# Using biosensors to measure and regulate the negative affect of drivers in simulated environments.

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## Abstract

Recent statistics have suggested that a proportion of drivers are killed or seriously injured on UK roads due to feeling nervous, uncertain or panicked whilst driving. The literature into negative emotions has primarily focused on the relationship between anger and driving. Not including the literature on driving phobias and fears after a motor vehicle accident, the literature on the relationship between anxiety and driving is limited and inconclusive. The aim of the thesis was to investigate the effects of both state and trait anxiety on driving behaviours and autonomic reactions using studies with varying methodologies. Chapter 2 describes a questionnaire study, which found that whilst driving anxiety can have a substantial impact on anxiety related thoughts, behaviours and active avoidance, trait anxiety had slightly differential effects regarding social concerns, aggressive reactions and anxiety and avoidance of specific driving situations. Chapter 3 established, in a laboratory study, that whilst trait anxiety predicted various self-reported driving reactions, it did not affect levels of behavioural or autonomic reactions to driving video stimuli. Chapter 4 expands on these findings with a study that demonstrated reductions in high frequency heart rate variability, indicating a potential lack of emotional regulation within this context. The research was then taken into a simulated environment, where state and trait anxiety were investigated. The studies reported in Chapters 6 and 7 found limited impacts of threatening instructional sets on levels of state anxiety, but demonsrated that increases in state anxiety could lead to changes in behaviour and skin conductance levels. Finally, a simulator study reported in Chapter 8 demonstrated that whilst trait anxiety did not affect driving behaviours, it did affect levels of attentional control and processing efficiency. This leads into a discussion of the theoretical and practical implications of these findings. Particular focus is given to the benefits of

interventions and exposure therapies, and it is argued that different types of intervention would be more beneficial depending on levels of state or trait anxiety.

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## Glossary

- **Anxiety**- the feeling of worry, nervousness of unease about an event with an uncertain outcome.
- **Appraisal**- the act of evaluating a current situation. From an emotional perspective, individuals evaluate the demands of a situation and compare this to their current perceived ability to cope.
- **Attention**- the act of applying resources to a specific stimulus.
- **Attentional Control Theory (ACT)**- an extension of processing efficiency theory proposed by Eysenck et al. (2007). It extends the original theory by suggesting that anxiety effects are due to a disrupted influence of top-down, goal-oriented resources in favour of bottom-up, stimulus-driven resources. Specific executive functions such as inhibition, shifting and updating are also argued to be affected by trait anxiety.
- **Autonomic Nervous System (ANS)** - an unconscious system in the human body that serves to maintain the homeostasis of internal organs.
- **Central Executive**- a component of working memory that acts as a supervisory system for the visuospatial sketchpad and phonological loop slave systems. It has limited capacity.
- **Deoxygenated haemoglobin (HbR)** - haemoglobin that is bound with oxygen molecules. A decrease of oxygenated haemoglobin within the frontal cortex is typically found in tasks requiring working memory and central executive resources.
- **Executive functions**- a set of processes that are concerned with managing resources efficiently in order to achieve a certain goal.
- **Fear**- an unpleasant emotion caused by the threat of a known danger, pain or harm.

- **Fidelity**- the degree to which a simulator's characteristics are reflective of a real vehicle. Fidelity can be affected by motion, cockpit controls and the degree of visual field.
- **Functional near infra-red spectroscopy (fNIRS)** - an optically-based method of measuring brain activity. Infra-red light is projected onto the cortical surface of the brain and is absorbed by oxygenated and deoxygenated haemoglobin (HbO and HbR respectively). Any unabsorbed light is then scattered back through the scalp and picked up by detectors, which capture and estimate the changes in HbO and HbR relative to a baseline level.
- **Headway**- the proximity between the driver's car and the car in front of them. This can be measured in either distance (m) or time (seconds).
- **Heart Rate Variability**- a measure of heart rate that takes into account the variability in time between heartbeats, also known as the inter-beat-intervals. This can be analysed using time-domain or frequency-domain methods. Measures of heart rate variability can inform us about sympathetic and parasympathetic activity.
- **Heart Rate**-a measure of both sympathetic and parasympathetic activity based on the amount at which an individual's heart beats. It is usually expressed in beats per minute (BPM).
- **Nottingham Integrated Transport and Environment Simulation Facility (NITES)** - a driving simulator facility based at the University of Nottingham. It consists of three simulators: a motion-base simulator (NITES 1), a fixed-base simulator (NITES 2), and a fully instrumented Ford Focus (NITES 3).
- **Oxygenated haemoglobin (HbO)** - haemoglobin that is bound with oxygen molecules. An increase of oxygenated haemoglobin within the frontal cortex is typically found in tasks requiring working memory and central executive resources.

