < 0.05$. Parameter estimates showed that the neutral mood is a significant predictor of the less time spent actively braking in NDRL load condition, t = 2.97, $p < 0.01$ and DRL load conditions, t = 2.92, $p < 0.01$.

In the PG event there was no significant main effect of Load and no interaction between changes from the baselines to the corresponding Mood and Load conditions.

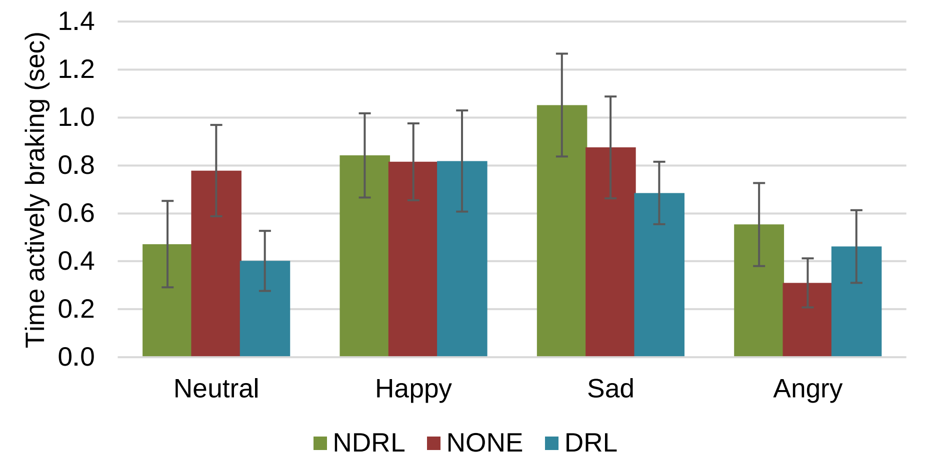


Figure 60: Time actively braking by Mood and Load

<u>Comparison of changes from the baseline to the corresponding condition:</u>

There were no main effects of Mood and Load and no interaction in changes from the baseline to the corresponding conditions, although Figure 61 and Table 16 in Appendix 2 show that the time actively braking decreased in all the conditions except the neutral mood condition when NONE or DRL was applied.

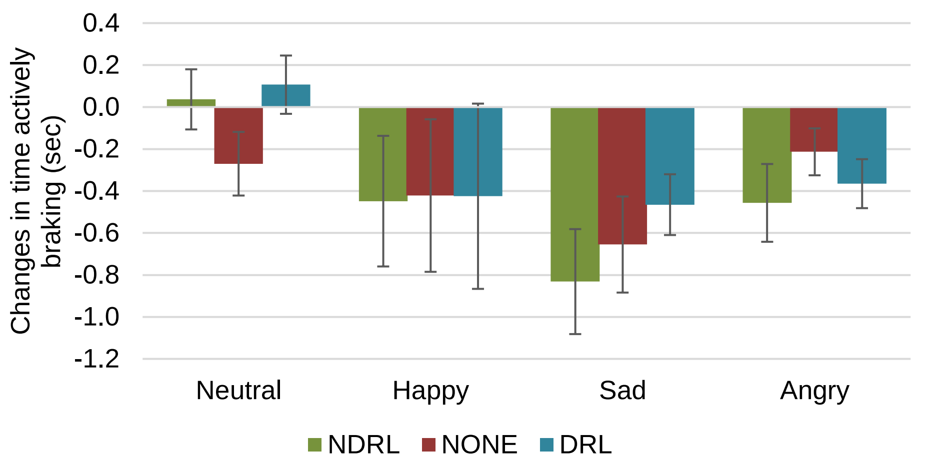


Figure 61: Changes in time actively braking from the baseline to the corresponding condition

5.5 Discussion

5.5.1 Self-reported evaluation of arousal and mood

The valence and arousal assessment grid reliably distinguished between the induced moods, with high arousal moods showing an increase in arousal from baseline and low arousal moods not inducing a significant change. The participants assigned to the happy group even indicated lower arousal level compared to their baseline arousal. This could be due to the participants feeling more tired after the experiment.

Participants assigned to the negative valence moods indicated a significant change in their mood valence after the experiment. Whereas participants in positive valence moods did not indicate that their mood would change.

5.5.2 Physiological measures

5.5.2.1 Mood induction

It was hypothesised that higher EDA and HR would reflect high arousal conditions [H4]. Both measures EDA and HR showed high sensitivity to changes in participants' arousal during mood induction. However, the results were dissimilar for the car following task and hazardous events.

5.5.2.2 Adaptation effect

EDA and HR data were calculated by subtracting the baseline measures from the corresponding conditions. EDA data showed the expected results, lower conductance in all conditions compared to baseline and an 'adaptation effect'. Dawson et al. (2007) argue that when the same stimuli are presented repeatedly, they lose the effect of novelty. EDA includes reaction to the stimuli peculiarity and novelty. Adaptation effect is the loss of the novelty effect.

5.5.2.3 Coherence task

Participants' EDA in the angry mood showed the lowest adaptation effect and in the neutral mood the highest adaptation effect. Dawson et al. (2007) argue that normally the adaptation effect is similar for every individual, therefore, the difference in the adaptation effect can be explained by some

EDA response to the angry mood. This difference did not reach a significance level, but however, showed a trend – angry mood elicits higher skin conductance, which does not fade over time.

There were changes in HR for those in the angry mood compared to the baseline, showing an enlarged effort of the angry drivers. Interestingly the increase in heart rate with the angry emotion induction (about 15 beats per minute) is similar to the increase in heart rate while driving affected by MethyleneDioxyMethAmphetamine (MDMA), as found by Brookhuis and De Waard (2010). Ward et al. (2003) also found an increase in heart rate with the addition of a secondary cognitive task, however to a lesser extent (3 beats per minute), indicating that the angry emotion influences heart rate more than the secondary cognitive task. Other moods appear not to have an effect on HR. A substantial effort is known to cause fatigue in many areas, including driving (Belmont, Agar, & Azouvi, 2009; Borghini et al., 2012), and drivers' fatigue has been named as one of the major causes of traffic accidents (Lal & Craig, 2001). Moreover, Matthews and Desmond (2002) argue that drivers' performance declines as a function of drivers' fatigue. Therefore, an increase in HR caused by angry emotions for a longer period of time can lead to a safety decline.

Cognitive load appears not to influence drivers' physiological measures, mainly due to the fact that the tasks were not designed to increase drivers' cognitive load to a level that could influence their processing effort, but only lower mind wandering induced by moods. Although drivers reported more effort in concentrating on the driving task while driving related questions were asked, this comparison was linked to the different nature of questions between NDRL and DRL. Therefore, whilst drivers reported more difficulty in concentrating while in the DRL condition compared to NDRL, this did not reach a level to affect their physiology.

5.5.2.4 Physiological measures during hazardous events

Although some changes were recorded with regards to HR, in the present research the HR measures are not representative of drivers' arousal level during hazardous events, neither with regards to drivers' mood nor their cognitive load. This could be due to limited sampling frequency available for the analysis. Empatika records heart rate with a frequency of 1 Hz. As hazardous event analysis was based on 3 seconds recording, there was not enough information for reliable analysis. The second reason could be huge variability, as Mood was a between groups variable, individual differences were too strong in the present study.

However, EDA data were collected with different frequency, 4 times in a second. This permitted for more power in statistical analysis. EDA increased as a result of physiological and emotional arousal (Treaty, 2004). However, the adaptation effect was recorded similarly as in the car following task. Interestingly, the biggest and significant decline was recorded in the neutral mood. This permits assuming that other moods had some arousing influence on participating drivers.

Alternatively, the highest habituation effect, recorded in the neutral mood, could be because these drivers were more aware of possible hazards on the approach to junctions, thus less surprised. Whereas, stress caused by disconnection from mind wandering, resulted in some increase in skin response (Smallwood et al., 2009).

5.5.3 Coherence metrics: coherence, phase shift and modulus

It was hypothesised [H6, H8], that a driver's ability to follow a lead vehicle, keeping the distance from it safe and constant, would be impaired as a function of their mood and cognitive load. Sad drivers would be affected the most, and the negative valence of angry mood would be compensated by high arousal. High arousal in the happy mood instead, would have a negative effect on driving performance. Non-driving related load (NDRL) would disengage drivers from their mood-related internal thoughts but still, compete for by attention. As a consequence NDRL would lower performance. Driving-related load (DRL) instead, apart from disengaging drivers' attention from emotional involvement, would direct drivers' attention towards road and traffic-related procedures. As a consequence, this would improve driving performance. Car following performance was assessed using three metrics suggested by Brookhuis and colleagues in 1994: coherence, phase shift and modulus.

Coherence is an important metric as it shows whether drivers complied with the task (Ward et al., 2003). The study did not reveal any significant differences in coherence between conditions in either of the two cycles. The study has shown that also the drivers needed some more time to adjust to the lead vehicle's speed in the first cycle, their compliance with the task was very high, with a minimum value of 0.35 in the sad mood with no cognitive load. The results suggest a good coherence throughout a drive. Therefore all the metrics are good representatives of drivers' ability for car following under different conditions (De Waard, 1996). In previous research sad mood showed to be the most self-centered condition with the slowest response times (Pêcher et al., 2009; Zimasa et al., 2017). When no questions were asked, the sad drivers were not distracted from their internal thoughts and mind wandering and showed the lowest coherence. However, the correlation value was still above the minimum value (0.3) set by Ward et al. (2003). Thus all the following metrics could be counted as valid. In cycle 2, drivers performed better in all the conditions, thus showing some habituation effect. Drivers' mood and cognitive load do not significantly affect coherence in the car following task.

Phase shift is a measure of drivers' reaction to a lead vehicle's speed variation, also called - delay. Phase shift was affected only in the first cycle, suggesting some habituation effect of Mood and Load on drivers' attention. In the first cycle, drivers' reaction times were significantly affected by their mood. The highest mean reaction delay showed sad and happy drivers, suggesting that these moods affect drivers' attention the most. Interestingly, the sad drivers had a similar reaction delay (5.27 seconds) to drivers solving secondary task while driving in Ward et al. (2003) study (5.17 seconds). This suggests that mind wandering affects the sad drivers similarly to additional cognitive load. The parameter estimates permit the examination of how the interaction between different Moods and Loads can predict changes in drivers' attentional delay. The results showed that neutral mood is a significant predictor of phase shift regardless of cognitive load. DRL affected only sad drivers, thus supporting the prediction [H8] of the possibility to direct drivers' attention only in this mood. Consequently, some load is beneficial for driving safety as a factor that can interrupt from mind wandering (De Waard & Brookhuis, 1991). However, not all moods can be affected by this type of cognitive load.

Changes in phase shift from baseline to the corresponding condition were significantly affected by drivers' mood, with sad drivers having significantly higher increase and all the other drivers decrease in reaction delay. These results resemble conclusions drawn by Smallwood and Schooler (2006), which state that low vigilance tasks can result in decoupling from external information in favour to internal information. It could be said that this finding contradicts the previous statement, saying that the sad and the happy moods are the most detrimental to driving safety. The analysis of changes shows that the happy mood, in fact, improves drivers' reactions. However, this improvement is still not big enough to be able to affect reaction time to the same extent as the neutral and the angry moods do. Parameter estimates show that neither Mood nor Load is a significant predictor of drivers' reactions.

Modulus metrics follow similar patterns to the phase shift metrics, being significantly affected by moods only during cycle 1. This difference was between the happy and the sad mood, with the sad mood having a significant overshoot and the happy mood provoking undershoot. Modulus reflects the following driver's reactions at the highest values of the lead car's speed. Modulus values in the sad mood (>1) reflect drivers' potentially aggressive overcorrection (Ranney et al., 2005). This overcorrection appears as a result of a large following distance. Happy drivers instead, showed some under-correction, which is another sign of inadequate following distance (Ranney et al., 2005). Parameter estimates show that positive moods and low arousal are significant predictors of good response to a lead vehicle's speed, regardless of cognitive load. No-load and NDRL did not appear being significant predictors to modulus changes in any mood condition with reference to neutral mood. Driving-related load instead is a significant predictor of changes in reaction times of the happy and sad drivers. In other words, DRL makes sad and happy drivers overshoot significantly more compared to the drivers in neutral mood.

Changes in modulus from the baseline to the corresponding mood condition showed that moods are significant predictors of drivers' reaction changes, with most changes appearing from the baseline to either the happy or the sad mood. The drivers in the neutral mood and the angry drivers did not alter modulus considerably after the mood induction, showing just a small increase. The sad drivers also increased modulus after the mood induction. This increase was significant compared to the modulus change in happy mood, which was the only mood with modulus decrease. Parameter estimates also showed that the changes from baseline to the happy mood are significant predictors for the decrease in drivers' attention.

In summary:

Regardless of drivers' mood and cognitive load they are disposed to some habituation effect. This effect is not recorded with reference to drivers' mood or cognitive load, but with reference to task repetition. In other words, when adapting to the task conditions, drivers did not increase their mind wandering or attentional failure, instead, they improved the driving performance to some extent.

Drivers' reactions to changes in speed of the lead vehicle are the most affected by the sad mood and the happy mood. The difference between these two effects is that the sad mood provokes a reaction delay, whereas the happy mood improves drivers' reactions on some parameters (e.g. phase shift). However, this improvement is still considerably lower compared to neutral state of mind. The neutral mood is a significant predictor of phase shift if all the other variables are held constant, drivers in the neutral mood improve their reaction sensitivity to a speed change in the lead vehicle.

Cognitive load does not induce considerable changes in drivers' attention. Only modulus in the happy and the sad moods were significant predictors of changes with reference to the neutral mood: with predicted overshooting in the sad mood and undershooting in the happy mood.

5.5.4 Time headway during the coherence task

The present research has investigated how different moods and cognitive load affect car following behaviours, as expressed by time headway. It was hypothesised [H6, H8] that the angry drivers would choose shorter following times (Tasca, 2000). It was also hypothesised that if following time can be accounted for by arousal, happy drivers following distance should be similar to that of the angry drivers. Sad drivers instead would increase the car following distance due to compensatory mechanisms and the internal nature of the sad mood (Zimasa et al., 2017). The drivers in the neutral mood should not be affected by the arousal, and due to no changes in the mood valence, their car following distance should not change from the baseline.

The time headway results partially support the hypotheses. The angry drivers increased their following time in the 0-1 and 1-2 segments, which are the most safety-critical, and in some countries (e.g. Sweden), not acceptable TH (Vogel, 2003). The happy drivers were not so consistent in their safety preferences. Some increase in the less safe 1-2 seconds segment was recorded along with an increase in the safer 3-4 seconds segment. This shows that there are some differences in choosing a safe distance between high arousal moods. A positive valence, in this case, moderates a negative effect of arousal. The significant decrease of time spent in the 3-4 seconds segment and increase in under 3 seconds segments for the angry drivers show that they are less concerned with possible consequences of driving too close to the car in front.

The sad drivers preferred travelling at 3-4 seconds headway significantly more often than the angry drivers and at 1-2 seconds headway significantly less than drivers in all the other moods, thereby increasing their safety gap. However, the increase in their eye fixation durations shows that the positive effect of this change reduces due to a slower switch of their attention and therefore less efficient road monitoring (Underwood, Chapman, Berger, et al., 2003; Zimasa et al., 2017). The biggest changes in time headway for low arousal moods were observed in the 2-3 seconds segment, indicating the importance of drivers' arousal in their perception of a safe following distance.

However, the changes in low arousal were mediated by the positive valence and affected only the sad drivers.

The type of the cognitive load also had a significant effect on the drivers' chosen following distances. When non-driving related questions were asked, drivers found it more difficult to maintain their chosen safety gap, showing time increase for about 20% in less than 2 seconds TH segment, and a significant decrease in safer 3-4 seconds segment. This change appears to have a negative effect on driving safety, as it encourages drivers to come closer to the car ahead.

5.5.5 Glance behaviour

It was hypothesised [H5, H8] that longer information processing and impaired attentional shift would be indicated by fixations larger in number and longer in duration, and mind wandering would be indicated by gaze concentration towards the road centre. It also was hypothesised that the most affected would be the drivers in the sad mood.

5.5.5.1 Fixation durations

Fixation durations are associated with difficulties in information extraction and processing (Wilson & Eggemeier, 1991) and increase in workload (O'Donnell & Eggemeier, 1986). In the present study Load was a significant factor influencing fixation durations, with no load having the shortest fixations and DRL – the longest. Therefore, DRL interferes the most with drivers' ability to switch their attention from subject to subject and their information processing speed.

These results reflect drivers' self-reports, where drivers acknowledged experiencing more disturbance when DRL questions were asked. It was hypothesised that DRL would disconnect drivers from mind wandering and bring their attention back to the road. Longer fixations in this condition indicate that drivers were processing information more extensively. Together with their statement that it was more difficult to concentrate when DRL questions were asked, it can be concluded that drivers experienced some amount of cognitive load in these conditions. However, the influence of this load on participants' driving ability is not clear before the driving-related data is analysed.

There was a significant main effect of Mood. Pairwise comparisons showed that the sad drivers processed information significantly slower compared to the drivers in the neutral and happy moods and drivers in the neutral mood marginally faster compared to the drivers in the angry mood. The results show that low arousal is not beneficial to drivers' information processing ability. Moreover, low arousal and negative valence is the worst mood for driving safety.

The significant interaction showed that the type of Load applied does not have the same effect on each Mood. The sad drivers were the most affected by the type of Load. When there was no load applied, drivers processed information faster, as compared to NDRL, and marginally faster when DRL was applied. This suggests that some amount of distraction is useful at times, as it prevents sinking deeply into a sad mood, which could be harmful to driving safety.

The change in fixation durations from baseline to the corresponding Mood condition is an important indicator of how Mood affects the ability to process information. There were significant main effects of Mood and Load, as well as a significant interaction. Post hoc tests showed significant differences between all the pairs, except Neutral-Happy and Sad-Angry pairs. The most affected conditions were the NDRL condition in the sad mood (the highest increase in the fixation durations) and the NDRL condition in the happy mood. This suggests that if the sad drivers are not distracted by any questions, their ability to process information is highly disrupted. Highly affected are also the happy drivers when asked non-driving related questions, but in a different direction. In this condition drivers' ability to process information increases the most as compared to baseline.

The comparison of overall Load conditions shows that when no questions are asked, the drivers are the most affected by their mood. The DRL condition, instead, is the less affected by the drivers' mood, thus showing the highest ability to disconnect from mind wandering.

Fixation durations in the present study are rather large. The drivers in the neutral emotional state fixated similarly as experienced drivers in Crundall et al. (1998), 340-380 milliseconds, but slightly longer than experts in non-driving professional fields Gegenfurtner et al. (2011), 325 milliseconds. Other emotions elicited longer fixation durations, 400-600 milliseconds, indicating longer information processing. Recarte and Nunes (2000) found longer fixations while driving and performing mental imagery task (450 milliseconds) and Salthouse and Ellis (1980) found fixations duration increase up to 600 milliseconds in cases when more time was needed to process complex stimulus. The present research shows that more processing time is also needed for individuals influenced by sad, happy and angry emotions, with the sad individuals requiring the most processing time.

5.5.5.2 Number of fixations

Number of fixations is strongly correlated with information processing effort and ability to switch attention; more fixations indicate more intensive visual search (Chapman & Underwood, 1998a). Christianson et al. (1991) state that the more fixations are made, the more scenery details are processed. Consequently drivers’ moods producing more fixations are beneficial to road safety.

However, there were no significant differences in number of fixations between the Mood and Load conditions, suggesting that neither Mood nor Load significantly affected the drivers’ attentional search patterns. However, there was a significant interaction between these two conditions, showing that the type of Load applied has an effect on the driver’s attention in the sad mood, with a higher number of fixations in DRL condition. This suggests that the sad drivers’ attentional search patterns can be improved by distracting them from their internal state of mind caused by the sad mood.

Changes in the number of fixations from baseline have confirmed this statement, the smallest decrease of fixations in the sad mood was in DRL condition. The significant interaction between Mood and Load indicates that the type of Load applied has different effects, depending on drivers’ mood. The sad drivers fixate more often when asked driving-related questions, compared to when not asked questions at all. This suggests that this type of intervention has a positive effect on driving safety. The happy, the angry and the neutral drivers seem not to be that much affected by the type of Load applied.

The changes also showed that the type of Load applied does not significantly change drivers' usual search patterns, unlike drivers' mood. The biggest increase in the number of fixations occurred in the neutral mood, showing that when the drivers' mood involvement is minimised, they are more prone to road exploration. The biggest decrease in the number of fixations occurred in the sad mood, suggesting that the sad drivers concentrate more on their internal feelings and are less interested in the surrounding environment. A similar effect occurred when the happy mood was induced. The number of fixations significantly decreased when drivers' mood changes to the happy. Overall only the neutral drivers increased their attentional search patterns, the sad, the happy and the angry drivers tend to search road less than before the mood induction.

5.5.5.3 Horizontal spread of fixations

It was hypothesised [H5] that participants' visual field of view (VF) would be narrowed under the influence of mood, due to mind wandering, but it would normalise once drivers are disrupted from mind wandering by some amount of cognitive load. Partially the hypotheses were supported, VF was affected by all the moods. The spread of fixations was similar to Recarte and Nunes (2000) who found the highest spread of fixations when driving without a task (10.5 degrees) compared to an imagery task (4.5 - 6 degrees). The drivers in the neutral emotional state had the widest visual field (7 - 8 degrees) compared to the drivers affected by emotions (5 - 6 degrees). These findings provide evidence that mind wandering can affect drivers' visual field similarly to additional mental imagery task applied while driving. However, neither type of cognitive load was able to change the width of the VF. With regards to mind wandering, previous research found that it is more affected by negative mood; Jonkman et al. (2017) found more mind wandering after the negative mood induction compared to the positive mood in self-reports and

Smallwood et al. (2009) came to similar conclusions using Response Times and self-reports. The present study does not fully support these statements.

The results suggest two possible explanations: mind wandering during driving somehow differs from mind wandering under other circumstances, and VF angle measure cannot distinguish between mind wandering in different moods. Certainly, the drivers mostly concentrate their attention on the road ahead, with some amount of attention devoted to dashboard and mirrors (Chapman et al., 2002). These observational patterns do not imply much variety. When drivers' thoughts are reflecting on emotional fragments, their interest in the car controls is probably also reduced, regardless of experienced emotions.

These observational lapses can seriously affect driving safety. For example, Galéra et al. (2012) argued that mind wandering has been allied with likely vehicle accidents. Indeed, VF narrowing can cause latency in recognising potential danger, thus reducing the time available for preparation and action.

The present study also examined possible ways of disengaging drivers from their internal thoughts, by applying some additional cognitive load in the form of questions. This additional load potentially could activate drivers' unused attentional resources (Young & Stanton, 2002). However, neither driving-related questions, nor non-driving related questions affected the width of the drivers' visual field. One possible explanation is that the applied cognitive load added to processing load caused by mind wandering, thus even if some kind of disengagement occurred, it would not be evident through measuring VF. Second, possibly VF narrowing, caused by mind wandering, reached a ceiling effect and there was no possibility for more reduction. Yet, questions asked while driving had a purpose of disengaging from mind wandering. Thus, some movement towards wider VF was expected. The results did not show any tendency towards this prediction, thus showing the ineffectiveness of cognitive load in visual search pattern improvement.

Interesting information was obtained by comparing changes in fixation spread from the baselines to the corresponding conditions. First, VF angle did not change much with mood induction in the happy and the angry moods.

This indicates that the happy and the angry drivers' visual patterns do not differ from their baseline (not affected by emotions) visual patterns. Drivers in the sad mood, instead, after mood induction narrowed their visual search patterns, and the visual field of drivers in the neutral mood became wider compared to their baseline driving. Although only changes in the neutral mood were significantly different, this analysis shows a change tendencies induced by other moods. Parameter estimates showed that if all the other variables are held constant, the neutral mood is a significant predictor of enlarging visual field only if no additional load is applied. This indicates that cognitive load had some influence on the drivers' search patterns when they were not emotionally affected. Similarly, the angry and the sad moods have more effect on VF narrowing when no questions were asked, indicating more mind wandering without distraction.

5.5.6 Cars merging from the side junctions

The results of the hazardous events showed more similarities between the driving patterns on approach to junctions (CFL and CFR), and between the driving patterns passing parked car hazards (PS and PG), rather than between expected and unexpected hazards. Therefore, 'cars merging from the side junctions' hazards are discussed together in this section, and 'parked cars suddenly moving off' hazards are discussed together in Section 5.5.7.

It was hypothesised [H3] that the drivers' performance in a neutral state of mind would not differ from their baseline performance. This prediction was not supported. The results showed performance improvements on some of the parameters after the neutral mood induction. After neutral mood induction, there was less speed variation. The amount of acceleration also decreased, however, not significantly. However, this performance change cannot be addressed by the improved performance while in the neutral mood, some improvement could be due to the stimulus repetition, as the baseline drive always was the first.

5.5.6.1 Speed, acceleration and deceleration approaching hazardous events at junctions

It also was hypothesised [H7] that a high arousal would initiate higher speeds. This prediction was not supported, as there were no differences in mean and maximum speed between different conditions. However, drivers in the neutral and the sad moods drove smoother in both events, and the happy drivers had higher speed variations in CFR event. Analysis of changes from baselines to the corresponding condition showed similar patterns: speed variation of the drivers in the sad and the neutral moods was lower than in the baseline and the happy and the angry drivers increased their speed variation. There were also no differences in acceleration between the conditions and no changes from the baseline, indicating that speed variation was not due to the participants accelerating harder in any of the conditions.

Investigation of deceleration style showed no differences on approach to CFL hazard between any of the Mood or Load conditions. This means that the difference in speed variation in CFL hazard was not caused by harder acceleration or deceleration. In CFR hazard, the happy participants decelerated significantly less than participants in other moods. This smaller deceleration together with no differences in acceleration implies that the changes in speed variation in CFR were also not caused by these actions.

The results also showed that, regardless of the cognitive load, the neutral mood predicts smoother driving. The happy mood, on the other hand, encourages more jerky driving only when non-driving related questions are asked, and only when a car is approaching from a right side junction. The sad mood changes drivers' normal driving style only when driving-related questions are asked. Therefore, the [H8] is partially supported with the respect to the happy and the sad moods.

Previous research has consistently concluded that drivers drop speed in response to cognitive load and distraction (Brouwer & Ponds, 1994; Chiang et al., 2001; Patten et al., 2004; Saad et al., 2005). The present speed analysis did not detect significances in driving speed on the approach to junctions between the conditions, which could be due to the participants being experienced drivers, anticipating hazards on the approach to junctions. However, Lajunen et al. (1997) argue that speed choice is restricted by traffic regulations and social acceptance, thus is not very good representative of driving performance. Speed variation, instead, can tell more about drivers' choice of driving style. The present findings show that non-emotionally affected drivers can cope with some amount of cognitive load and still maintain smooth driving. Moreover, a neutral mood is a significant predictor of less speed variance only when some amount of load is applied, thus supporting the statement that mental underload can be detrimental for driving safety (Young & Stanton, 2002).

Another aspect of the present investigation is mood induced mind wandering. Mind wandering has been found to occupy some of the processing capacity (Smallwood & Schooler, 2006), with negative emotions having a more powerful effect (Smallwood et al., 2009). Although the sad drivers in the present research did not drive less jerkily than the happy and the angry drivers, driving-related questions asked while driving, disrupted them from mind wandering and made their driving smoother. These findings support Pêcher et al. (2009), who found that the sad drivers prefer to drive slower, and are in contrast to Eherenfreund-Hager et al. (2017), who found speed increase in negative affect condition. However, it must be noted that Eherenfreund-Hager et al. (2017) did not distinguish between high and low arousal of negative valence. For mood induction, they used negative priming without specifying how much arousing were stimuli.

Two of the predictions were not supported by the present results [H7]: first, there was no sharper acceleration in high arousal conditions. It appears that jerky driving in high arousal conditions was caused by sharper braking. Second, the happy drivers did not adapt a smoother braking style, instead, their braking was sharper. The reason for this behaviour is not clear from acceleration and braking data only. It also was hypothesised [H5] that the happy drivers would adapt different visual search patterns, which affect their driving style, thus adding these results would provide a clearer understanding of braking behaviour.

5.5.6.2 Braking approaching hazardous events at junctions

The analysis showed that neither acceleration nor deceleration caused jerky driving in a happy mood. Instead for CFR hazard, there was less deceleration in the happy mood. Three braking metrics were analysed to understand how this difference was caused: time braking, braking force and maximum braking. Time actively braking showed that the happy participants pressed brake pedal significantly longer than participants in all the other conditions. Moreover, when no load was applied, the happy mood was a significant predictor of longer braking [H8]. There were no other braking differences found for CFR hazard, neither in braking force nor in maximum braking. This indicates that the happy drivers tend to change from accelerator to brake, and prefer gentler active braking, but for a longer time on approach to hazards from a right side junction.

The results of the braking force during the CFL event showed that the neutral mood resulted in significantly milder braking than all the other moods. The neutral mood was also a significant predictor of milder braking regardless of cognitive load, indicating that when drivers are not affected by mood induced thoughts, a certain amount of an additional load does not have a negative impact on driving safety. The happy drivers instead adapted a significantly harder braking style compared to their usual braking.

Although there were no significant differences in maximum braking force between the conditions, most of the drivers, tended to brake more gently in mood conditions compared to their usual driving. The happy drivers in CFL event and the angry drivers in CFR event instead, increased their maximum braking force compared to their usual driving styles. As the baseline was always the first drive, some habituation effect was expected, as drivers collected some experience during the first drive. Therefore, the increase in maximum brake could be due to higher arousal in these conditions.

An interesting finding here is the differences in the braking style recorded between CFL and CFR. When a car is approaching from the left side, drivers tend to adapt sharper braking style with less time decelerating and actively braking, but pressing the brake pedal harder instead. In contrast, when a car is approaching from the right side of the junction, drivers tend to press brake pedal not as hard, but for a longer time, making braking less hazardous. The reason for this behaviour could be the different time needed to reach the junction: when approaching from the left, a car becomes visible later and cuts straight into the participants' lane; when approaching from the right, the car appears earlier, thus leaving more time for reaction. In the case where driving style is affected by emotions, the sudden appearance of a hazard is more likely to result in rear-end collision due to mind wandering (McGehee, Dingus, & Horowitz, 1992; McGehee et al., 2000).

Brake reaction time (BRT) was defined as a time from the onset of lead car's brake lights until the moment the brake pedal of the following vehicle is pressed (Winsum & Heino, 1996). Most often researchers use the exact time to calculate the impact of experimental variables on drivers BRT. However, the present experiment does not consider great time precision but focuses more on the aspect influencing drivers' reactions. In the current experimental setting, driving hazards were used to initiate drivers' decision to brake. It was expected that this decision would depend on their current emotional state as well as other factors. For example, Green (2000) argues that fully alerted drivers' road information processing is significantly faster compared to relaxed drivers. He also states that expected signals are responded to faster, compared to unexpected signals, and response time also depends on cognitive load, age and urgency of the situation. It is possible to apply Green's findings to the present study: fully alerted drivers, or those who were not distracted by mood induced mind wandering, adapted smoother driving styles with less speed variation and more even braking style. CFL appeared more unexpectedly, thus causing sharper braking, so cognitive load at times helped in maintaining alertness to unexpected road events. For example, DRL applied to the sad drivers mediates their mood and brings their speed variance to the same level as drivers in the neutral mood. Whereas, an angry mood encourages sharper braking when no questions are asked.

It also could be argued that higher arousal provoked more self-confidence (Wrisberg, 1994), thus raising drivers' confidence in their braking skills and prolonging their braking initiation time (Winsum & Heino, 1996).

5.5.7 Parked cars suddenly moving off

5.5.7.1 Speed, acceleration and deceleration while passing 'cars moving off' hazards

Drivers' speed control patterns while passing suddenly moving off cars were different from those on the approach to the junctions. Participants' speed choice was not affected by their emotional state when approaching junctions, in contrary to [H7], unlike their speed driving along roads. This shows that moving off cars were less anticipated than hazards at junctions. It was hypothesised that high arousal would encourage higher speed, thus sharper braking, and more jerky driving. On the approach to junctions, high arousal resulted in jerky driving, indicating that, for drivers in high arousal moods, their mood influences their decision of the most appropriate time to brake, and they keep changing from brake to accelerator, thus maintaining similar speed average, but higher speed variation. Instead, when driving along the road, drivers under influence of a high arousal drove faster, but there was no speed variation, they drove with the same smoothness, as drivers under a low load condition.

However, mood valence in the high arousal conditions did not have the predicted effect on drivers' speed and acceleration. Analysis of changes in speed between the baselines and the corresponding conditions showed that these differences were due to speed decrease in the low arousal conditions, rather than speed increase in the high arousal conditions. This could be due to speed in all conditions being already high during the baseline drives: thus, increasing speed in the high arousal condition would result in driving well above the speed limit, set for that road. However, all the participants in all the moods already had experience with parked cars suddenly moving off, but only drivers in the low load condition took into account this fact. The angry and the happy drivers preferred to drive with the same speed, without slowing down. This shows higher self-confidence in the high arousal conditions (Woodman & Hardy, 2003). Moreover, the happy participants always drove faster, regardless cognitive load, and even increased their speed compared to the baseline. Whereas the angry participants did not increase their speed that much, and in cognitive load conditions even drove slower than in the baseline, thus indicating that some amount of cognitive load can disrupt from the influence of mood. These results partially support the prediction [H8], showing that the cognitive load not always can redirect drivers' attention to the driving task.

According to Gasper (2004), the happy individuals adapt heuristic information processing styles, with more global information processing, this could cause some lapses in hazard perception. Although this style speeds up information processing, it leaves some details unattended. In the present study, the happy participants drove faster ignoring the potential risk caused by suddenly moving off cars.