- **Parasympathetic Activity**- one of two main components of the autonomic nervous system. It is more apparent when energy needs to be conserved during rest.
- **Polyplethysmography (PPG) -** an optical-based method of obtaining heart rate measures. It records pulse rate information from a peripheral location such as a fingertip or earlobe.
- **Polyvagal Theory**- a theory of emotion proposed by Porges (2007).
- **Prefrontal cortex (PFC) -** the anterior part of the frontal lobe. It plays a role in complex emotional and cognitive processes, such as central executive functions.
- **Processing Efficiency Theory (PET) -** a theory proposed by Eysenck & Calvo (1992) that makes a distinction between performance effectiveness and processing efficiency. It argues that whilst individuals may be able to perform a task to the same level of quality, those with higher levels of trait anxiety require more processing resources to do so, hence their processing efficiency is reduced.
- **Skin Conductance**- a measure of sympathetic activity that is based on measuring the amount of electrical activity within the surface of the skin. It can be measured in long-term recordings known as skin conductance levels (SCLs), or short-term recordings known as skin conductance response (SCRs). It is usually measured in microSiemens (mS).
- **Somatic marker hypothesis**- a theory proposed by Damasio (1996) that accounts for the fact that making decisions on a rational basis is time-consuming. To account for this, autonomic responses can be used to provide internal feedback and increase the speed at which such decisions are made.
- **Speed Variability**- the degree to which a driver's speed changes.
- **Standard Deviation of Lane Position (SDLP) -** the degree to which a driver's lane position changes.

- **State Anxiety**- a measure of how anxious an individual is at a specific moment in time.
- **Sympathetic Activity**- One of two main components of the autonomic nervous system. It acts on a basic level to maintain homeostasis, but increases when energy needs to be exerted during 'fight-or-flight' situations.
- **Task Capability Interface Model**- a model of driver behaviour proposed by Fuller (2005). This suggests that feelings of task difficulty whilst driving are dependent on an interaction between the demands of the task and the capabilities of the driver. When demand exceeds individual capability, then the task becomes more difficult and risky in the eyes of the driver.
- **Trait Anxiety**- a dispositional measure of how anxious an individual is.
- **Transactional model of stress**- a theory of appraisal proposed by Lazarus (1982). It argues that negative emotions such as stress may occur when the demands of a given task or environment exceed an individual's perceived ability to cope.
- **Validity**- the degree to which findings from a driving simulator can be generalised to findings in the real world.
- **Virtual Reality Exposure Therapy (VRET)** - a method of attempting to alleviate driving anxiety that exposes drivers to anxiety-provoking driving situations in a simulated environment.
- **Workload**- the amount of physical or mental effort an individual must invest in order to complete a task. When task difficulty increases, individuals are able to complete a task, but their workload increases.

# Chapter 1. General Introduction

## 1.1 The Current State of Driving

Driving is an activity that has become increasingly necessary over the years, whether it be due to work or recreational-related purposes. Driving is important for both social (Stanley & Stanley, 2007) and psychological (Vella-Brodrick & Stanley, 2013) well-being, as it allows the individual to explore and expand their individual experiences. Drivers also suggest that they prefer the choice of using a car over other methods such as public transport (Innocenti, Lattarulo, & Pazienza, 2013); this highlights the importance that driving has on everyday behaviour, from a personal as well as a practical perspective.

There has simultaneously been an increase in concern on the impact of road traffic accidents. According to the World Health Organisation, they are the 8$^{th}$ leading cause of death globally; around 1.24 million people die in road accidents each year and 20-50 million obtain non-fatal injuries (World Health Organisation, 2013). In the UK, there were over 1700 deaths and over 200,000 injuries in 2013 (Department for Transport, 2014). However, due to the fact that some crashes are not reported to police, the number of those injured could in fact be around 720,000 (Department for Transport, 2014).

These statistics highlight the need for improvements in road safety. Thus, in 2010 the United Nations adopted a resolution that prompted a 'Decade of Action for Road Safety' (General Assembly, 2010). The purpose of the Decade, which started in May 2011 and is active until 2020, is to stabilise and hopefully reduce the increasing trend in road-related injuries and fatalities.

Driving psychology research may help explore the psychological factors behind the increased risk in accidents, and use this information to provide implications for road safety. Current findings suggest that a variety of external factors such as on-street parking (Rudin-Brown, Edquist, & Lenne, 2014) and endogenous factors such as stress history (Clapp, Olsen, et al., 2011a) can result in an increase in mistakes on the road, which could subsequently lead to an increased risk of an on-road accident. This results in the formation of theories that consider the influence of both environmental and internal factors within driving behaviour (Fuller, 2005), and it may suggest that research also needs to provide evidence of how internal factors such as mental load, fatigue and personality, can influence the likelihood of accident involvement. This could subsequently result in appropriate training programs (Petzoldt, Weiss, Franke, Krems, & Bannert, 2013) or therapies (Townend, 2003) that could be recommended to drivers.

## 1.2 Overview of the Chapter

This chapter will highlight some factors that have already been shown to be related to dangerous driving behaviour. This will include a discussion on the relationships between emotion and driving, which has seen an increase in research within the last 20 years. It will be established that emotions can have a significant effect on driving behaviours. Then, there will be a particular focus on the relationship between anxiety and driving, and what research has done to investigate this. Some of the practical and theoretical reasoning behind some potentially mixed conclusions on the topic will be discussed. This will lead on to the research questions that are posed within this thesis, along with a summary of the thesis's structure.

## 1.3 Emotions and Anxiety

One internal factor that could have a potentially negative effect on driving behaviour is emotion. Emotion is defined as a conscious mental state that is separate from cognitive states in the sense that the individual can experience a strong positive or negative feeling. There has been debate in the literature as to whether emotions operate separately from cognition. However, one of the more generally accepted theories of emotion is that the cognitive appraisal of events or situations can determine the subsequent emotions felt. Appraisals can be formed at a primary level, which evaluates the valence of an environmental situation, or at a secondary level, where the individual takes into account whether they have sufficient resources to cope with the given situation (Lazarus, 1982). This appraisal theory was later developed to identify specific components for each stage of appraisal. At the primary level, the motivational relevance and congruence of the situation can be assessed, whilst at the secondary level, the degree of accountability and ability to use problem or emotionally focused coping can be assessed (Smith & Lazarus, 1993). Specifically, it is argued that negative emotions such as stress occur when the demands of the environment or a given task exceed an individual's perceived ability to cope (Lazarus & Folkman, 1984). This negative cognitive evaluation results in a stress response, commonly characterised by a negative emotional reaction, and changes in behaviour and physiological arousal.

Anxiety itself can be considered a stress response, since it is an emotive reaction to a negative situation. The literature defines anxiety as a feeling of tension or unease at the prospect of a threatening, but not guaranteed, event (Rachmann, 2013). According to appraisal theories, whilst negative emotions share a common component of motivational incongruence, anxiety differs from other negative emotions in that it is related to a lower evaluation of emotion-focused coping potential. However, not only can anxiety be a state of unease, it can also take

the form of a more dispositional characteristic, also known as trait anxiety. Moreover, many patient groups with an anxiety-specific condition are frequently researched; these groups include those with generalised anxiety disorder, panic disorder, post-traumatic stress disorder, and phobic patients.

When investigating the consequences of either state or trait anxiety, research often collects measures of behavioural and physiological activity simultaneously to draw its conclusions. Commonly used behavioural measures include accuracy and reaction times, and often measures of heart rate and skin conductance are reported as physiological measures. The physiology literature has argued that the amygdala plays an important part in the role of anxiety, and electrical stimulation of this area can result in projection of nuclei from the amygdala's central nucleus to other areas of the brain, which mediate the behavioural and physiological symptoms associated with anxiety. For example, nuclei are projected to the lateral hypothalamus, which in turn results in increased skin conductance, increased pupil diameter, blood pressure elevation and increased heart rate (Lang, Davis, & Ohman, 2000). Research generally supports the notion that anxiety is associated with increased heart rate and skin conductance. Various studies agree that heart rate is associated with an increased risk of cardiovascular disease (Kawachi et al., 1994; Kubzansky et al., 1997), and a recent meta-analysis confirms that this finding seems to be consistent across non-patient populations (Suls & Bunde, 2005). Likewise, skin conductance has been shown to increase when participants are anxious, and this has mainly been demonstrated in the fear conditioning literature; when an anxious participant is shown a negatively valenced or fear inducing image, it can result in increases in skin conductance, even when images have subliminally been shown or images have been incorrectly identified as positive (Globisch, Hamm, Esteves, & Ohman, 1999; Ohman & Soares, 1994).

Another characteristic that distinguishes anxiety from other negatively valenced emotions is an attentional bias towards threat. Looking at the previously reported findings on skin conductance, quick responses in the absence of awareness or accuracy could indicate a quick preference towards threat. The attention literature supports this idea. It argues that whilst negative disorders such as anxiety and depression can be characterised by persistent negative cognitions, those who are anxious are also able to preferentially and quickly attend to sources of threat (Mathews & MacLeod, 2005). This is evident in research investigating attentional allocation to facial stimuli; anxious participants often have faster reaction times to, and are more quick to look at, negative stimuli (Bradley, Mogg, Falla, & Hamilton, 1998; Bradley, Mogg, & Millar, 2000), particularly when facial expressions are seen as threatening (Mogg, Millar, & Bradley, 2000) or angry (Mogg, Philippot, & Bradley, 2004). Moreover, those with higher levels of trait anxiety have also shown an inability to disengage away from threatening stimuli (Sheppes, Luria, Fukuda, & Gross, 2013). However, this may be dependent on the type of anxiety in question. For example, in social anxiety, participants have demonstrated an increase in heart rate as a result of processing faces, without it necessarily leading to changes in gaze behaviour (Wieser, Pauli, Alpers, & Muhlberger, 2009).

However, whilst these effects are said to be characteristic of anxiety, there is some debate as to whether they are specific to anxiety or general levels of threat. For example, research into skin conductance responses has found subliminal effects for negative images, regardless of individual anxiety levels (Reagh & Knight, 2013). Additional research into viewing film stimuli has found increases in heart rate and skin conductance, with no effect of anxiety levels (Hubert & Dejongmeyer, 1990). Thus, it is argued that reactions that could be

attributed to anxiety are simply reactions to negative stimuli or the consequence of general negative emotion (Fuller, 2005).

To summarise, anxiety is characterised by a state of increased worry and negative cognitive ruminations. Behavioural and physiological indicators of anxiety include increases in heart rate and skin conductance, as well as quick threat detection and possible inability to disengage from threat. However, it is also important to note that some of these responses have also been linked to general negative emotion, and whilst findings seem to be consistent across different types of anxiety, it is important to differentiate between state and trait when making inferences about reactions to stimuli.