Participants' speed in low arousal conditions did not differ between the sad and the neutral moods and was slower compared to their corresponding baselines in both cases. However, it cannot be concluded that driving in the sad mood is equally safe as driving in the neutral mood. The slower speed in the sad mood could be simply compensation for additional task difficulty caused by mind wandering (Smallwood et al., 2009). Thus using only the speed parameter makes it difficult to understand the influence of the sad mood on driving safety.

Although differences in speed between passing PS and PG hazards were not statistically assessed, speed patterns were visually very similar, with some higher speed increase in PG hazard during happy mood, and some higher speed decrease in PS hazard in the neutral and the sad moods.

5.5.7.2 Braking while passing parked cars

Braking was assessed using three metrics: time actively braking (total time driver was pressing the brake pedal, measured in seconds), braking force (force applied to the braking pedal, measured in Newtons) and maximum braking force. It was hypothesised [H7] that participants in low arousal conditions would brake smoother, thus pressing the brake pedal longer but with less intensity, compared to the participants in the high arousal conditions. These metrics were different for PS and PG, hazards. For the PS hazard, the time actively braking did not differ between the moods, indicating that the participants preferred a different method of reducing speed. Although the ANOVA test for PG hazard was only marginally significant, deviation contrasts showed that time actively braking in the angry mood was significantly lower compared to all the other moods.

When passing PS hazard the participants preferred to reduce their speed by pressing the brake pedal harder, with the angry mood resulting in significantly harder brake presses compared to all the other moods. Interestingly, these differences were due to the braking force increase while angry, as there was not much change from the baselines to all the other moods in braking force. Only angry drivers significantly increased brake pressure compared to their normal driving, thus showing a significant influence of this emotion on braking habits.

The combination of the braking results with the speed results shows that participants employ different speed reduction techniques when passing PS and PG hazards. For slowing down during PG hazard, participants prefer to press brake longer but lighter, PS hazard instead, encourages shorter and harder braking. One of the reasons for these alterations could be the differences in the hazard perception times. If PG hazard is spotted later, there is less time left for slowing down, which requires sharper braking. According to Smallwood et al. (2009), negative moods result in greater mind wandering, compared to positive moods, thus, a greater attentional shift away from the main driving task. Angry mood fully supported Smallwood’s argument, sad mood, instead, did not result in the same braking patterns as angry mood, yet being also negative valence. However, sad participants drove slower, thus had more time to deal with the hazards compared to angry drivers.

Importantly, the reasons causing different reactions to PS and PG hazards are not clear. Possibly a single car attracts less alertness compared to the group of cars or is perceived as less hazardous or easier to deal with. The present study cannot answer this question.

Chapter 6 Discussion and conclusions

6.1 Overview

This thesis has focused on understanding of the effects of mood and cognitive load on driving safety. Mood is considered as a distractor from the primary task and cognitive load as an intervention to reconnect the driver to traffic related information. In the desktop study, reported in Chapter 4, the influence of drivers' mood on glance behaviours and hazard response times (HRT) were examined, using a comparison of neutral, happy and sad emotions. The study was expanded in the simulator study, reported in Chapter 5, by adding angry mood condition, to have both dimensions of valence, positive and negative, and both dimensions of arousal, low and high. The addition of two types of cognitive load were also added in the simulator study: driving related load and non-driving related load. The simulator study permitted the continuous tracking of Mood and Load induced changes in drivers' behaviours, their glance patterns and their responses to hazardous traffic situations. In this chapter, the results will be discussed with reference to their utility for driving safety assessment. Hypotheses about drivers' Mood and Load are summarised below.

Mood

Based on information processing and mind wandering hypotheses (sections 2.7.1 and 2.7.2), it was predicted that induced emotions would affect with driving performance by causing daydreaming and mind wandering. These processes would prolong road related information processing as indicated by slower responses to hazardous situations and jerkier driving. It was hypothesised that a negative mood valence should result in longer information processing as compared to a positive mood valence due to the systematic mode of processing (Schwarz, 2000). The sad mood, being the most internal state with attentional self-focus of mind and passive attitude to surroundings (Bulmash et al., 2006; Pêcher et al., 2009), should result in longer response times. The angry mood should mediate decrease of processing speed usually observed in a negative valence, being a high arousal and energetic physiological state. A positive mood valence, on the other hand, affects drivers differently in both high and low arousal conditions. High arousal in the happy mood would not mediate a decrease of processing speed compared to a low arousal in a positive valence. This is due to arousal in the neutral mood not being sufficiently low to be detrimental for task performance.

It was also hypothesised that high arousal would encourage riskier driving, with drivers choosing shorter following distances and higher speeds. Higher speeds would result in a more jerky style of driving.

Load

Cognitive load in this study was used to disconnect drivers from mind wandering and bring their cognitive resources back to the driving task. Olivers and Nieuwenhuis (2006) observed that tasks involving divided attention can be useful in activating attentional resources. An easy additional task not only does not deteriorate performance in the main task but can actually improve this performance. Taking into account that the executive function is involved in updating information process, such as monitoring and evaluating current stimulus inputs to the task on hand (Baddeley, 1992; Cohen et al., 1997), the disruption of mind wandering was hypothesised to enhance the performance in the main task, in this case driving. Two types of cognitive load were applied in the simulator study: driving related load (DRL) and non-driving related load (NDRL). NDRL was intended to disconnect drivers from mind wandering. However, the attention would be directed to non-driving related issues, which would decrease the driving performance. DRL, apart from disconnecting drivers from internal thoughts, would direct drivers’ attention to the road, thus enhancing driving performance, the ability to switch attention and processing of road information.

6.2 Induction and assessment of mood valence and arousal

Two different methods were used to both induce and assess participants’ emotional involvement. In the desktop study, mood was induced using a mixed method whereby participants listened to mood music and watched corresponding pictures. To assess mood, participants were then asked to rate their mood on a 10 point subscale of the Brief Mood Introspection Scale (BMIS). This subscale distinguished well between negative and positive valence moods but did not include the assessment of arousal, thus did not distinguish between the two positive moods, happy and neutral.

In the simulator study the affect grid by Russell et al. (1989) was used for participants' self-reports instead of BMIS. This enabled the assessment of both mood arousal and valence. In addition mood corresponding pictures were replaced by a mental imagery technique. In addition to self-reports, participants' physiological arousal was recorded, to differentiate between low and high arousal emotional states. This method enabled the assessment of participants' mood valence and arousal while driving. Moreover, this combined method distinguished between the two high arousal conditions. For example, the happy and the angry moods are both high arousal moods (happy and angry). Although physiological measures can reliably detect high arousal, it would be difficult to confirm whether the participant was happy or angry at that time (Stemmler, 2004).

In the simulator study, it was hypothesised that HR and EDA would be higher in the high arousal conditions (angry and happy) than in the low arousal conditions (sad and neutral). This hypothesis was partially supported. EDA and HR were sensitive to changes in participants' arousal during the mood induction. The HR was significantly different between all the mood pairs except angry-happy and neutral-sad, showing an increase of HR in the high arousal moods. EDA data showed similar results, except that skin conductance was not different between the happy and the sad moods, perhaps due to lack of power.

In summary:

Both mixed methods, music with pictures and music with mental imagery, have been successful in mood induction. The affect grid by Russell et al. (1989) enabled the assessment of participants' arousal in addition to their mood valence. During the mood induction, EDA and HR were able to distinguish between high and low arousal conditions. Both methods physiological measures and self-reports complimented each other.

6.3 Drivers' response times

Drivers' reactions and responses to hazardous events are important components of driving safety. Depending on how early a driver recognises a road situation as being dangerous and makes the right decision about actions to take to avoid or minimise risk, the consequences can change from being simply "alarming" to a "near miss" or even a "fatal accident". Section 3.4.3 explains in detail what constitutes 'brake reaction time' (Green, 2000). Reaction time was measured in both studies: in the desktop study, as 'hazard response time' and in the simulator study as 'reaction to speed change' of the lead vehicle. Hazard response time provides a measure of a drivers' ability to recognise a driving situation as being hazardous in a time that permits a timely reaction. Reaction time, measured during the coherence task, reflects a driver's ability to sustain their attention for a longer period of time. Therefore, the influence of drivers' moods on their reactions is an important factor that has to be studied to understand the best ways of intervention and the best ways to minimise the harmful effect of mood.

As indicated by Wetton et al. (2010), hazard awareness is one of the most important skills in a fast-changing driving environment. This statement leads to two actions: first, driving style and drivers' behaviours that can affect hazard awareness should be determined and second, factors affecting those behaviours should be identified. These actions are necessary for development, preparation and implementation of interventions.

To present stimuli and collect the response time data in the desktop study, a computer was used. Three different emotions were induced: neutral, happy and sad. Participants pressed a button as soon as they spotted a hazard. This method has several advantages: data collection is not as expensive as using a simulator, and the delay, related to mechanical responses, is minimal (Green, 2000; Ising, Droll, Kroeker, D'Addario, & Goulet, 2012). It was predicted that the happy drivers would notice hazards earlier due to better peripheral observational patterns (Carver, 2003). Consequently, they would react faster, showing shorter reaction times. Contrary to prediction, the neutral mood resulted in faster responses and faster attentional switch. The results showed that drivers' reactions depend on their emotional state, with the sad participants affected the most and participants in the neutral mood being the quickest to react. The results are in line with the previous research (Pêcher et al., 2009) in relation to the sad mood. In their study, the drivers reported thinking about personal lives and feeling sad. They also reported that their attention was caught by the rhythm and lyrics of the sad music and directed to internal feelings. Pêcher et al. also reported more disturbance while driving in the happy mood compared to the neutral mood. The mean speed in the happy condition dropped while driving with music, and they positioned the car closer to the hard shoulder which, according to Summala (2000), is evidence of compensating for the mental load.

Interestingly, the results of the desktop study contradict those reviewed by Green (2000). Green states that the reaction times for surprise events are always longer than for expected events as they need more time at all three stages of mental processing: detection, perception and response. The desktop study, reported in Chapter 4, has shown that unexpected hazards take less time to react to. This reaction difference was explain by the fact that unexpected hazards do not leave much time for the driver to decide how dangerous the situation is, and they have to react immediately. It also has to be noted that the desktop study did not include some stages of the response components, such as movement time and device response time. However, all the mental-processing stages were still present: drivers still had to detect a suspicious object (sensation), recognise it as a possible danger (perception), and select a response. The most ambiguous stage here seems to be the response selection, as in the desktop study there was not much variety available, and the participant had to decide whether to press the button or not. This stage seem to be the one that makes the difference to response times. As soon as an obstacle was recognised, the participant had to press the button if he/she thought that the obstacle could develop into a real hazard. Surprise events in this case likely work as a facilitator for a reaction, whereas in simulator and naturalistic experiments, the surprise is an inhibitor for drivers’ reaction. This finding is important regarding the validation of hazard perception tests. In hazard perception tests, surprise obstacles are classified the same as expected obstacles, whereas in real life it takes much longer to react to the surprise obstacles.

However, desktop experiments do have several disadvantages compared to simulator experiments. While response time measures are valuable and reliable predictors of driving safety, many more factors are relevant. For example, hazard response times measured on a computer only indicate that the participant has registered a hazard. Their driving style prior to the hazard, and their behaviour reaction to the hazard, are still unknown. Another important aspect in measuring drivers' response times is the assessment of their ability to sustain attention for a period of time, and not only for a single reaction to a hazardous event. Sustained attention is needed to be able to follow a lead car keeping a constant distance. Thus this task has been named as a good indicator of drivers' attention.

The simulator study used the coherence task developed by Brookhuis et al. (1994) to evaluate the impact of drivers' mood and cognitive load on their ability to sustain attention. Previous research has found that coherence is impaired by mental effort (Ranney et al., 2005). On the other hand, Ünal, de Waard, Epstude, and Steg (2013) showed that performance in a monotonous task, such as coherence, could be improved by mild arousal. Similarly to the desktop study, the sad drivers' (low arousal) reactions were slower, as indicated by increase in phase shift and modulus. The increase in the phase shift is evidence of slower reactions and the increase in modulus can be interpreted as compensation for slower reactions. In the simulator study there were two main findings with regards to modulus. The sad drivers tended to overreact (significant). This tendency was also evident in changes from the baseline to the corresponding mood. The happy drivers, in contrary to the sad drivers, tended to under-react. These reactions are easie to explain when analysed together with time headway. The sad drivers' preference for longer THs, was possibly caused by their internal thoughts occupying their attention, thus making them feel more comfortable when further away from the lead vehicle. When the lead vehicle increased speed, the slower reactions of the sad drivers did not permit them to respond in a timely and promptly manner. This caused an overreaction in distance correction This overreaction was permitted by a larger distance between the two vehicles.

The happy drivers, on the other hand, selected a shorter following time, thus not leaving much space for speed variation. When occupied with internal thoughts, the happy drivers found it difficult to synchronise their speed with the lead vehicle's speed, which caused under correction. The angry drivers and drivers in the neutral mood also overreacted. This overreaction was very minimal and similar to their baseline modulus. However, it cannot be assumed that both these conditions did not influence drivers' response times. The TH results show that drivers in the neutral mood preferred driving at 2 – 4 seconds TH from the lead vehicle. This distance is considered to be the most optimal (Pasanen & Salmivaara, 1993; Piao & McDonald, 2003; Vogel, 2003), with lower speed initiating larger time gaps in real traffic situations (Piao & McDonald, 2003). The angry drivers, instead, choose closer distances, under 2 seconds, which is a sign of aggressive driving and tailgating (Tasca, 2000; Y. Zhang & Kaber, 2013). Therefore, the drivers in the neutral mood had sufficient time to react to the lead vehicle's speed changes, without investing additional effort to maintain constant TH. The angry drivers, instead, had to use additional attentional resources, to maintain a close and constant distance from the lead vehicle (Young & Stanton, 2002). Interestingly, DRL affected only the happy and the sad drivers. The modulus of these two conditions improved when driving-related questions were asked, thus providing evidence that some additional load can disconnect drivers from mood-related invasive thoughts.

Similarly, the phase shift analysis showed that this parameter was significantly larger for the happy and the sad drivers. Phase shift reflects a delay in drivers' response to the lead vehicle's speed change, confirming the biggest influence of mood on drivers' reaction time in these conditions.

Parameter estimates showed that the neutral mood is a significant predictor of phase shift regardless of cognitive load, indicating that the cognitive load used in the simulator study did not have enough power to influence drivers' reactions when they are not emotionally affected. Parameter estimates also showed that the sad mood was a significant predictor of drivers' reaction delay in relation to the neutral mood, but only when no load was applied, again confirming that the cognitive load can distract from the non-task related thoughts.

The important additional information here is provided by analysing mood induced changes from the corresponding baselines. This analysis showed that phase shift increased only after the sad mood induction. After the neutral mood induction, drivers’ reactions become faster compared to their baseline reactions. Now the predictions from parameter estimates look differently; the neutral mood is a significant predictor of better reactions, and the sad mood is a significant predictor of reaction delays. In light of this finding, the influence of cognitive load should be interpreted differently. In the neutral mood, drivers are not affected by the distracting effect of mind wandering. Thus, they can dedicate all their attention to the road and traffic. In this situation, cognitive load would act as a distractor from the primary task, driving. In contrast, the sad drivers’ reaction time was highly influenced by mind wandering, causing reduced attention to the primary task of driving. In this situation, cognitive load disconnected drivers from mind wandering, bringing their attention back to the road (Unsworth, Redick, Lakey, & Young, 2010). In this context, the previous statement, that the sad mood is a significant predictor of reaction delay only when no-load is applied, looks logical: without distraction, drivers are the most affected by their internal emotional state.

The analysis of changes from the baseline to the corresponding mood showed that the happy drivers’ reactions were similar to the reactions of drivers in the neutral mood (better reactions after mood induction). The happy drivers also reacted faster to the speed changes of the lead vehicle compared to the sad drivers. However, this improvement did not reach significance. Moreover, the glance measurement analysis showed a decrease in information processing and some difficulties in an attentional shift. This leads to the conclusion that the happy drivers were successful in the coherence task due to high concentration, but used all the available attentional resources to complete the task. This finding contradicts Luce et al. (1997) and Schwarz (2000) stating that individuals in a positive mood adapt more heuristic processing styles with less attention to detail and a high reliance on previous knowledge. This is true at least for the coherence task, when happy individuals concentrate on the car ahead (one thing at a time) regardless of other possible dangers (previous knowledge). However, these conclusions could be influenced by the experimental setting. Possibly, participants felt that they had to concentrate on the main task, and did not expect other hazards to be present. The same method, but applied in the natural driving environment, might reveal different results.

The angry drivers' reactions were similar to the neutral and the happy drivers' reactions, showing improvement in car following ability. Averill (1983) differentiates anger from other emotions. He states that anger is often expressed by aggression and that the aggression is not necessarily directed towards the source of the feeling. Often individuals target unrelated inanimate objects or strangers. Abrams (2010) concluded that anger could increase concentration and facilitate achievements in sport. Possibly, drivers in the simulator study, directed their angry feelings to the car ahead and task completion, thus decreasing their reaction times. Similar to the happy drivers, the angry drivers showed decreased peripheral vision and information processing. Consequently, attentional improvements diminish due to their concentration to a particular place.