## 1.4 The effects of Negative Emotions on Driving Behaviour

Whilst it may seem less obvious, negative emotion has consistently been demonstrated as a risk factor in the likelihood of dangerous driving behaviours and accident involvement. The literature suggests that all negative emotions, including anger, discontent and jealousy, are likely to have a deleterious effect on driving (Dula & Geller, 2003), and the 2013 Road Casualties report provided by the UK's Department for Transport revealed that 5630 of all accidents in that year were associated with a previous experience of negative emotions whilst driving (Department for Transport, 2014). Inductions of negative mood whilst completing driving tasks have reported physiological changes such as increased blood pressure and heart rate, (Fairclough, van der Zwaag, Spiridon, & Westerink, 2014), and behavioural changes such as higher perceptions of risk (Hu, Xie, & Li, 2013) and poorer steering performance (Trick, Brandigampola, & Enns, 2012).

The two most commonly reported negative emotions experienced and reported whilst driving are anger and anxiety. However, the more frequently researched topic is the relationship between anger, aggression and driving. Of the 5630 accidents reported in the UK in 2013 due to experience of negative emotions, 3730 of these were due to anger and aggressive reactions, suggesting that becoming angry behind the wheel increases the likelihood of this occurring. Though it is acknowledged that driving anger may not necessarily lead to aggressive behaviours (Dula & Geller, 2003), a significant positive correlation has been reported between driving anger and the likelihood and severity of aggressive driving behaviours (Deffenbacher, Huff, Lynch, Oetting, & Salvatore, 2000; Lajunen & Parker, 2001). Such behaviours can include acts of physical violence, verbal aggression, use of swearing whilst driving and changes in driving behaviour. Questionnaire data suggests that situations that can provoke anger include those that impede progress, and driving behaviour from others that can be seen as risky, hostile or discourteous (Sullman, 2006). Such acts from other drivers include weaving between lanes, slow driving, speeding and tailgating (Wickens, Roseborough, Hall, & Wiesenthal, 2013).

Whilst it has been demonstrated that young drivers show more aggressive behaviours (Przepiorka, Blachnio, & Wiesenthal, 2014), there are less clear findings regarding the relationship between gender, anger and driving. Many studies report no greater likelihood of aggression according to gender (Deffenbacher et al., 2000); instead, it is suggested that gender differences are highly dependent on context. For example, males are more likely to use physical anger to express driving aggression (Gonzalez-Iglesias, Antonio Gomez-Fraguela, & Angeles Luengo-Martin, 2012), whilst females are more likely to show anger in response to traffic obstructions and the observation of illegal behaviours committed by other drivers (Lonczak, Neighbors, & Donovan, 2007).

It has also been suggested that those who report higher levels of driving anger also report more risky and less safe driving behaviour (Deffenbacher, Lynch, Filetti, Dahlen, & Oetting, 2003), as well as a greater number of traffic violations and fines (Gonzalez-Iglesias et al., 2012). These suggestions are supported by the driving behaviours observed during simulator studies. In simulation research, anger is either often induced offline by asking a driver to recall a recent anger-provoking memory, or by including a series of obstructions or delays in a driving scenario in order to induce anger whilst the task is taking place. Regardless of method, simulator research has found negative effects on behaviour, such as increased risk of crossing at yellow lights (Abdu, Shinar, & Meiran, 2012), an increased number of errors in lane-keeping and abidance to traffic rules (Jeon, Walker, & Yim, 2014), and a smaller amount of time spent looking at hazards such as pedestrians and emerging cars (Stephens, Trawley, Madigan, & Groeger, 2013). Physiological reactions to experimentally-induced anger whilst driving include increased heart rate, increased corrugator muscle activity, and lower levels of activity within the frontal lobes (Fairclough & Spiridon, 2012). However, simulator research has also highlighted that it is likely that driving anger is likely to be a state-based effect rather than influenced by trait. Research has shown that whilst higher levels of trait anger can result in higher reports of anger and frustration in simulator tasks, it is only higher levels of state anger that result in behavioural changes during the same drive (Stephens & Groeger, 2009).

To summarise, the study of negative emotions suggests that they do have some influence on driving behaviour and physiological reactivity, to the degree that there is an increased risk of accident involvement. The most frequently researched emotion in relation to driving is anger. Findings suggest that those higher in driving anger are more likely to show risky driving

behaviours and commit more traffic violations. Simulator research supports this, and adds to the questionnaire literature by suggesting changes in attentional patterns and physiological reactivity in response to anger. However, it is clear that state anger rather than trait anger may have more of an influence on behaviours on the road.