In relation to drivers' reaction times, the simulator study did not find a negative effect of cognitive load on drivers' ability to sustain attention on the car following. For the neutral, the happy and the angry moods there was no effect of cognitive load. The sad drivers, however, improved their task performance when driving related questions were asked. This finding supports the conclusion of Pêcher et al. (2009) that a sad mood encourages a withdrawn attitude and attentional focus towards internal thoughts and feelings, and Smallwood et al. (2009) stating that low arousal and negative valence encourages more mind wandering and more difficulties to re-engage with the task on hand.

The glance measures can be seen as another predictor of drivers' response to hazards, as it has been named as an indicator of attentional shift (Chapman & Underwood, 1998b; Underwood, Chapman, Brocklehurst, et al., 2003). In the simulator study, the glance measures showed the different effect of NDRL and DRL on drivers' attention. The attentional shift was affected only in the sad mood without cognitive load, NDRL did not have much effect on mood induced attentional decline, whereas DRL maintained drivers' attention at the pre-mood induction level. Similar results were obtained from fixation duration analysis. When no cognitive load was applied, the sad drivers were the most affected by mood. It was the only mood when fixation durations increased considerably showing evidence for the tendency to self-focus and longer information processing times (Bulmash et al., 2006; Pêcher et al., 2009). Interestingly, the ability to process information was the most impaired when no load was applied. NDRL improved drivers' attention by minimising the negative effect of mood, and DRL further minimised this effect.

In summary:

The present research showed that drivers modify their TH not only to accommodate their performance ability (Winsum & Heino, 1996) but also with respect to their current emotional state, as longer THs permit for more time to react. RTs were found to depend on drivers' moods, as indicated by both hazard awareness and car following ability. Sad drivers tended to respond later to appearing hazards, thus shortening the time available for safe braking, should it be needed. To compensate for this deficit, sad drivers seemingly increase their TH. This influence of mood can be overridden by applying some cognitive load while driving. The angry drivers compensate for mind wandering by dedicating additional attention to task completion, and the drivers in the neutral mood can cope with some additional cognitive load without a decline in primary task performance.

6.4 Choice of time headway

It was hypothesised [H6, H8] that the higher arousal moods would result in the shorter THs, whilst the lower arousal moods would elicit different behaviours; the sad mood would result in larger THs to compensate for mind wandering, and the neutral mood should not differ from the baseline. The current research sees TH analysis differently from how it was most often used in analising driver behaviour in car following situations. Most often, TH in coherence tasks is used to measure drivers' ability to sustain attention for a period of time. For this, a variation of TH is calculated, and inferences are drawn from the results: the higher variation, the less successful was the driver in maintaining attention on the car in front. The interest within this simulator study is the choice of TH that drivers in different moods would prefer for the most comfortable driving. This method permits to examine influence of the drivers' mood on their choice of time headway when they feel easier to focus on the car ahead. The drivers were instructed to follow the lead vehicle keeping the constant distance, which they felt is safe and convenient. During the experiment drivers' perception of a safe and convenient distance changed as a function of their emotional state and cognitive load. To calculate these changes, the following time was divided into six 1 second segments, and a separate analysis was performed for each time segment. This permitted the tracking of mood induced changes in preferred TH, which is impossible in TH variance analysis, as it does not indicate how long the driver was following with a TH of 1 second, or 2 seconds, or 5 seconds.

The results show overall larger THs compared to previous research: the average of accepted minimum TH 0.66 s (Taieb-Maimon & Shinar, 2001), and the average of comfortable TH 0.98 s (Taieb-Maimon & Shinar, 2001), around 1 s (Chen, 1996; Winsum & Heino, 1996), and 1.4 s (Ota, 1994). Although average TH was not a factor of interest in the present research, it is useful to investigate the reasons for a shorter or larger THs. Harms (1968) explains shorter TH by constantly increasing traffic density. Ohta (1993) supports this statement and adds that drivers do not feel comfortable with large headways because they are perceived outside the social norms. Mizell et al. (1997) argue that headways are getting shorter as drivers become more aggressive. This statement is in line with the present findings, as the angry drivers preferred much shorter THs, regardless of additional cognitive load, aimed to disconnect them from mind wandering.

Abdu et al. (2012) found that the angry drivers adapted riskier driving styles, such as faster speed and shorter headways. Surprisingly, this aggressive driving style was not correlated to the number of accidents. It has already been suggested in section 6.3 that the angry drivers can afford shorter THs due to them involving additional attentional resources. This could be the reason for shorter THs not correlating with accident involvement. However, the more attentional resources are involved, the faster drivers get tired, and the less are left in case of an emergency (Young & Stanton, 2002); thus the involvement of additional resources can have only a short-term benefit. However, it would be useful to investigate the degree to which the angry drivers can expand their attentional resources.

Ranney et al. (2005) found that drivers compensate for the additional cognitive load by increasing car following distance. Similarly, the present results show that cognitive load can bring some changes in preferred TH: when non-driving related questions were asked, drivers reduced following time in the 3-4 seconds TH segment. Figure 35 shows that these changes were mostly caused by the angry drivers reducing the proportion of time spent in this segment. As it also can be seen from Figure 35, the angry drivers did not increase driving in longer THs. Instead, an increase in time was evident only under 2 seconds TH. This shows that overall, drivers come closer to the car ahead if their mood changed to angry.

Cognitive load affected the choice of TH only in the 3-4 seconds segment. The analysis of changes from baseline showed that NDRL did not change in the neutral, the happy and the sad moods, but reduced in the angry mood. No-load and DRL increased in the neutral, the happy and the sad moods and decreased in the angry mood as well. This shows that the angry drivers' choice of TH was not affected by cognitive load, whereas the neutral, the happy and the sad drivers increased their presence in this time segment when no-load and DRL was applied.

In summary:

The present research showed that the effect of emotions on chosen TH is more complicated than being simply an influence of mind wandering. Similarly to Tasca (2000) and Y. Zhang and Kaber (2013), the angry drivers employed a more aggressive driving style and tended to drive closer to the lead vehicle. They also engaged additional attentional resources in the completion of the primary task, which permitted them to feel more comfortable with short THs. However, this could have negative consequences if practised for a longer period of time or in the event of an additional hazard as it does not permit for any extra attentional stretch. The sad drivers are shown to be the most affected by mind wandering and thus had to compensate for the attentional decline by increasing following distance. Cognitive load had a different effect depending on mood: the angry drivers were not affected by cognitive load, whereas the neutral, the happy and the sad drivers tended to drive less in the safe 3-4 seconds TH when no questions were asked and when driving-related questions were asked. NDRL did not change drivers' behaviours in these moods.

6.5 Hazard perception and anticipation

Hazard perception and anticipation depends on drivers' observational patterns (Chapman & Underwood, 1998b; Sabey & Taylor, 1980) and risk misperception, leading to riskier driving styles (Ferguson, 2003). Both of these factors were studied, regarding their vulnerability to drivers' emotional state, and found support in the present research. The desktop study investigated how mood-related changes in observational patterns can affect drivers' hazard response times [H1, H2]. The desktop study found contradicting results: there were no significant differences in the spread of eye fixations among drivers in different mood conditions. This finding is in conflict with Carver's (2003) theory stating that individuals in a positive mood are more prone to explore a surrounding environment and look for new sources of danger. Yet, individuals in the positive moods responded quicker to appearing hazards, by a button press. This mismatch could be due to the study being performed on a desktop PC, thus not permitting for the more precise distinction between the deviations in drivers' eye fixations. Nevertheless, drivers' fixation durations indicated that the sad drivers required longer time to decide on response. Moreover, drivers' hazard response times indicate their faster responses in a positive mood compared to a negative mood, thus providing evidence for Carver's statement of additional attentional resources available to the individuals in a positive mood.

Although Carver (2003) does not distinguish between arousal levels, the desktop study showed some response impairment of the happy individuals compared to the individuals in the neutral mood, which could be caused by different levels of arousal in both of these positive moods. Indeed, the simulator study confirms this assumption by establishing differences in driving behaviours between low and high aroused drivers. The way of assessing hazard awareness was different in the desktop and the simulator studies. In the simulator study participants' attention was not explicitly directed to the hazard identification. This permitted, instead of measuring the response times, the evaluation of their driving style in different conditions, and how this driving style affects driving safety while facing hazardous situations. Hazard awareness was assessed separately for 'car moving off' hazards and 'junction hazards'. Measures of speed, acceleration and braking were calculated to understand how these parameters vary with different moods and cognitive loads, as well as how they interact with each other. The driving parameters are discussed in Sections 6.7 and 6.8 of this chapter.

In summary:

The sad drivers are the slowest in hazard response. This response delay can be caused by longer information processing as reflected by longer fixation durations. The happy drivers are also inferior to the neutral drivers, thus showing that road safety does not benefit from emotional involvement

6.6 Glance behaviour

The number of eye fixations, fixation durations and spread of fixations were hypothesised to reflect drivers' information processing speed and their ability to switch attention from task-unrelated thoughts to task-related thoughts. Different moods and types of cognitive load were hypothesised [H5, H8] to have a different effect on these ability.

Glance behaviour measures, were able to differentiate between different moods and cognitive loads. The sad drivers in both studies had the longest fixations, providing strong evidence of having less ability to switch attention to the most important road events. The simulator study also found a significant drop in the number of fixations after the sad mood was induced, as well as a significant drop in fixation durations. This showed both more difficulties in information extraction and processing (fixation duration) (Wilson & Eggemeier, 1991) and less effort invested in this processing (number of fixations) (Chapman & Underwood, 1998b). Moreover, only the sad drivers narrowed their visual field, thus making more probable a delayed in the reaction in case of an unexpected hazard.

Some types of cognitive load were able to disengage the sad drivers from their internal state of mind. The sad mood slowed down drivers' processing speed, as evidenced by longer fixation durations, the most when no load was applied. NDRL and DRL significantly improved processing time. This shows that mind wandering, initiated by the sad mood, can be interrupted by some amount of additional load.

The additional load has a similar effect on drivers' information processing effort. The significant interaction between Mood and Load showed that the sad "undisrupted" drivers invested less attention in the road processing compared to when they were asked general questions, and the biggest improvement in invested effort appeared when the sad drivers' attention is directed towards road safety.

A reduction in the horizontal spread of fixations has been related to an increase in mental load (Li, Markkula, Li, & Merat, 2018; Recarte & Nunes, 2000). A similar effect was found in the simulator study. Interestingly, 'reduction in horizontal fixation spread' is not a precise description of the changes in the spread of fixations, as a noticeable reduction was recorded only in the sad mood. A more precise statement would be 'increase in horizontal spread of fixations' in the neutral mood, as this is what the analysis of changes from the baseline to the corresponding conditions has shown. This finding, to some extent, supports Carver's (2003) theory on differences in information processing between positively and negatively affected individuals. Indeed, the neutral state of mind is an emotion with positive valence and low arousal. The 'regulatory system' does not need to invest any effort in minimising the effect of positive emotions, as there is no harm associated with them. This saves attentional resources, which can then be used for environmental exploration. The above-mentioned effect was not found in the desktop study. Therefore some interruption caused by arousal was assumed (Zimasa et al., 2017). This assumption was supported in the simulator study.

Changes in the number of fixations from the baseline to the corresponding mood also support this statement. Fixations increased in number with the neutral mood induction and decreased with the sad mood induction. This difference was significant, thus confirming increased exploration and information processing effort in the positive mood.

High arousal did not affect the spread of drivers' fixations, showing only a slight decrease after the happy and the angry mood induction. Similarly, fixation durations were only slightly shorter after the angry and the happy mood induction, indicating that high arousal improved the drivers' information processing ability regardless of the valence, but not significantly. Changes in the number of fixations in the high arousal conditions showed that the drivers' effort invested in information processing in the high arousal was similar to their effort during the baseline drives. This finding is in line with (Smallwood et al., 2009) and (Jonkman et al., 2017), who found more mind wandering and less intention to reengage in a task after mind wandering in negative moods compared to positive moods.

In summary:

Glance measurements are valuable indicators of drivers' search patterns and indicators of mood induced mind wandering. None of the glance behaviour measures analysed in the two studies, distinguished between high and low arousals. Moreover, all the moods negatively affect drivers' search patterns. Cognitive load, applied while driving, can disengage drivers from the mood induced mind wandering and improve drivers' search patterns. The sad mood has the most detrimental effect on driving safety. Possibly this is the reason why it is the most affected by cognitive load.

6.7 Speed

Drivers’ speed behaviour was different when on approach to junctions and when facing cars suddenly moving off. On approach to junctions, drivers’ mean speed was not affected by their mood or cognitive load, whereas while passing parked cars drivers’ speed choice was affected by their mood. Interestingly, this change was not a speed increase in high arousal conditions, as predicted. Instead, the neutral and the sad drivers slowed down when passing parked vehicles. The speed decrease was nearly 4 miles per hour. This slowing down could be caused by the necessity of moving into the opposite lane on the approach to the parked cars, to prepare for passing (Figure 62). The consequences of this passing manoeuvre and high speed could be differently assessed by drivers in different moods. Regardless of the displayed speed limit of 40 mph, drivers in low arousal conditions preferred to drive slower. High arousal is known to cause overestimation of personal ability (Fuller, 2005) and lower risk perception (Jonah, 1986), which could cause the speed increase. For valence and arousal grid see Figure 1. Similarly, in this simulator study, the happy and the angry drivers did not reduce speed when passing close to the parked vehicles.

Figure 62: Participant approaching a row of parked cars.

Alternatively, passing can be seen as an additional task during driving. Completion of this task requires concentration and extra effort. Humphreys and Revelle (1984) found that high arousal increases the amount of cognitive resources available for information processing. Additionally, these resources are reallocated to the task of higher interest for the individual, thus facilitating the performance in this particular task. In relation to this simulator study, it can be concluded that drivers in higher arousal moods concentrated on the passing of parked cars, which permitted them to complete this manoeuvre without slowing down.

On the approach to junctions, mood valence and arousal did not impact drivers' mean speed. However, there was a significant difference in speed variation, with less variation in low arousal conditions. This variation indicates that high arousal interferes with the driver's judgement of distance to the junction and their speed on the approach to it, causing a jerky driving style (Robertson et al., 1992). Jerky driving can be a better determinant of driving style than speed, as acceleration and deceleration, unlike speed, are not restricted by traffic regulations and are entirely the drivers' choice. This driving style is especially evident on the approach to junctions, when drivers reduce speed later, thus using sharper and more dangerous braking styles (Saad et al., 2005). The analysis of changes in speed variation from the baseline to the corresponding mood condition showed that differences in speed variation were caused by the neutral and the sad drivers decreasing their speed variation, similarly as when passing the parked cars.

Cognitive load did not affect high arousal conditions with regards to mean speed and speed variation but had a positive effect on low arousal conditions by increasing the already smoother driving style in these conditions. It could be argued that the changes in speed are caused by drivers' distraction (Patten et al., 2004; Saad et al., 2005). Thus emotion induced mind wandering being more influential in the neutral and the sad moods. Rakauskas et al. (2004) argue that higher speeds require more attention and drivers compensate for these extra requirements by slowing down. If these results were the same in this simulator study, it would mean that the neutral and the sad moods affect drivers more than the happy and the angry moods.

However, the happy and the angry moods are both influenced by a higher arousal, which is known to involve additional cognitive resources, facilitate performance and account for attentional underload (Humphreys & Revelle, 1984; Young & Stanton, 2002).

In summary:

Drivers in different moods behave differently when passing parked cars and on approach to junctions. In busy road conditions with speed restrictions the angry and the happy drivers do not tend to increase their speed and speed variability. The sad drivers and the drivers in the neutral mood, on the other hand, tend to drive slower when approaching hazards. The happy and the angry drivers employ additional cognitive resources when facing the usual driving sub-tasks (e.g. on approach to junction). These additional resources account for the extra burden imposed by the questions asked while driving.

6.8 Braking

As mentioned in Section 6.7, speed variation was significantly different depending on mood. However, contrary to the prediction [H7], high arousal did not cause higher acceleration; drivers in all the conditions were accelerating equally smoothly. Instead, speed variation was caused by deceleration style. Drivers can employ two methods to decrease their speed: either release the accelerator pedal, thus using engine power to slow down, or actively pressing the brake pedal. Releasing the accelerator pedal results in a smooth and gradual slowing down and is evidence of a well-planned action. On the contrary, pressing the brake can be viewed as a more aggressive driving style, depending on the pressure applied and the total time needed to fully stop (Wells & Stacey, 2013). Consequently, learner drivers are taught forward planning and gradual engine braking (slowing down by easing off the accelerator pedal) instead of having to slam on the brake due to late hazard recognition.