## 1.5 Studies on the Relationship between Anxiety and Driving

As described in the previous section, anxiety is also one of the most frequently reported emotions during on-road driving (Mesken, Hagenzieker, Rothengatter, & de Waard, 2007). The 2013 Department for Transport statistics show that 1900 accidents were caused by drivers who felt nervous, uncertain or panicked (Department for Transport, 2014), suggesting that anxiety can lead to behavioural changes that increase the risk of an accident. Additionally, the literature suggests that up to 8% of some samples report moderate to extreme driving anxiety (Taylor & Paki, 2008), and as a consequence a small subset of these drivers will avoid using cars or will change their daily activities in order to overcome such anxiety (Taylor, Alpass, Stephens, & Towers, 2011). This highlights the fact that anxiety whilst driving may not only increase the risk of an accident, but it may also result in maladaptive avoidance behaviours in everyday life. Therefore it is important for research to measure the extent to which anxiety may affect driving, both in a behavioural and physiological perspective.

Whilst some of the research investigates groups with anxiety disorders, such as those with clinically diagnosed driving phobia (Alpers, Wilhelm, & Roth, 2005) or those with post-traumatic stress disorder due to motor vehicle accidents (Baker, Litwack, Clapp, Beck, & Sloan, 2014), this thesis focuses on levels of anxiety within the general population.

Research looking into the relationship between anxiety and driving often takes one of three approaches: it either measures the behaviours of those who self-report anxiety about driving prior to taking part in a study, it measures changing levels of state anxiety during a driving task, or it will look at the effects of trait anxiety on driving. All of these approaches seem to broadly suggest that increased levels of anxiety may be less beneficial to driving. Those who self-report anxiety about driving tend to have what is called an anxious driving style; this is defined as a style that reflects tendencies to feel distress when driving, express anxiety when driving, and express a lack of confidence regarding driving skills (Taubman-Ben-Ari, Mikulincer, & Gillath, 2004). Those who report this style of driving are also said to have low levels of sensation-seeking, which would suggest a lower risk of accident involvement due to avoidance of high-risk situations (Ulleberg, 2001). However, whilst subsequent studies have also used cluster analyses to find similar driver subtypes, they have also suggested that such drivers are more prone to lapses of attention and memory (Lucidi et al., 2010) and are more likely to crash their vehicle during a simulated driving task (Marengo, Settanni, & Vidotto, 2012). Moreover, an avoidance of situations may not be an adaptive strategy for anxious drivers. Many who report anxiety related to driving also report a greater rate of avoidance and self-regulation of driving (Gwyther & Holland, 2014), which have both been argued as strategies that could be detrimental to an individual's health and well-being (Gwyther & Holland, 2012). Whilst simulator and on-road research into anxious drivers is limited, some of the behavioural and physiological effects that have been found include a greater number of on-road errors (Taylor, Deane, & Podd, 2007b), and increases in heart rate, skin conductance and acoustic startle response (Muhlberger, Bulthoff, Wiedemann, & Pauli, 2007).

Studies looking at state anxiety in relation to driving often try to induce anxiety prior to completing a task, or by asking for anxiety levels whilst completing a task, and comparing these levels to various outcome measures. Findings from these studies are reflective of some of the characteristics of anxious driving styles. For example, one study found that higher levels of anxiety result in higher levels of perceived risk in traffic situations (Lu, Xie, & Zhang, 2013), which has previously been reported as a characteristic of anxious drivers (Lucidi et al., 2010). Simulator studies have found additional effects of state anxiety on driving. These include behavioural effects such as increased brake times at pedestrian crossings (Morton & White, 2013) and greater levels of velocity and speeding (Roidl, Frehse, & Hoeger, 2014), and attentional effects such as increases in pupil diameter and a smaller spread of search in the horizontal field (Wilson, Smith, Chattington, Ford, & Marple-Horvat, 2006). Physiological effects have also been found in on-road studies. Reports of anxiety whilst driving on real roads have been associated with increases in heart rate as well as increases in risk perception (Mesken et al., 2007). This has also been found in studies looking at anxiety in the British Driving Test; in this particular study, heart rate did increase, but only for those who failed their driving test (Fairclough, Tattersall, & Houston, 2006). Those that failed their test had a significantly greater number of major errors in the test compared to those who passed, but not a greater number of minor errors. This indicates that anxiety-induced levels of sympathetic activation, as shown by increased heart rate, may be indicative of more dangerous driving behaviours on the road.

Whilst the body of literature on trait anxiety and driving is small, it does suggest overall that an anxious personality can also make a driver more dangerous. The majority of studies have used questionnaire methods to come to these conclusions, by investigating the relationship between levels of trait anxiety and the rate of self-reported driving errors and violations. It

has been suggested that higher levels of trait anxiety are associated with a greater number of driving mistakes (Panayiotou, 2015), but not necessarily higher levels of accident involvement (Oltedal & Rundmo, 2006). Questionnaire research has also suggested that those higher in trait anxiety are more likely to commit aggressive and ordinary violations, as well as errors and lapses, whilst driving (Pourabdian & Azmoon, 2013; Shahar, 2009). Dula and colleagues (Dula, Adams, Miesner, & Leonard, 2010) found that higher trait anxiety was specifically linked to a greater frequency of dangerous behaviours such as intoxicated driving, passing stop signs, tailgating other cars and being at-fault in accidents.

This suggests that individuals may not necessarily need to be anxious drivers in order to be more at risk on the roads; they may simply only need to have an anxious personality. However, as already noted the literature on the relationship between trait anxiety and driving is small, and self-report measures may not necessarily reflect real-world driving behaviours. Moreover, within the questionnaire studies there are conflicting opinions as to whether trait anxiety does make someone more likely to commit risky driving behaviours (Scott-Parker, Watson, King, & Hyde, 2012) or not (Oltedal & Rundmo, 2006). With these factors in mind it is important that researchers not only further investigate the influence of trait anxiety, but it also uses alternative methods such as simulation research to do so. Some have already attempted to do this, finding that whilst those higher in trait anxiety are more likely to comply with speed limits (Stephens & Groeger, 2009), they also show higher variations in steering wheel and accelerator movement, as well as an increase in search rates and pupil dilation (Wilson et al., 2006).

In summary, there is a small yet growing amount of literature on anxiety within driving, and it can broadly be placed into three categories: studies attempting to profile anxious drivers,

and studies looking at the effects of state and trait anxiety respectively. Overall, it seems that anxiety can lead to potentially dangerous behaviours such as an increased number of on-road errors, as well as increases in sympathetic activity, an increase in effort to complete tasks (as indicated by pupil diameter increases), and less efficient search strategies (as indicated by increases in search rate). However, it should be acknowledged that there needs to be an increased shift to more objective methods of studying anxiety and driving, such as simulator and on-road studies, as opposed to primarily questionnaire-based methods. This is particularly true for the effects of trait anxiety, where the small amount of research conducted is currently conflicted on its influence on risky driving behaviour.

## 1.6 Methods used to Study Driving Psychology

There are a wide range of measurements that can be taken from drivers, in order to assess their behaviours and reactions to everyday driving situations. This section aims to discuss three of those that are common to the majority of studies within the thesis: questionnaires, eye movements and physiological measures. Their general use will be discussed, along with their strengths and weaknesses and their applicability to the field of driving psychology.

### 1.6.1 Questionnaires

Questionnaires typically comprise of a set of questions that a participant is required to complete. They are commonly used within psychology, and allow researchers to obtain subjective information about certain attitudes, emotions or dispositions. Particularly within emotion and driving research, questions are often administered on a Likert scale (Likert, 1932). Questions administered on a Likert scale consist of a series of statements that the participant must answer on a scale of fixed responses. These statements, or items, are often

representative of one construct, or one subscale of the given construct, and the scores of these items are often summed to provide an overall score. This overall score can then inform us to what degree a participant falls on one end or another of a given dimension.

When constructing a questionnaire, it is important that it is high in reliability and validity. Reliability refers to the degree to which questionnaire responses are stable; this can be either across time, making it externally reliable, or across items, making it internally reliable. Reliability can be assessed by either having a set of participants complete the same questionnaire at two different time points, or by measuring the degree of internal reliability using statistical values such as Cronbach's α. Validity refers to the degree to which a questionnaire is measuring what it intends to measure. This can be assessed in several ways, for example by asking other researchers to validate that a questionnaire reflects its proposed construct (thus providing face validity), comparing scores to already established questionnaires in order to establish criterion validity, or by conducting factor analyses to support the idea that already proposed constructs are stable across studies. It is also important that it is standardised in order for others to compare their obtained scores to a set of provided norms. This is particularly important within the context of emotion and personality questionnaires, as these can be used for clinical diagnoses as well as research (Coolican, 2014).

There are a wide range of reasons that using questionnaires can be beneficial to research. They allow subjective insight into different constructs, a large amount of responses are often provided, and the administration of them can be relatively inexpensive (Christensen, Johnson, & Turner, 2015). However, there are several issues to consider when administering questionnaires, particularly in relation to the responses received. Firstly, it is sometimes

possible that response rates can be low, or participants may only be responding if they are interested in the questionnaire's topic. It is often desirable for research to have a response rate of at least 50%, although response rates of at least 2% have also been reported (McBurney & White, 2010). Of those that do respond, one concerning issue is that participants may either respond in such a way that suggests they have tried to reinterpret the purpose of the questionnaire, or they may respond in a way that deems them to be favourable to the researcher. Regardless of whether demand characteristics or social desirability may influence responses, it suggests that they may not be a true reflection of the participant's subjective judgements. However, recent research comparing responses to driving questionnaires in public and private settings has suggested that social desirability may not have an effect on such responses (Sullman & Taylor, 2010).

A wide range of questionnaires are used within driving research, to assess both the emotions and personalities of participants, and to measure the frequency of various driving behaviours. In both contexts, the range of questionnaires is extremely broad, therefore the focus of the next section is to discuss the anxiety questionnaires most frequently used within the studies conducted in this Thesis. A discussion of driving questionnaires is provided in greater detail in Chapter Two, which uses a variety of questionnaires in an online survey.