Traditionally, research examining drivers’ braking style explores at drivers’ brake reaction times and variables that can affect drivers’ reactions (Alm & Nilsson, 1994; Green, 2000; Lamble et al., 1999; Van Winsum & Brouwer, 1997), Green (2000) has also described what constitutes brake reaction times. These reaction times vary considerably, from less than 1 second when the driver is alerted to the possible situation involving braking, to more than 2 seconds for surprise events (Lee, 1976). Lee (1976) also states that brake lights are an essential attribute, shortening brake times.

However so far research has not focused on braking style, and variables influencing them. Braking time is not always representative of safe driving. Instead, a short braking time can result in a rear-end collision, because it leaves less manoeuvring space for the vehicles behind (Wells & Stacey, 2013). When assessing hazard perception, it is important to adopt a complex approach to analysis, including the way in which drivers increase and decrease speed. With relation to speed decrease, several actions can be performed: deceleration via releasing the accelerator pedal, smooth and long brake pedal press, or sharper and quicker slamming on the brake pedal. These braking methods can have different consequences for the drivers following behind, as they require different times for the following drivers to react. It is important to understand why drivers chose a particular style of braking, how much individual preferences are involved and whether these individual preferences are affected by extraneous variables.

This thesis focuses on the influence of mood on drivers’ reactions and hazard perception, and the way moods change driving style. To this end, drivers’ braking styles were compared on approach to hazards. Drivers’ braking styles were different while passing parked cars compared to on approach to junctions in different moods. When passing parked cars, drivers did not use engine power to slow down in any of the conditions; the speed changes were attained by actively braking. However, as the sad and the neutral drivers reduced their speed when passing parked cars, they did not have to apply hard braking. More gentle brake pedal press for a longer time reduced their speed to the appropriate level. On the approach to junctions, on the other hand, some engine braking was involved, mainly by the neutral drivers. This indicates that hazard appearance on the approach to junctions was anticipated more than the possibility that a parked car would suddenly move off, thus the drivers prepared by disengaging the accelerator pedal.

However, the happy drivers still had to apply significantly more brake force, especially when unexpected hazard appeared, showing some lack of forward planning.

Interestingly, regardless of the type of hazard, participants either used engine power and pressed the brake pedal longer (smoother slowing down), or pressed the brake pedal with more force (harder braking). The drivers' mood had an impact on their braking style in all the hazards. Some of these changes were also affected by the type of the cognitive load applied while driving. Drivers in the neutral mood showed better hazard anticipation and they preferred to slow down using engine power and longer and smoother braking as the second option. On approach to junctions, drivers in the neutral mood decelerated, and when passing parked cars, pressed the brake pedal longer, but more gently. Participants in the other low arousal condition, the sad mood, showed less hazard anticipation and did not decelerate on approach. This indicates some attentional disengagement and mind wandering towards task-unrelated thoughts. Nevertheless, the sad drivers' braking times and braking forces also decreased after mood induction, compared to the corresponding baseline. These results might look strange, as they do not explain the preferred braking style for the sad drivers. However, the results also showed the speed reduction after the sad mood induction. These parameters did not reach significance level, but the tendency can be clearly seen (Figure 58).

On the other hand, high arousal conditions initiated a different braking style, with a tendency towards shorter and harder pressure of the brake pedal. These differences did not reach significance for the happy drivers, but did so for the angry drivers. The effect of hard braking on road safety depends on many factors, such as driver, weather, tyres etc. Braking distances have been mathematically calculated for different road surfaces and checked by car manufacturers. Green (2000) argued that harder braking leaves less time for the following drivers to react. If this driving style is coupled with other risk factors, such as shorter time headways, attentional deficits, a speed violation, the risk of collision may rise.

Interestingly, the type of cognitive load affected drivers' braking styles differently in different mood states. Cognitive load did not have any effect on the drivers in the neutral mood. This is not surprising, as the cognitive load was designed to disengage drivers from the mood-related mind wandering and bring their attention back to the primary task of driving. When there was no mind wandering present, cognitive load was not a distracting factor affecting driving safety. However, when drivers' attention was interrupted by intrusive thoughts, cognitive load tended to redirect their attention and improve their driving safety by making them more aware about the surrounding environment and anticipating possible hazardous situations.

In summary:

Engine braking, employed by drivers in the neutral mood on the approach to hazards, indicates drivers' awareness and readiness for possible dangers. The results also indicate that a positive mood valence can mediate an aggressive braking style induced by high arousal. Mood-related intrusive thoughts affect drivers' braking style differently in different moods. The sad drivers still tended to adapt a smoother braking style; however, it could be caused by a slower speed prior to the braking. The angry drivers adapted the most dangerous braking style, which can add to other unsafe behaviours causing higher probability of accidents. Some simple questions asked while driving, did not affect drivers in the neutral mood, but can minimise the harmful effect of the angry mood.

6.9 Physiological measures

It was hypothesised [H4] that the level of arousal would be reflected in HR and EDA, with higher rates for drivers in high arousal conditions, e.g. happy and angry (Cai et al., 2007), as well as while driving under cognitive load (Stemmler, 2004). The hypothesis was partially supported, mainly with respect to the mood-related arousal using EDA and HR measurements.

Contrary to prediction, there were no systematic changes recorded in HR and EDA during the NDRL and the DRL conditions. This suggests that the cognitive load applied in this simulator study did not have enough power to influence the level of the drivers' arousal (Steinberger, Schroeter, & Watling, 2017). Alternatively, it could be argued that the mood-related arousal has reached a ceiling level and adding more load could not affect it further. However, if this had been the case, it would be evident as an interaction between the Mood and the Load in the neutral mood condition, but such an interaction was not recorded. This assumption is supported by the executive control theory (Baddeley, 1992). The theory states that processing is designed as input (information gathered from the senses) - processing (information stored and processed by the brain) and output (stored information execution and behavioural response). Research is also in agreement that executive control can process only a certain amount of information at any given time. This makes informational inputs to compete for processing. Thus when additional load is applied, drivers disengage from mind wandering, but this disengagement does not affect their arousal level, as a mood-related arousal has been replaced by a cognitive load related arousal. Therefore, the amount of attention devoted to driving should be balanced for the safe driving to be maintained. When accumulated driving experience permits for mind wandering, an intervention should take place to prevent attentional drift to non-driving related thoughts. To achieve this, one should have a clear understanding of the necessary cognitive load, being not too high to occupy too much of essential attention and not too low to permit for mind wandering. Importantly, this assumption should be viewed as a direction for further research, as more evidence is needed to add support to this conclusion.

With regards to the drivers' mood, physiological measures provide different results for the coherence task and when facing hazards. This dissimilarity could be caused by the nature of the tasks. The coherence task is designed to assess the influence of different variables on drivers' reactions to the speed change of the lead vehicle. It requires permanent maintenance of attention. Thus HR and EDA changes during the task are mostly related to the permanent influence of the experimental variables. The current study has shown that when sustained attention is needed, HR is more sensitive to changes in drivers' arousal, with angry emotions affecting drivers the most.

EDA shows similar results; however, less sensitivity does not permit for statistical inferences. HR and EDA measures were also associated with different behavioural attributes: HR is recognised as an indicator of invested effort, whereas EDA increases in the response to arousal (Fowles, 1980; Healey & Picard, 2005; Schmidt-Daffy, 2012). Thus it can be concluded that different moods do not differ in the arousal levels when sustained attention is needed, yet, the angry drivers put in more effort for this task completion. Moreover, this conclusion is supported by the drivers' choice of time headway: the angry drivers chose much closer following distances, thus have to invest more effort in the driving task.

On the other hand, the sudden appearance of a hazard does not require steady and permanent investment of effort, but rather a quick one-off action, making the HR response less representative of drivers' physiological condition. A sudden increase in arousal level, instead, would be predicted in the case of an unexpected appearance of a hazard (Collet et al., 2005). If drivers' minds are occupied by task-unrelated thoughts, this abrupt change can affect their arousal level (Steinberger et al., 2017). To this end, HR appears to be a less reliable indicator of drivers' arousal. EDA, instead, shows a stable and significant trend, with all the emotions eliciting similar arousal levels, and a clear habituation effect in the neutral mood condition (Dawson et al., 2007).

Nevertheless, strong changes in the EDA level were recorded only on approach to junctions. The EDA changes while passing parked car hazards did not reach significance when each hazard was analysed separately. Having a clear trend in the arousal level permitted the combination of the EDA data for these two hazards and build an argument based on these results. Still, there must be a reason for this statistical weakness. Steinberger et al. (2017) argue that unexpected events provoke more arousal compared to anticipated events. In relation to the current study, it can be concluded that the parked car hazards were more associated with possible danger compared to the junction hazards.

Another important aspect to account for is a habituation effect (Dawson et al., 2007). Following mood induction, EDA and HR were collected continuously during the experiments and demonstrated different sensitivity depending on whether participants were driving with a speed restrictions (coherence task) or in a free speed choice situation (hazardous events). During the coherence task, no significant differences were found in EDA between the mood conditions. Observation of the data showed that EDA in all the conditions displayed a habituation effect. In other words, EDA, collected while driving affected by a mood, was lower than EDA collected during the corresponding baseline drive (Dawson et al., 2007). Although this effect was evident in all mood conditions, it was very small in the angry mood (mean -0.47) and large in the neutral mood (mean -2.33). This means that the angry mood initiates EDA more extensively; however, not enough to reach significance level. HR, instead, showed a significant effect of Mood, with the angry mood initiating significantly higher HR than the low arousal moods (sad and neutral). Thereby the angry drivers had to invest more effort to complete the coherence task. One of the reasons for this could be the shorter time headways chosen by the angry drivers, as short following leaves less time for the assessment of speed changes of the lead vehicle.

During hazardous events, HR showed a similar pattern to the coherence task with a higher rate only in the angry mood. However, none of the results reached significance level. For the majority of the Mood and Load conditions, HR was lower during the conditions, as compared to the corresponding baselines, except the angry mood. The baseline drives were always the first drives, therefore stimulating physiological arousal due to task novelty. During the subsequent drives (after the mood induction), participants were more familiar with the roads and the tasks. Therefore, the increase in HR in the angry mood could be associated with arousal related to the driver's mood. EDA results were similar to the coherence task recordings, with a high habituation effect for the drivers in the neutral mood. During the hazardous events the neutral mood was a significant predictor of lower EDA levels in all hazards: PS, PG, CFL and CFR.

In summary:

During the mood induction, EDA and HR were able to distinguish between high and low arousal conditions. However, during the drives, the results were not straightforward, with different results during the coherence task and the hazardous events. While following the car, HR was a better indicator of arousal than EDA. However, EDA data showed clear patterns, with the highest habituation effect in the neutral mood. During hazardous events, EDA was a better indicator of drivers' arousal than HR. HR data did not show any patterns.

In line with the previous research, EDA was always lower in the neutral mood, indicating that emotional involvement results in some physiological arousal (Cacioppo et al., 2000; Jahn et al., 2005). Most of the time EDA was higher in the baseline compared to the subsequent drives. This habituation effect could be overcome by eliminating stimulus repetition. One of the solutions to this problem could be field studies.

Physiological measures did not differ between cognitive loads; possibly because Load conditions did not add enough arousal. Similarly, Ward et al. (2003) found increased HR during the coherence task only when a difficult secondary task was added: neither an easy secondary task nor driving without performance of a secondary task, significantly increased HR.

6.10 The effects of mood on driving performance – a justification for the use of multiple measures

Many driving behaviours are claimed to be potentially dangerous and detrimental to safety: speeding (Lajunen et al., 1997), acceleration (Robertson et al., 1992), time headway (Saad et al., 2005 ; Vogel, 2003), visual search patterns (Chapman et al., 2002), reaction to hazards (Velichkovsky et al., 2002) and braking style (Green, 2000; Saad et al., 2005 ; Winsum & Heino, 1996). However, each of these parameters taken individually provides little information about a task as complex as driving. For example, it is clear that high speeds are dangerous due to various reasons: less time for braking in a case of an emergency (Green, 2000), less time for situational assessment (Saad et al., 2005) and high speeds result in more severe accidents (Lajunen et al., 1997). Therefore, it could be concluded that speed reduction is a good behaviour to compensate, for example, for additional load (Chiang et al., 2001; Rakauskas et al., 2004). The difficulty here is to determine how much attention is still required and whether the speed reduction is sufficient to maintain safe driving. Another concern is that speed reduction can have negative consequences, such as increased traffic volume and emissions due to traffic concentration (Soriguera, Martínez, Sala, & Menéndez, 2017). Moreover, driving under the speed limit for a particular road can cause annoyance and stress for other road users (Lajunen & Parker, 2001).

Understanding the relationship between driving performance and accident risk is the most important and most difficult task in contemporary driving safety research. This difficulty is due to the variety of behavioural measures involved in safety assessment and the variety of variables influencing these measures (Hirsch, 1997). Hirsch (1997) also underlines the importance of distinguishing between the terms ‘legal’ and ‘safe’ driving, as these can create confusion. He states that legal driving is simply defined by ‘the letter of the law’, whereas safe driving is defined as an absence of actions that potentially can lead to accidents and near misses, thus increasing the risk of collisions. Moreover, he argues that legal driving is not always safe driving as well as safe driving not always being legal. For example, speed limit violation is not always unsafe, as speed limits are set with reference to traffic and weather conditions.

Saad et al. (2005) argue that a decline in performance in one of the parameters cannot reliably predict accident increase. For example, an increase in mental workload can be compensated for by a speed decrease. They argue that for an accident to take place the risk factor should exceed the compensatory factor by a critical level. For example, a drunk driver can underestimate a braking distance on a slippery road. As a result, a speed reduction could exceed the safe stopping distance in an emergency situation. De Waard (2002) suggests that although extra effort can help maintain necessary attention while driving, it can be only a short-term solution. Over a longer period, the mental effort can activate a cardiovascular defence response, which can lead to hypertension and performance decline.

One of the difficulties in generalising experimental results to a wider population is the variety of individual differences. With respect to driving safety, these individual differences can be defined by different aspects, such as proneness to risk-taking or attentional ability. Willingness to take risk has been the subject of controversy. For example, Wilde (1982) proposed a theory of risk-homeostasis, stating that an individual, at any given time, tends to preserve a constant personal risk level. Summala (1988), in contrast, states that individuals prefer risk levels close to zero, and Fuller (2005) argues that individuals are mostly guided by threat avoidance rather than a risk-taking. Nevertheless, personal risk level is different for every individual and therefore varies considerably between individuals. For example, Taieb-Maimon and Shinar (2001) found that drivers choice of minimum and comfortable headways were significantly correlated with drivers' age, with younger drivers keeping shorter headways. Evans and Wasielewski (1983) came to a similar conclusion: shorter headways were maintained by young drivers, drivers who had accidents and traffic violation history and those who did not wear a seatbelt. They included these drivers in a risky driver group. In addition, Evans and Wasielewski (1983) found gender differences in maintaining safe headway, with male drivers choosing shorter headways. Jonah (1997) reviewed studies looking at relationships between personality factors, such as sensation seeking and risky driving, and concluded that sensation-seeking motivates risky driving.

The willingness to adapt a risky driving style can be conditioned not only by individual differences but can fluctuate within an individual as well (Vaa, 2007). Vaa states that drivers' emotional states are largely responsible for risk acceptance or refusal and can vary within an individual. Both studies in this thesis have provided evidence in support of this statement. Moreover, this thesis provides evidence for the need of complex assessment of driving safety that takes into account a variety of measurements. Similarly to Robertson et al. (1992), the simulator study found that mean speed is not a representative measure when assessing driver behaviour on the approach to junctions. The results show that in these situations 'jerky driving' is more representative of dangerous driving style. Speed variation was higher in high arousal moods: happy and angry. The important task now is to determine the cause of the jerkiness. The logical conclusion is – acceleration and braking style. Table 22 shows that drivers in a neutral mood decreased speed variance. This decrease was due to less braking force and more deceleration. The sad drivers decreased speed variation by pressing the brake pedal for a longer time. Both of these moods did not facilitate harder braking, which could be potentially dangerous. The speed variance in the happy and the angry moods increased, but for different reasons: the happy drivers preferred to press the brake pedal for longer, but not as hard, the angry drivers preferred shorter and harder braking, thus adapting the most dangerous driving style. The numbers are calculated as averages by Mood ignoring Load from CFR and CFL hazards. The ▬ symbol indicates non-systematic and non-significant changes.

Figure 63 represents examples of neutral and angry driving styles on the approach to junctions. It shows that the drivers in the neutral mood tend not to accelerate on the approach to junctions, which could be the reason for not applying the brake. The angry drivers, instead, prefer to press the accelerator until very close to the junction, which necessitate hard braking when a hazard appears. These parameters support the conclusion that drivers in an angry mood are less proactive and less planning of their speed on the approach to junctions.

Table 22: Speeding and braking behaviour by Mood

Mood	Speed variance	Acceleration	Deceleration	Braking time	Braking force
Neutral	⇩	▬	⇧	▬	⇩
Happy	⇧	▬	⇩	⇧	⇧
Sad	⇩	▬	⇩	⇧	⇩
Angry	⇧	▬	⇩	⇩	⇧

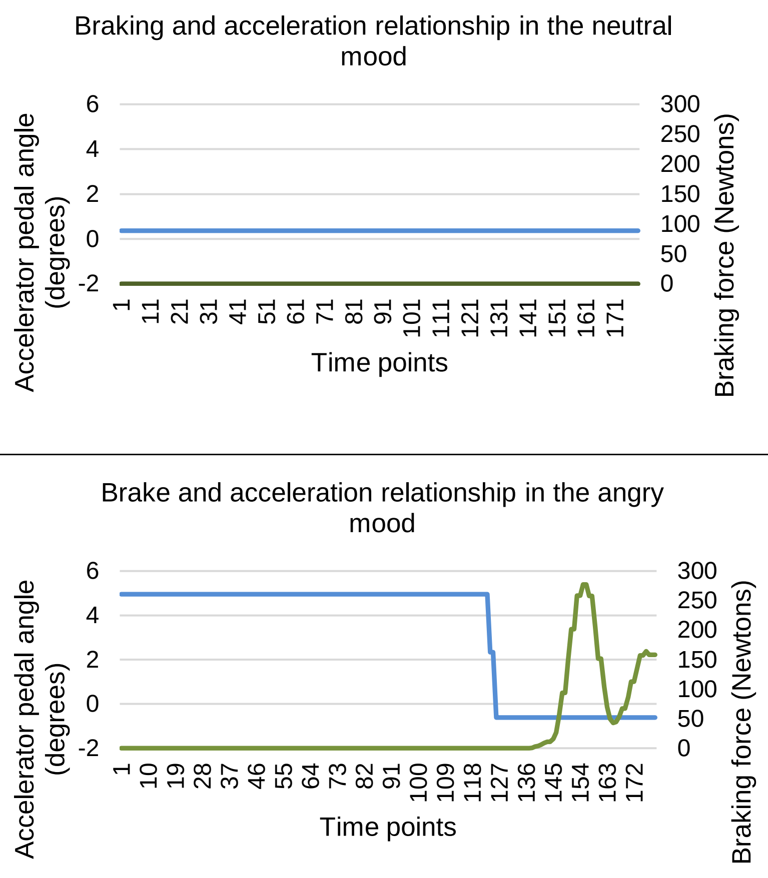


Figure 63: Relationship between acceleration and braking force in the angry and the neutral moods. Time points represent simulator sampling frequency, 60 Hz

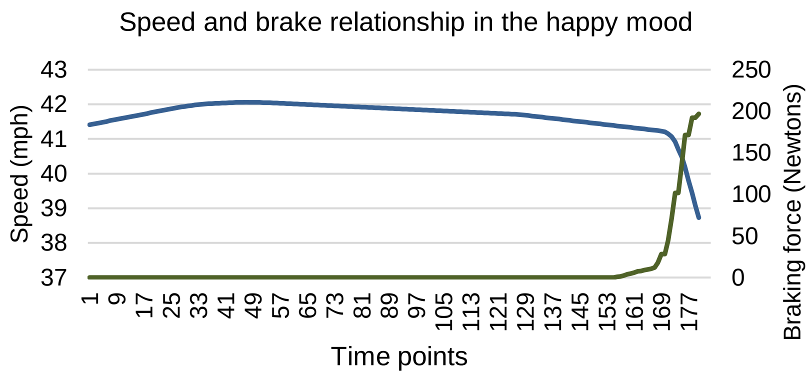
Drivers' behaviours while passing parked car hazards differed from their behaviours on approach to junctions. Possibly when passing the parked cars, the drivers did not expect the car to pull out without indicating, but on the approach to junctions drivers were more aware of the possible dangers. A parked car should indicate before commencing a manoeuvre, however, in reality this does not always happen. In every day driving, unexpected hazards can occur, for example, a pedestrian suddenly running across the road. Thus it is important to understand drivers' behaviours when facing unexpected hazards while affected by different emotions.

In the simulator study the speed changes from the corresponding baseline varied by mood, with high arousal moods resulting in a speed increase and low arousal moods resulting in a speed decrease (Table 23). The numbers are calculated as average by Mood ignoring Load from PS and PG hazards. The symbol indicates non-systematic and non-significant changes. Due to the unexpected nature of these hazards, participants tended to brake harder instead of slowing down using just engine power. However, the brake pressure they applied varied by mood. The angry and the happy participants increased brake force compared to the baseline. Participants in the neutral mood pressed the brake pedal longer and more gently. Probably they did not need to apply the same brake pressure to slow down due to the lower speed. The sad participants had a similar braking pattern, except without much increase in the braking time, which again could be due to the slower speed on the approach to these hazards.

Interestingly, there was no difference in speed between the low arousal moods (neutral and sad), regardless of the evidence of mind wandering in the sad mood, gained from other measures, such as longer fixation durations. This could be due to several reasons. First, driving speed in the low arousal moods was not high enough to require rapid braking. Second, the impact of mind wandering on the sad drivers' performance was not strong enough to make impact on their ability to notice the hazard. This result shows that speed reduction can appear not only as a compensation for additional load (the sad drivers) (Patten et al., 2004; Saad et al., 2005) but also as awareness of a current road situation (the drivers in the neutral mood). SWOV (2012) report shows that drivers tend to violate speed limits if the speed limits are not credible. This is true in both directions: when driving faster than the speed limit and when driving slower than the speed limit. The neutral mood encourages responsible driving and hazard anticipation, making drivers analyse the road situation instead of blindly following speed limit signs. Figure 64 represents speed, acceleration and braking in the neutral and the happy moods. The example is for one participant only, but it is representative of the trend in these moods. It shows that when a slower speed is employed, the brake pressure is lower and with a higher speed the brake is pressed harder.

Table 23: Speeding and braking behaviour by Mood

Mood	Mean speed	Acceleration	Deceleration	Braking time	Braking force
Neutral	↓	−	−	↑	↓
Happy	↑	−	−	−	↑
Sad	↓	−	−	−	−
Angry	↑	−	−	−	↑



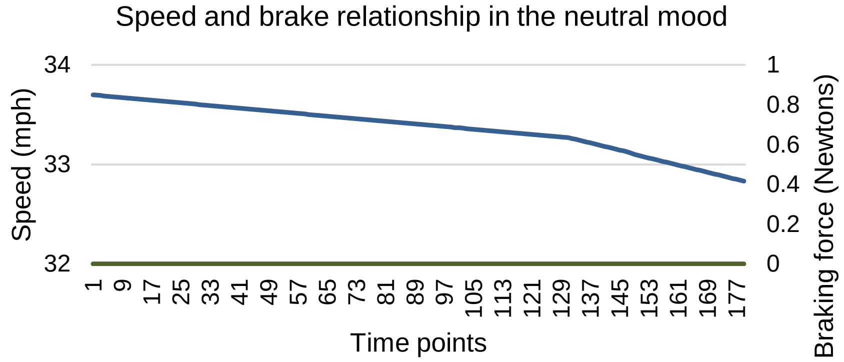


Figure 64: Relationship between speed and braking force in the happy and the neutral moods. Time points represent simulator sampling frequency, 60 Hz

6.11 Discussion summary

Drivers' mood valence and arousal have a significant effect on driving safety. This influence also differs as a function of traffic scenarios. The present studies found different behaviours for: the car following event, when drivers' speed choice is restricted by the lead car's speed and the driving when drivers' speed choice is restricted only by their hazard awareness and traffic conditions. The mood induced mind wandering affects driving safety in various ways. The effects of the neutral, the angry and the sad moods are the most consistent. The happy mood shows contradictory results. The reason for this contradiction requires further investigation.

6.11.1 Driving performance in situations requiring sustained attention

The best performance in driving requiring sustained attention was in **the neutral** mood. In comparison to the baseline, the drivers showed improved information processing and the ability to shift attention, the wider visual field of view, and similar to the baseline responses to the actions of the lead vehicle. Participants were calm, with similar to the baseline HR and lower EDA. Parameter estimates showed that the driving performance is not affected by the type of cognitive load applied while driving. The participants also reported that both types of the cognitive load did not distract them from the driving task. None of the measurements showed a decline in performance compared to the baseline. **Conclusions –** drivers not affected by emotions show safe driving and can cope with some amount of additional load without the performance decline.

The sad mood is also an emotional state with low arousal, but a negative valence. In comparison to the baseline, drivers' attention and information processing ability as well as the width of peripheral road scanning, declined. This caused an increase in time headway (TH) as a “compensation” for the loss of attention. However, large headways resulted in reaction delay and overshooting, which could cause confusion in the following vehicles. The analyses showed that the sad drivers could be diverted from their internal feelings by applying some amount of additional load. In other words, asking some driving-related questions improve their attentional shift, information processing and reactions to the speed changes in the lead vehicle. The sad mood also is the most harmful when no cognitive distraction is applied. The sad drivers' HR and EDA was lower than in the baseline, but only minimally, showing low arousal level. **Conclusions –** larger following distance is not always a safety advantage. When other measurements are evaluated, enhanced results are found. Larger TH might occur as a compensation for attentional lapses and reaction delay. Consequently, the sad mood is detrimental to driving safety and some amount of cognitive distraction improves the drivers' road awareness.

The angry mood is another mood with a negative valence, but with a high arousal. Angry drivers' EDA did not change much from the baseline, but HR showed a significant increase. This shows that HR is a more sensitive measure of drivers' arousal level during a task that requires sustained attention. In comparison to the baseline drivers' attentional shift, information processing and peripheral vision did not change much, showing that a high arousal can compensate for the harmful effect of a negative valence. The drivers preferred THs close to the lead vehicle, thus leaving no much time for another emergency, should it occur. The high attentional effort permitted them not only for the closer following distance but also for fast reactions and swift adjustments to the speed change of the lead vehicle. When no cognitive load was applied, the angry drivers mostly concentrated on the car ahead, thus narrowing their horizontal VF. **Conclusions –** the angry drivers might seem to employ all the safety behaviours: high attention, fast reactions and wide visual field. These features permit them for a minimal distance from the lead vehicle. However, this driving style has two possible dangers: first, the drivers leave too little space and time for actions in case of additional hazard (e.g. the need for emergency stop), and second - fatigue, which can occur without drivers' conscious awareness and unexpectedly slow drivers' reactions. Therefore, driving in the angry mood is harmful to driving safety, some amount of cognitive load can lower their concentration on the car ahead, thus increasing hazard awareness from a side road.

The happy mood is another emotional state with a high arousal, but a positive valence. Attention, information processing and peripheral vision did not change much after the happy mood induction, similarly as in the angry mood. However, the happy drivers preferred following distance further away from the lead car, compared to the angry drivers. Their reactions to the speed change of the lead vehicle also improved. HR and EDA were similar to the baseline measurements, showing that arousal level was not high enough to overcome attenuation effect of repetitive events. Applying some additional load improved drivers' visual field and reactions to lead vehicle's speed changes. **Conclusions –** driving in the happy mood does not cause a performance decline during car following. Cognitive load can disconnect drivers from internal thoughts and improve driving safety.

Overall some cognitive load does not affect drivers in the neutral mood and improve the safety of other drivers.

6.11.2 Driving without speed restriction by the car ahead

Driving when the speed choice is not restricted by the car in front differs from the coherence task. In this instance, drivers can choose how to adjust their speed in accordance with road and traffic conditions, as well as legal speed limits and social pressure. In this situation, the effects of drivers' behaviours on their ability to deal with hazards is examined. Although drivers behaved differently on the approach to junctions (JH) and when passing a car suddenly moving off (CH) hazard, the influence of mood on drivers' behaviour was evident in all hazardous situations.

Drivers in **the neutral** mood showed the most responsible and safe driving style. On approach to JH, they anticipated a possible hazard from the side road, dropping speed in advance and preferring milder and longer braking with engine brake involved, instead of rapid and sharp press of the brake pedal. While passing CH, drivers in the neutral mood preferred to drop their speed on the approach of the parked cars. Slower speed permitted for milder braking on hazard onset time. These parameters showed an improvement in comparison with the baseline driving. HR and EDA showed that drivers in the neutral mood did not feel stressed when hazard appeared, providing additional evidence for hazard anticipation. Cognitive load did not affect drivers' speed and speed variation. The only parameter affected by cognitive load was deceleration, when drivers came off the accelerator pedal later if distracted by questions. However, when compared to the baseline, it appeared that, distracted drivers still anticipated hazards better than while driving in their usual style. **Conclusions –** the neutral mood is beneficial for driving safety with some parameters improving compared to the baseline. Drivers also can cope with the additional load without performance deterioration.

The drivers in the **sad** mood adapted driving style similar to the drivers in the neutral mood, with slower speed on the approach of CH and less speed variation on the approach of JH. However, the sad drivers' braking was sharper with more braking force involved. This is explained by poor hazard anticipation due to mind wandering. This statement is also supported by the slower hazard response times and longer information processing in the desktop study. Cognitive load lowered drivers' speed variation on the approach of the junctions. Physiological measurements did not show systematic arousal changes during these hazardous events. **Conclusions –** the sad drivers had to brake harder regardless of slower driving, showing some impact of mind wandering. Cognitive load had a positive effect on the speed variation.

On approach to the junctions **the angry** drivers' speed variation did not change significantly from the baseline. On the approach to junctions, they preferred braking style applying harder pressure to the brake pedal. When passing CH, the angry drivers preferred fast driving, close to the speed limits. This was not a consequence of the speed increase in the angry mood; the speed was similar to the baseline. However, as the baseline was always the first drive, some hazard anticipation was expected in the subsequent drives. The angry drivers either did not anticipate that parked car could move off, or felt confident passing them. The angry drivers also differed in their braking style. Similarly like during JH, they preferred sharper and shorter braking. HR increase during these four hazards indicate higher arousal when angry compared to the baseline. EDA, however, did not change significantly from the baseline. When no cognitive load was applied, the angry drivers tend to press the brake pedal harder on the approach to junctions and when passing the car moving off from the group of parked cars. They also preferred fast driving regardless of the cognitive load when passing CH. **Conclusions –** high speed and rapid braking characterise the angry drivers as being less predictable for the other road users, thus, adapting more dangerous driving style. The type of questions, asked while driving, did not change their driving styles, only had some influence on approach of the junctions. The angry mood was not included in the desktop study. Thus data regarding hazard response times and attentional ability are missing from the analysis.

The mean speed when passing parked cars and the speed variation on approach to the junctions increased after **the happy** mood induction showing that the happy drivers adapt faster and jerkier driving styles. Analysis of braking style revealed that this was due to the sharper braking for most of the hazards. However, the happy drivers were inconsistent in their braking habits, for some hazards showing longer braking times, for others sharper braking. Similarly, inconsistent was HR and EDA data. Moreover, sometimes cognitive load had a positive effect on speed and braking, sometimes the other way round. For example, the happy drivers pressed the brake pedal longer on approach to the junctions when no load was applied and increased the speed passing the parked cars when no questions were asked and when DRL was applied. Longer brake pedal press was a positive effect of mood as it resulted in less braking force, the speed increase is a negative impact as it resulted in harder braking. However, these changes were significant in comparison to the neutral mood. This makes conclusions being dependent on both moods. The analysis did not show the clear effect of cognitive load on the happy drivers. **Conclusions –** the happy drivers are inconsistent in their driving habits. This inconsistency is mirrored in their HR and EDA. However, from the present data, it is difficult to conclude whether these contradictions were due to the individual differences, or the happy mood inconsistently affecting driving styles.

6.12 Limitations and suggestions for further research

The studies, reported in this thesis, have improved the understanding of effects of mood on driving performance and established possible direction for minimising its negative effect. This thesis comprises two studies: the desktop study and the simulator study. Both of them have advantages and disadvantages which are outlined in Chapters 4 and 5. The studies also have several limitations. First, the conclusions would be more detailed and the directions for further research would benefit from a field study, investigating the effects of drivers' mood and cognitive load on their driving performance in real road situations.

Second, the study as big as this simulator study, would benefit from the larger number of participants. The larger number of participants would provide with more power in statistical analysis and more clarity in the cases when marginally significant results or trends in the predicted directions were recorded.

Third, this thesis have investigated two dimensions of mood valence (positive and negative) and two dimensions of arousal (low and high). However, valence and arousal are not discrete metrics in real life. Thus, more detailed research is needed to determine the threshold when valence and arousal become detrimental to driving safety.

Forth, the simulator study could be viewed as comprising of two studies. One investigating the effects of drivers' mood on driving performance, and the other investigating possible interventions, in case of performance decline. The implementation of the cognitive load in this study should be viewed differently from the usual use of cognitive load in driving related research. Typically, cognitive load during driving is applied as a distractor from the main task, driving, and the impacts of this distraction on driving safety is investigated. In this simulator study, cognitive load was used as a disconnector from the mood induced mind wandering. Because, to the best of the author's knowledge, this is the novel approach in utilising cognitive load, the exact amount of distraction was difficult to determine. Two types of cognitive load were applied: DRL and NDRL. The results showed that the most sensitive to these interventions were glance behaviour measures. Cognitive load did not show much effect on driving styles and did not show any effect on physiological measures. Nevertheless, this first step in developing a method that would permit for drivers’ attention direction to the road environment, is promising. The type of load was not too high to affect physiological measures, as the previous research shows that increased HR and EDA is associated with drivers’ workload which is detrimental to driving safety. However, the precise amount of cognitive load, able to reallocate drivers’ attention without deteriorating driving performance, is still to be determined.