#### 1.6.1.1 Anxiety Questionnaires

One of the most commonly used anxiety questionnaires within research and clinical practice is the State-Trait Anxiety Inventory (STAI- Spielberger, 1983). The STAI consists of 40 items, 20 each regarding state (STAI-Y1) and trait (STAI-Y2) respectively. Each item is rated on a 4-point Likert scale ranging from 1 to 4. In both cases, 1 refers to 'Not at all' and a

score of 4 indicates an item 'Always'. Scores may range from 20 to 80, with a higher score indicating a greater presence of anxiety. According to Spielberger (1983), items on each scale are phrased according to whether they describe the presence or absence of anxiety. For example, an anxiety-present item may ask whether someone feels 'nervous and restless', and an anxiety-absent item may ask whether someone feels 'cool, calm and collected'. Scores on anxiety-absent items are reversed prior to totalling each scale. Standardised state and trait scores for college students and working adults are provided in Table 1.1.

**Table 1.1: Standardised norms for Spielberger's State-Trait Anxiety Inventory-Y (1983) for college students and working adults.**

| | | College Students | | Working Adults | |
|---|---|---|---|---|---|
| | | Male (*n*=324) | Female (*n*=531) | Male (*n*=1387) | Female (*n*=451) |
| State Anxiety | *m* | 36.47 | 38.76 | 35.72 | 35.2 |
| | *sd* | 10.02 | 11.95 | 10.4 | 10.61 |
| | Cronbach's α | .91 | .93 | .93 | .93 |
| Trait Anxiety | *m* | 38.3 | 40.4 | 34.89 | 34.79 |
| | *sd* | 9.18 | 10.15 | 9.19 | 9.22 |
| | Cronbach's α | .9 | .91 | .91 | .91 |

The STAI is one of the most widely used anxiety questionnaires in psychology, and since its development it has been translated into over 60 languages (Spielberger & Reheiser, 2009), and it has been adapted into a shorter, six-item form to enable faster test administration (Marteau & Bekker, 1992). It also consistently shows high levels of internal consistency; studies consistently produce a Cronbach's α greater than .8 (Andrade, Gorenstein, Vieira, Tung, & Artes, 2001) or .9 (Bados, Gomez-Benito, & Balaguer, 2010), and a recent meta-analysis across over 800 studies confirmed an average α of over .8 for both state and trait anxiety scores (Barnes, Harp, & Jung, 2002). Test-retest correlations are often high for trait

anxiety, but less so for state anxiety; however, this simply reflects the fluctuating nature of state anxiety (Rossi & Pourtois, 2012). However, the STAI has often been criticised for low levels of validity. It has been suggested in previous research that not only do factor analytic procedures fail to find the anxiety present and absent subscales originally proposed (Elwood, Wolitzky-Taylor, & Olatunji, 2012), they also tend to find more than one factor outlining negative affect (Kaupuzs, Vazne, & Usca, 2015). Often, a factor outlining general negative affect is suggested, along with additional factors outlining depression and anxiety respectively (Andrade et al., 2001; Bados et al., 2010). This has led some researchers to claim that the STAI may not necessarily be assessing 'pure' anxiety (Bieling, Antony, & Swinson, 1998).

Recent anxiety questionnaires have been constructed in order to provide an assessment more closely related to anxiety. One of these is State-Trait Inventory for Cognitive and Somatic Anxiety (STICSA- Ree, French, MacLeod, & Locke, 2008) (See Appendix 'A'). The STICSA is a 42-item questionnaire, 21 of each measuring state and trait anxiety. These items are distinguished according to whether they are measuring cognitive (10 items) or somatic symptoms of anxiety (11 items). Cognitive items may ask whether an individual 'cannot concentrate without irrelevant thoughts occurring', whilst somatic items may ask whether an individual's 'heart beats fast'. As with the STAI, each item is administered on a 1 to 4 Likert scale, with a score of 1 meaning 'Not at all' and 4 meaning 'Very much'. Total scores for state and trait range from 21 to 84, cognitive scores range from 10 to 40, and somatic scores range from 11 to 44. In all cases, a higher score indicates a greater presence of anxiety. Unlike the STAI, no items are reversed on this scale.

When initially constructed, the STICSA demonstrated good evidence of reliability and validity; good internal reliability was demonstrated with a Cronabch's α of .9 across all factors, and strong correlations with the STAI and weak correlations with depression inventories provided evidence of convergent and discriminant validity respectively. Furthermore, predictive validity was established when cognitive and somatic stressor tests resulted in successful increases in cognitive and somatic anxiety (Ree et al., 2008). Further research comparing the STICSA to the STAI also demonstrated that the STICSA was more strongly correlated with symptoms of anxiety, whilst the STAI was correlated with depression measures (Gros, Antony, Simms, & McCabe, 2007). Recent research has also confirmed its high internal consistency with αs higher than .9 (Balsamo, Innamorati, Van Dam, Carlucci, & Saggino, 2015; Gros, Simms, & Antony, 2010). However, despite stronger correlations with anxiety than the STAI, some components of the STICSA have still been found to correlate with depression measures (Lancaster, Melka, Klein, & Rodriguez, 2015). This is particularly true for cognitive anxiety subscales (Roberts, Hart, & Eastwood, 2016). It is possible that despite attempts to create purer measures of anxiety, components of the STAI and the STICSA may be associated with depression due to a general negative affect component that is common to both anxiety and depression, which is outlined in the tripartite model (Clark & Watson, 1991).