Future research could benefit from separately investigating methods of disengaging drivers from mind wandering and redirecting their attention to the road. This would permit for more detailed choice of cognitive distractors and optimisation of application methods.

6.13 Contributions to existing knowledge

This thesis presents research that extends on understanding of the effects of mood and cognitive load on driving safety in the following ways:

- It has demonstrated that the effects of mood on time headway is more nuanced than previously thought.
- It is the first to use a driving simulator to investigate the effect of moods on driving accelerating.
- It adds to the existing knowledge of the relationship between drivers’ mood, their driving style, hazard perception and anticipation and their ability to act safely in case of an unexpected road event.
- behaviour, such as braking styles, proneness to speeding or
- It is the first to assess driving safety using many components of safety indicators not only from the perspective when they complement each other, but when they seem to contradict each other.
- It established the possibility to interfere with mood related intrusive thoughts and mind wandering, and offered a possible method to implement this interference.

- The knowledge of effects of mood and cognitive load can help to develop in car devices and support tools able to detect and interfere with drivers' attentional lapses.

6.14 Concluding remarks

This thesis has contributed to the existing knowledge of possible consequence of drivers' mood and emotional state on driving behaviours and, as a consequence, driving safety. The findings have a high value for practical implications, described in Section 1.4. The construction of devices, capable of completing this type of assessment of drivers' mental and physical condition, might seem too complicated at present. However, with development of non-invasive methodologies for assessment of physiological arousal and emotional state, along with tools capable of measuring drivers' attention using their glance patterns, it all becomes practical and easy to implement. This makes it important to accurately identify drivers' emotional state by using multiple measures, such as eye tracking and physiological measures along with driving related measures, such as speed and braking patterns.

This complex assessment is the first step in developing such "assessment systems". The next step is to develop possible interventions. This thesis is the first step in understanding of what type of intervention is the most useful in re-engaging drivers to the driving task.

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Appendices

Appendix 1: Questionnaire

Demographical information

Could you please provide the following information about yourself?

1. **Your name ………………………………..**

2. **Your age ………………………………………**

3. **Your country of origin ……………………………………..**

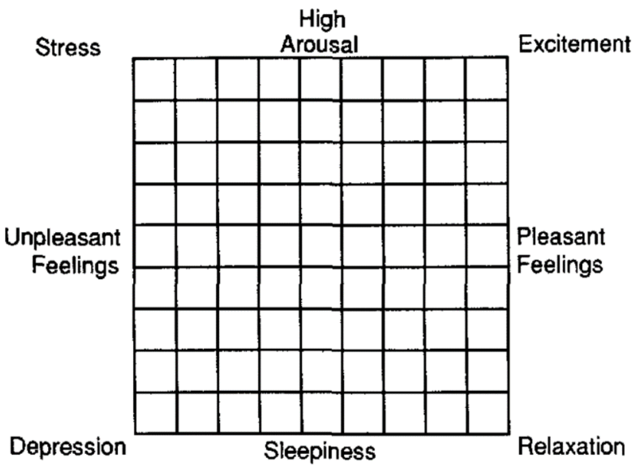
4. **How long have you lived in the UK …………………………………**

5. **Do you like western classical music ……………………………………**
   (please circle a number from 1 to 5, with 1 not at all and 5 really love it)

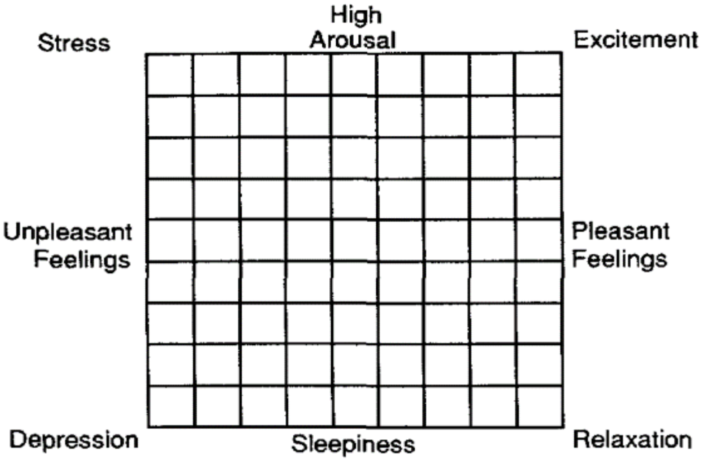
1……………2…………3…………4…………5

Could you please assess your present mood using a grid below?

Self-assessment grid (pre study)



Self-assessment grid (post study)



Rate on a scale from 1 to 5 how much of the following questions apply to you. With 1 not at all and 5 totally apply. Please circle the number.

1. Did you feel calm/happy/sad/angry (only 1 option was available) during the drive?

1.................2……………3…………….4…………..5

2. Did you find it difficult to concentrate on driving while feeling this emotion?

1……………2……………3……………4……………5

3. Have you noticed that some of the questions where driving related and some were about general life event?

Yes No

4. Did you feel distracted when asked driving related questions?

1……………2…………….3……………4…….………5

5. Did you feel distracted when asked general questions?

1…………….2……………3…………….…4…………….…5

Appendix 2: Means and standard deviations (in brackets) for measurements collected in the simulator study

Table 1: Post-study self-reported mood valence and arousal[4]

Mood	Valence	Arousal
Neutral	6.7(2.4)	3.89(1.17)
Happy	6.4(1.65)	5.7(1.64)
Sad	4.2(1.14)	4(1.5)
Angry	3.7(1.57)	6.3(1.34)

Table 2: Changes from the baseline in EDA (micro-Siemens) and HR (beats per minute) by Mood and Load

Mood	EDA (µS)	HR (BPM)
Neutral	-0.74(1.52)	-9.75(7.63)
Happy	0.45(0.75)	4.86(4.91)
Sad	-0.81(0.85)	-3.5(6.49)
Angry	0.3(0.36)	14.22(11.24)

Table 3: EDA (micro-Siemens) and HR (beats per minute) by Mood and Load during the car following task

	Load	Neutral	Happy	Sad	Angry
EDA	NONE	-2.81 (5.35)	-0.23 (0.52)	-1.16 (1.28)	-0.64 (0.64)
	NDRL	-2.34 (4.32	-0.23 (0.45)	-1.24 (1.24)	-0.23 (0.38)
	DRL	-1.85 (3.345)	-0.9 (1.82)	-1.19 (1.54)	-0.55 (1.16)
HR	NONE	-0.6 (13.06)	0.74 (6.96)	-6.98 (5.18)	14.2 (27.96)
	NDRL	4.53 (7.86)	3.47 (7.73)	-7.3 (16.36)	19.8 (33.9)
	NONE	-6.62 (9.26)	-1.87 (4.76)	-3.62 (8.16)	11.28 (26.99)

4 Self-rated on an assessment-grid from 1-not at all to 9-felt a lot

Table 4: Number of fixations, fixation durations (measured in seconds) and changes in number of fixations and fixation durations from the baseline by Mood and Load during car following task

	Mood / **Load**	**Neutral**	**Happy**	**Sad**	**Angry**
Number of fixations	NONE	190.1(20.83)	144.4(24.67)	182.1(21.97)	187.8(27.51)
	NDRL	190.6(20.58)	156.5(16.14)	172.7(20.72)	185.8(28.5)
	DRL	186.9(20.61)	154.5(27.11)	206.4(18.02)	176.8(26.98)
Changes in number of fixations	NONE	12.7(16.22)	-31.3(12.04)	-30.9(12.92)	-4.6(5.89)
	NDRL	13.2(14.5)	-19.2(6.99)	-40.3(12.61)	-6.6(5.76)
	DRL	9.5(16.01)	-21.2(8.39)	-6.6(8.37)	-15.6(7.5)
Fixation durations	NONE	0.39(0.03)	0.52(0.04)	0.66(0.07)	0.47(0.05)
	NDRL	0.39(0.03)	0.42(0.03)	0.55(0.07)	0.46(0.04)
	DRL	0.42(0.03)	0.53(0.05)	0.57(0.08)	0.46(0.04)
Changes in fixation durations	NONE	-0.09(0.03)	-0.03(0.02)	0.08(0.03)	-0.02(0.02)
	NDRL	-0.09(0.04)	-0.104(0.05)	-0.02(0.01)	-0.03(0.01)
	DRL	-0.06(0.02)	-0.03(0.02)	-0.01(0.01)	-0.02(0.01)

Table 5: Horizontal spread of fixations and changes in spread of fixations from the baseline by Mood and Load during car following task, measured in degrees

	Mood / Load	Neutral	Happy	Sad	Angry
Spread of fixations	NONE	8.29 (3.39)	5.78 (2.53)	5.32 (2.53)	5.03 (1.49)
	NDRL	7.38 (2.73)	5.68 (1.88)	5.42 (1.32)	5.32 (2.02)
	DRL	6.99 (2.73)	5.09 (1.26)	4.87 (1.57)	5.21 (1.63)
Changes in spread of fixations	NONE	2.39 (3.79)	0.096 (2.85)	-1.03 (2.7)	-0.48 (2.5)
	NDRL	1.48 (3.73)	-0.02 (3.14)	-0.93 (2.35)	-0.19 (2.44)
	DRL	1.09 (2.33)	-0.6 (2.76)	-1.48 (2.17)	-0.31 (2.5)

Table 6: Phase shift and changes in phase shift from the baseline by Mood and Load in the cycle 1, measured in seconds

	Mood / Load	Neutral	Happy	Sad	Angry
Condition comparison	NONE	3.68 (3.21)	5.2 (1.22)	5.74 (0.47)	2.96 (2.27)
	NDRL	3.78 (2.5)	4.34 (1.48)	5.19 (1.49)	4.53 (1.73)
	DRL	4.06 (2.23)	4.71 (1.94)	4.88 (3.54)	1.74 (2.51)
Changes from baselines	NONE	-1.11 (4.1)	-0.09 (2.05)	1.02 (2.21)	-1.88 (1.64)
	NDRL	-1.01 (3.63)	-1.47 (4.12)	1.16 (1.43)	-2.23 (3.59)
	DRL	-0.73 (4.06)	-1.14 (2.96)	0.69 (1.69)	-2.01 (1.82)

Table 7: Modulus and changes in modulus from the baseline by Mood and Load in cycle 1

	Mood / Load	Neutral	Happy	Sad	Angry
Condition comparison	NONE	0.76 (0.29)	0.6 (0.21)	1.13 (1.02)	0.99 (0.34)
	NDRL	0.84 (0.51)	0.55 (0.3)	1.13 (0.86)	0.98 ()0.24)
	DRL	0.84 (0.2)	0.59 (0.3)	1.09 (0.29)	0.91 (0.27)
Changes from baseline	NONE	-0.003 (0.44)	-0.22 (0.42)	0.36 (0.89)	0.09 (0.43)
	NDRL	0.08 (0.5)	-0.31 (0.41)	0.41 (0.72)	0.08 (0.3)
	DRL	0.08 (0.33)	-0.23 (0.35)	0.26 (0.31)	0.01 (0.24)

Table 8: Modulus and changes in modulus from the baseline by Mood and Load in cycle 2

	Mood / Load	Neutral	Happy	Sad	Angry
Condition comparison	NONE	0.75 (0.32)	0.76 (0.37)	1.01 (0.57)	0.58 (0.32)
	NDRL	0.85 (0.33)	0.61 (0.33)	1.14 (0.76)	0.72 (0.26)
	DRL	1.09 (0.73)	0.78 (0.37)	0.85 (0.27)	0.54 (0.34)
Changes from baseline	NONE	-0.02 (0.42)	-0.04 (0.34)	0.15 (0.84)	-0.04 (0.47)
	NDRL	0.08 (0.24)	-0.2 (0.53)	0.27 (0.36)	0.1 (0.24)
	DRL	0.31 (0.57)	-0.03 (0.8)	-0.01 (0.56)	-0.08 (0.35)

Table 9: TH by Mood and Load, measured in seconds

Mood/Load	Time	Neutral	Happy	Sad	Angry
NONE	1	0.1 (0.22)	0.13(0.31)	0.01(0.19)	0.26(0.42)
	1-2	0.26(0.21)	0.24(0.19)	0.05(0.09)	0.26(0.24)
	2-3	0.24(0.16)	0.25(0.15)	0.36(0.25)	0.21(0.2)
	3-4	0.26(0.21)	0.29(0.22)	0.33(0.18)	0.14(0.16)
	4-5	0.07(0.09)	0.04(0.06)	0.13(0.11)	0.1(0.15)
	5-6	0.06(0.15)	0.002(0.007)	0.13(0.16)	0.04(0.08)
NDRL	1	0.16(0.29)	0.12(0.29)	0.01(0.13)	0.12(0.25)
	1-2	0.25(0.21)	0.3(0.29)	0.1(0.14)	0.41(0.29)
	2-3	0.29(0.2)	0.24(0.14)	0.42(0.24)	0.25(0.19)
	3-4	0.19(0.17)	0.18(0.19)	0.25(0.14)	0.11(0.13)
	4-5	0.06(0.06)	0.09(0.13)	0.13(0.16)	0.07(0.11)
	5-6	0.02(0.04)	0.05(0.12)	0.09(0.11)	0.04(0.12)
DRL	1	0.07(0.12)	0.14(0.29)	0.01(0.02)	0.17(0.32)
	1-2	0.32(0.25)	0.19(0.28)	0.04(0.05)	0.3(0.29)
	2-3	0.33(0.23)	0.28(0.26)	0.29(0.14)	0.23(0.2)
	3-4	0.19(0.19)	0.18(0.19)	0.4(0.16)	0.14(0.14)
	4-5	0.03(0.05)	0.1(0.16)	0.2(0.1)	0.12(0.19)
	5-6	0.003(0.14)	0.03(0.06)	0.07(0.11)	0.05(0.14)

Table 10: Changes in TH from the baseline by Mood and Load, measured in seconds

Mood/Load	Time (Sec)	Neutral	Happy	Sad	Angry
NONE	1	0.02(0.05)	0.05(0.12)	-0.25(0.08)	0.25(0.43)
	1-2	0.03(0.21)	-0.07(0.24)	-0.19(0.22)	0.0002(0.34)
	2-3	-0.23(0.2)	-0.05(0.19)	0.01(0.24)	-0.11(0.2)
	3-4	0.09(0.17)	0.14(0.15)	0.09(0.23)	-0.08(0.16)
	4-5	0.03(0.09)	-0.05(0.15)	0.05(0.19)	-0.02(0.17)
	5-6	0.05(0.15)	-0.01(0.02)	0.08(0.22)	-0.04(0.1)
NDRL	1	0.12(0.26)	0.001(0.04)	-0.03(0.08)	0.1(0.25)
	1-2	0.02(0.25)	-0.06(0.34)	-0.14(0.25)	0.14(0.37)
	2-3	-0.17(0.24)	-0.09(0.2)	0.07(0.31)	-0.06(0.17)
	3-4	0.01(0.12)	0.02(0.1)	0.11(022)	-0.11(0.22)
	4-5	0.01(0.07)	-0.006(0.05)	0.05(0.23)	-0.04(0.16)
	5-6	0.01(0.02)	0.04(0.12)	0.04(0.2)	-0.03(0.06)
DRL	1	0.04(0.29)	0.09(0.23)	-0.03(0.08)	0.15(0.23)
	1-2	0.09(0.18)	-0.12(0.34)	-0.2(0.22)	0.03(0.3)
	2-3	-0.13(0.32)	-0.01(0.26)	-0.06(0.28)	-0.08(0.16)
	3-4	0.02(0.14)	0.03(0.14)	0.16(0.24)	-0.08(0.15)
	4-5	-0.01(0.06)	0.004(0.12)	0.11(0.18)	0.0003(0.2)
	5-6	-0.01(0.02)	0.01(0.07)	0.01(0.21)	-0.02(0.05)

Table 11: Speed variation and changes in speed variation from the baseline during CFL and CFR hazard by Mood and Load, measured in miles per hour

		Mood/Load	Neutral	Happy	Sad	Angry
CFL	Conditions	NONE	0.56 (0.63)	1.05 (1.18)	0.45 (0.51)	0.75 (0.63)
		NDRL	0.16 (0.1)	1.06 (0.97)	0.42 (0.48)	0.35 (0.29)
		DRL	0.37 (0.38)	0.99 (1.04)	0.3 (0.27)	0.91 (1.17)
	Changes	NONE	-0.53 (0.89)	0.21 (1.24)	-0.53 (1.46)	0.36 (0.77)
		NDRL	-0.93 (1.1)	0.22 (1.23)	-0.56 (0.94)	-0.04 (0.45)
		DRL	-0.72 (1.02)	0.15 (1.16)	-0.68 (1.29)	0.52 (0.78)
CFR	Conditions	NONE	1.12 (0.95)	1.29 (1.2)	0.44 (0.52)	0.68 (0.65)
		NDRL	0.35 (0.29)	1.21 (0.93)	0.42 (0.47)	0.16 (0.11)
		DRL	0.84 (1.03)	1.25 (1.11)	0.3 (0.27)	0.52 (0.52)
	Changes	NONE	0.3 (0.66)	0.35 (1.54)	-0.54 (1.1)	0.74 (1.15)
		NDRL	-0.21 (0.39)	0.24 (1.19)	-0.07) (0.44)	-0.03 (0.45)
		DRL	0.15 (0.67)	0.32 (1.54)	-0.19 (0.92)	0.45 (0.59)

Table 12: Changes in deceleration from the baseline by Mood and Load during CFR hazard

Mood/Load	Neutral	Happy	Sad	Angry
NONE	0.63 (0.9)	0.13 (0.73)	0.05 (0.51)	-0.49 (0.68)
NDRL	0.65 (0.83)	-0.45 (0.75)	-0.03 (0.7)	-0.25 (0.65)
DRL	0.34 (1.05)	0.12 (0.51)	-0.25 (0.55)	-0.13 (0.68)

Table 13: Changes in time actively braking (measured in seconds) from the baseline by Mood and Load during for CFL and CFR hazards

	Mood/Load	Neutral	Happy	Sad	Angry
CFL	NONE	0.31 (0.43)	0.25 (0.74)	0.34 (0.95)	0.02 (0.53)
	NDRL	0.42 (0.49)	0.09 (0.92)	0.62 (1.51)	-0.35 (1.51)
	DRL	0.24 (0.71)	-0.07 (0.47)	-0.16 (0.55)	-0.41 (1.48)
CFR	NONE	0.21 (1.22)	-0.85 (1.29)	0.15 (0.72)	0.12 (0.89)
	NDRL	0.32 (1.13)	-0.78 (1.69)	0.2 (1.03)	-0.03 (0.3)
	DRL	0.13 (0.87)	-0.28 (1.19)	0.35 (0.72)	-0.17 (0.45)

Table 14: Braking force and changes in braking force from the baseline by Mood and Load during CFL and CFR hazards, measured in Newtons

		Mood/ Load	**Neutral**	**Happy**	**Sad**	**Angry**
CFL	Conditions	NONE	26.91 (34.07)	44.05 (60.6)	18 (16.98)	58.58 (50.22)
		NDRL	17.95 (31.74)	54.28 (56.14)	15.56 (18.02)	42.69 (35.59)
		DRL	22.89 (28.79)	43.46 (48.1)	15.07 (16.47)	49.53 (42.95)
	Changes	NONE	-5.67 (12.24)	-21.8 (52.6)	14.73 (38.9)	-2.93 (29.96)
		NDRL	-11.58 (28.53)	-32.43 (56.81)	10.71 (38.08)	3.92 (41.47)
		DRL	-8.6 (24.28)	-22.21 (65.42)	10.28 (33.05)	-11.98 (21.4)
CFR	Conditions	NONE	16.41 (31.03)	18.55 (15.66)	37.11 (34.58)	15.13 (12.94)
		NDRL	43.9 (88.83)	28.3 (24.39)	38.85 (30.92)	18.97 (32.32)
		DRL	26.9 (53.51)	38.1 (44.99)	28.36 (26.22)	41.49 (57.6)
	Changes	NONE	-9.93 (33.19)	4.58 (28.4)	-23.41 (24.35)	24.96 (88.84)
		NDRL	-37.42 (90.77)	-5.17 (44.39)	-25.15 (29.23)	21.12 (90.78)
		DRL	-23.13 (54.96)	-14.97 (55.16)	-14.66 (25.45)	-1.4 (32.09)

Table 15: Average speed and changes in average speed from the baseline by Mood and Load for 'parked car' hazards, measured in miles per hour.

		Mood/ Load	Neutral	Happy	Sad	Angry
PS	Conditions	NONE	33.77 (3.5)	39.99 (4.48)	36.66 (2.68)	41.48 (2.98)
		NDRL	34.53 (3.89)	40.2 (4.04)	35.12 (3.77)	40.06 (4.08)
		DRL	32.83 (3.55)	40.38 (3.89)	34 (4.21)	41.24 (2.92)
	Changes	NONE	-4.95 (4.18)	0.41 (5.99)	-3.78 (3.75)	0.36 (2.79)
		NDRL	-4.18 (5.46)	0.62 (6.05)	-5.32 (4)	-1.06 (4.81)
		DRL	-5.88 (6.31)	0.8 (6.09)	-6.44 (5.62)	0.13 (3.57)
PG	Conditions	NONE	35.62 (6.22)	40.05 (3.63)	37.61 (4.28)	40.4 (3.73)
		NDRL	37.85 (4.09)	39.31 (4.55)	37.11 (3.99)	40.79 (4.06)
		DRL	35.19 (6.04)	41.46 (3.51)	36.14 (3.69)	38.9 (3.85)
	Changes	NONE	-3.33 (7.87)	3.68 (5.74)	-2.01 (6.09)	-0.03 (2.58)
		NDRL	-1.1 (6.45)	2.95 (6.13)	-2.51 (5.93)	0.36 (4.81)
		DRL	-3.76 (7.83)	5.1 (4.87)	-3.48 (5.36)	-1.53 (4.62)

Table 16: Time actively braking and changes in time actively braking from the baseline by Mood and Load for PG hazard, measured in seconds

	Mood/Load	Neutral	Happy	Sad	Angry
PG	NONE	0.78 (0.6)	0.82 (0.51)	0.88 (0.67)	0.31 (0.32)
	NDRL	0.47 (0.57)	0.84 (0.56)	1.05 (0.68)	0.55 (0.55)
	DRL	0.4 (0.4)	0.82 (0.67)	0.69 (0.41)	0.46 (0.48)
Changes	NONE	-0.27 (0.48)	-0.42 (1.15)	-0.66 (0.72)	-0.21 (0.35)
	NDRL	0.04 (0.45)	-0.45 (0.98)	-0.83 (0.79)	-0.46 (0.59)
	DRL	0.11 (0.44)	-0.43 (1.4)	-0.47 (0.46)	-0.37 (0.37)

Table 17: Braking force and changes in braking force from the baseline by Mood and Load during PS hazard, measured in Newtons

	Mood/Load	Neutral	Happy	Sad	Angry
Conditions	NONE	10.92 (17.19)	45.49 (44.99)	16.82 (19.49)	67.09 (67.89)
	NDRL	14.44 (17.09)	27.41 (27.55)	9.22 (8.68)	48.18 (49.74)
	DRL	20.06 (23.99)	31.52 (35.54)	9.01 (13.77)	27.09 (27.55)
Changes	NONE	7.73 (21.36)	2.87 (29.61)	9.28 (29.28)	65.12 (65.56)
	NDRL	4.2 (24.31)	-7.39 (27.26)	1.67 (15.18)	46.21 (48.28)
	DRL	13.35 (19.61)	4.22 (31.32)	1.46 (22.21)	25.11 (46.82)

Table 18: Maximum braking force and changes in maximum braking force from the baseline by Mood and Load, measured in Newtons

	Mood/Load	Neutral	Happy	Sad	Angry
Conditions	NONE	18.89 (29.89)	54.75 (46.89)	44.41 (39.09)	106.69 (140.61)
	NDRL	29.7 (29.22)	84.51 (85.92)	28.73 (29.22)	78.72 (90.65)
	DRL	27.39 (41.19)	60.88 (62.87)	21.96 (33.15)	81.42 (96.83)
Changes	NONE	-12.73 (52.67)	26.77 (62.73)	26.78 (62.73)	101.37 (134.35)
	NDRL	-1.92 (44.15)	56.53 (89.5)	11.1 (51.81)	73.4 (85.94)
	DRL	-4.22 (51.47)	32.89 (71.96)	4.32 (56.45)	76.1 (99.33)

Table 19: EDA during CFL hazard, measured in micro-Siemens

	Load	Neutral	Happy	Sad	Angry
EDA	NONE	-1.3 (1.17)	-0.51 (0.59)	0.32 (1.56)	-0.11 (1.09)
	NDRL	-1.89 (2.04)	-0.13 (0.44)	-0.01 (0.78)	-0.03 (1.15)
	DRL	-1.68 (1.75)	0.77 (3.53)	0.28 (0.92)	0.17 (0.78)

Table 20: EDA during CFR hazard, measured in micro-Siemens

	Load	Neutral	Happy	Sad	Angry
EDA	NONE	-0.89 (1.06)	-0.33 (0.44)	-0.51 (0.68)	-0.53 (0.78)
	NDRL	-1.53 (1.73)	0.09 (0.65)	-0.28 (0.59)	-0.37 (0.78)
	DRL	-1.23 (1.38)	0.47 (2.04)	-0.37 (0.49)	-0.45 (1.15)

Table 21: EDA during parked car hazards and for combined data for both of these hazards, measured in micro-Siemens

Hazard	Load	Neutral	Happy	Sad	Angry
PS	NONE	-1.03 (1.34)	-0.28 (0.62)	-0.25 (2.85)	-0.29 (0.58)
	NDRL	-1.46 (1.46)	0.58 (2.14)	-0.32 (2.38)	-0.37 (0.59)
	DRL	-1.32 (1.39)	0.97 (4.38)	-0.41 (1.51)	-0.33 (1.02)
PG	NONE	-0.74 (1.16)	-0.18 (0.76)	-0.33 (2.28)	-0.46 (0.58)
	NDRL	-1.38 (1.36)	-0.06 (0.92)	-0.05 (2.36)	-0.53 (0.55)
	DRL	-1.44 (1.41)	0.79 (4)	-0.32 (1.73)	-0.44 (0.73)
PS & PG	NONE	-0.88 (1.23)	-0.23 (0.68)	-0.29 (2.49)	-0.37 (0.57)
	NDRL	-1.42 (1.37)	0.26 (1.63)	-0.19 (2.3)	-0.45 (0.56)
	DRL	-1.38 (1.37)	0.88 (4.07)	-0.37 (1.57)	-0.39 (0.86)

Appendix 3: Participant Information Sheet

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Participant Information Sheet

Research on Drivers Mood, Cognitive Load and Driving Safety.

Tatjana Zimasa, supervised by Dr Samantha Jamson and Dr Brian Henson

Contact information for Tatjana Zimasa

Email: tstz@leeds.ac.uk
Contact information for Samantha Jamson
Email: s.l.jamson@its.leeds.ac.uk
Contact information for Dr Brian Henson
Email: b.henson@leeds.ac.uk

Please read the following information carefully as it is important that you understand the purpose of this study and what the experiment will involve. Please do not hesitate to contact Tatjana Zimasa the organiser of this study, if you have any questions or concerns.

Please proceed only if you agree with the following statements:

- **I am not on any type of medication that could affect my reactions (please consult with the researcher if you think you are),**
- **I have held full driving license for the period of time no less than three years,**
- **I drive at least 5000 miles per year,**
- **I do not wear glasses when driving (contact lenses are accepted).**

1) What is the purpose of the study?

The aim of this study is to investigate how listening to music affects drivers' performance. You will drive in the University of Leeds Driving Simulator on roads containing potential and developing driving hazards. You will have to press a pad on the steering wheel when you think that the situation may become hazardous such that you would need to brake or steer to avoid a collision. The time from the beginning of the hazard till the button press will be measured as well as the pattern of your eye movements. At the same time some driving related measurements will be taken as well (i.e. average speed, brake pressure).

2) Why are you asking me to take part?

We are looking for 60 participants aged between 20 and 50 with normal/corrected to normal (contact lenses) vision.

3) What will happen if I agree to take part?

Once you have agreed to take part, we will arrange a mutually convenient date and time for your experiment. You will read the Participant information form and fill in the Consent form before the day of the experiment.

You must not return any of these forms to us by email as they contain your personal information and email does not protect your privacy.

4) Do I have to take part?

No, you should only take part if you wish to do so. Even if you agree to take part, you may change your mind at any time without giving a reason.

5) What will happen on the day of the experiment?

On the pre-arranged date you will need to go to the University of Leeds Driving

Simulator building main entrance, where I will meet you and go through your consent forms.

During the experiment you will drive as you would normally do in your everyday life and will be required to press a pad on a steering wheel when you think that a situation on the road may become potentially hazardous and cause you to brake or steer. You will receive training and instructions immediately before the experiment.

The total duration of the experiment will be approximately 60 minutes. This will allow for pre-experimental training, briefing, safety checks and the experiment itself.
You will be free to stop the experiment at any time.

6) What are the possible disadvantages and risks of taking part?

1. General eye tracker safety

Experiments using eye trackers are safe and non-invasive, as long as proper procedures and protocols are followed. We will do our best to minimise any sources of discomfort or stress you may experience during the experiment. Of course, you are free to stop the experiment at any time.

2. Biopac safety

For the recording of your heart beat rate and skin conductance a tool kit called Biopac will be used. Biopac measures are safe and non-invasive. . BioPac is a non-invasive measurement tool, which includes attaching electrodes to non-working hand's index and middle fingers for skin response measurements. Two electrodes will be attached to your chest for hart beat rate measurements. There will be minimum of discomfort experienced during the experiment, as the car used in the driving simulator is automatically driven and do not require gear change.

3. Allergy advice

Non allergic gel will be used to collect the data from skin response. However, if you think that you might have any allergy as a consequence of using the gel, please ask the experimenter to make a probe on your skin response before the experiment.

7) What if something goes wrong?

If you are concerned about any aspect of the study please contact Tatjana Zimasa, Samantha Jamson or Brian Henson (contact details are provided above), who will do their best to answer your question.

8) Who is organising and funding the study?

Tatjana Zimasa is a PhD student. Dr Samantha Jamson is in The Institute for Transport Studies and is main supervisor of the project; Dr Brian Henson is a Senior lecturer in School of Mechanical Engineering and is co-supervising the project. This study is being jointly funded by the Engineering and Physical Science Research Council (EPSRC) and Jaguar Land Rover (JLR).

9) Can you assure me of confidentiality?

Yes, the University of Leeds staff adheres to the Data Protection Act 1998. Any information that you give us and any data that we collect from you will remain confidential. We will store personal information in locked filing cabinets and store the data in anonymous computer files under password protection. We will store names and addresses separately from other data. Only authorised staff will have access to your personal information.

If the results of this study are published, data and images will be anonymised. No individual person will be identified in any way without the person's prior written consent. Other researchers may access the data for use in research and teaching, but these researchers will require the approval of the Research Ethics & Governance Committee of the University of Leeds, they and will be allowed access to your data in anonymous form only.

10) What if I have any concerns?

Please do not hesitate to contact us if you have any questions or concerns. Contact information is provided at the start of this document.

11) Who has reviewed this study?

This study was approved by the Research Ethics and Governance Committee of the University of Leeds.

12) **Will my identity be disclosed?**

All information disclosed within the experiment will be kept confidential, except where legal obligations would necessitate disclosure by the researchers to appropriate personnel.

13) **What will happen to the information?**

All information collected from you during this research will be kept secure and any identifying material, such as names, will be removed in order to ensure anonymity. It is anticipated that the research may, at some point, be published in a journal or report. However, should this happen, your anonymity will be ensured, although it may be necessary to use your words in the presentation of the findings and your permission for this is included in the consent form. You can withdraw you data at any time up to point of analysis. After the data has been analysed the withdrawal will not be accepted. If you wish to do so, you will need to provide the number that identifies you, as written on your consent form.

Thank you for reading this document.

Appendix 4: Consent form

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CONSENT FORM FOR ADULT PARTICIPANTS

Research on Drivers Mood and Driving Safety.

Participants should complete items 1 to 9 themselves

Please circle either YES or NO

1. I have read the information sheet entitled 'Research on Drivers Mood and Driving Safety'.

YES/NO

2. I have had the chance to discuss the study and to ask questions

YES / NO

3. I have had satisfactory answers to all my questions

YES / NO

4. Who has explained the study to you?

Prof/Dr/Mr/Mrs/Ms………………………………….

5. I understand that I am free to withdraw from the study:

- At any time

YES / NO

- Without having to give a reason

YES / NO

6. Do you agree to take part in the study?

YES / NO

7. I understand that I can discuss the research with a researcher at any time, if I wish.

YES / NO

8. I know that the research information will be kept strictly confidential. When the results are published no individual person will be identified in any way without the person's written agreement.

YES/NO

9. If I have any questions or concerns about the research, I know I can contact Tatjana Zimasa by email tstz@leeds.ac.uk or Samantha Jamson by email: s.l.jamson@its.leeds.ac.uk

YES/NO

****

11. PARTICIPANT

Signature of Participant………………………………
…………………….…………Date……………………..

Name (BLOCK LETTERS)……………………………………………………………………………
…….

****

12. INVESTIGATOR

I have explained the study to the above participant and he/she has indicated his/her willingness to take part.

Signature of Investigator…………………………………………………………Date……………
………..

Name (BLOCK LETTERS)……………………………..……………………………………………………
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