#### 1.6.1.2 Summary

In summary, questionnaire data is extremely useful, as it can provide rich, subjective data on an individual's thoughts, attitudes and behaviours. When conducting research using questionnaires, it is important to establish levels of reliability, and when evaluating the psychometric properties of a scale, it is important to assess levels of convergent and

discriminant validity. This practice is evident in research that evaluates the psychometric properties of widely used anxiety questionnaires.

### 1.6.2 Eye movements and Eye Tracking

Whilst questionnaire methods allow us insight into an individual's perceptions of a given subject, such as driving, it has been made clear from the previous section that they may not necessarily reflect real-world behaviours. At the same time, behavioural measures such as reaction times, accuracy measures, and longitudinal and latitudinal measures of acceleration do not provide information on the processing that may influence such behaviours. However, there is general consensus in the literature that suggests a close relationship between locations of glances and the information to which an individual attends to (Taylor et al., 2013). Therefore oculomotor data, which can provide information from eye movements, allows us to understand the attentional priorities of a person at any given time. In particular, within the field of driving it has been suggested that perceptual factors may be the cause of the majority of crashes (Shinar, 2008). This makes the study of eye movements important within the field, as identifying inappropriate fixation patterns could lead to an understanding of the perceptual causes of crashes and dangerous behaviours.

#### 1.6.2.1 Types of Eye Movements

There are four basic types of eye movements, yet the one that is considered most important when understanding the nature of cognitive processing is the saccade. Saccades are rapid eye movements that change the location of the eyes from one place to another. After the onset of a stimulus that needs to be fixated upon, it takes around 200 milliseconds for a saccade to

begin (this is also known as saccade latency). During this latency, a comparison is made between the initial location of the fovea and the next intended location of the fovea; the difference between the two, or the "motor error" is then converted into a motor command that moves the fovea from one location to another (Purves et al., 2001). However, whilst the choice to make a saccade can be considered voluntary, the movement itself is considered to be ballistic, as the oculomotor system cannot respond to changes in the environment during a saccade. A second saccade must be made in order to respond to this. Vestibulo-ocular movements can also considered to be automatic, but this is due to the need to stabilise an image onto the fovea when the head and body move. When driving, we constantly make saccades between the outside environment and instrument clusters; the spread of these saccades can provide us with vital information regarding visual allocation, or the variation of visual attention, in certain situations.

The other two basic eye movements, pursuit and vergeance movements (which align the two foveas in order to focus on a near or far object) are considered to be more conscious movements. Pursuits, particularly smooth pursuits, are a type of movement of interest, as they require the individual to continuously track a moving target. Pursuits correspond to the desire for an individual to continuously keep gaze on a target (Duchowski, 2007); however, whilst they are a useful method of tracking gaze, they have been not generally been dissociated from fixations within the field of driving.

In-between two saccades, the eyes can stop and look at a given stimulus; these 'stops' between saccades are better known as fixations. Typically, these fixations last for around 200-600 milliseconds, although this can depend on luminance, cognitive load and the complexity of the environment (Kapitaniak, Walczak, Kosobudzki, Jozwiak, & Bortkiewicz,

2015). This makes the analysis of fixation durations particularly important within the field of driving, where fixation duration of the visual scene could indicate the intake of environmental information. As will be seen in the following sections, cognitive load and environmental complexity in particular have been shown to have an effect on fixation durations.

In summary, the three main types of eye movements that are measured in order to gain insight into the nature of visual attention are saccades, fixations and smooth pursuits. However, the latter has not generally been dissociated from fixations in driving research; thus the remainder of the review into eye movements focuses particularly on saccades and fixations. Whilst the spread of saccades can tell us about the nature of changing focus of attention between fixation locations, fixation durations can tell us about the need to process information regarding an object of interest within the visual field. Both of these are considered within great detail in the driving literature and will be discussed in more detail in the following sections.

#### 1.6.2.2 Methods of Tracking Eye Movements

Eye trackers are used to measure the nature of eye movements; the most widely used method of tracking the eyes is the video-based corneal reflection eye tracker. Other methods of eye tracking include the electrooculographic technique, which measures bioelectric potential differences between corneal and retinal eye movements using electrodes placed around the eyes, and the galvanometric method, which measures changes in the electromagnetic field by using contact lenses applied to the cornea (Kapitaniak et al., 2015). However, these are considered to be invasive and are not often applied to the field of driving. Therefore the method of corneal-reflection eye tracking will be discussed here.

The corneal reflection method of eye tracking is based on the reflective properties of the cornea. Typically using HD cameras and an infrared source in its centre, infrared reflections from the cornea are compared to images of the pupil. These corneal reflections are also known as Purkinje reflections (Crane, 1994); the construction of the eye means that four Purkinje images are typically formed, however infrared-based eye trackers only typically require the first of these for detection and tracking, which reflects from the external surface of the cornea and is the brightest and easiest reflection to detect (Morimoto & Mimica, 2005). Due to the static nature of the cornea, and the dynamic movements of the pupil, a differentiation between head and eye movements can be made, and a measurement of the orientation of the eye in the visual field can be determined. Corneal reflective eye tracking can be achieved using either head-mounted devices, or devices that record the light source within the target field, and create a corneal reflex 'point of regard' (Young & Sheena, 1975). Typically within driving research, both of these types of tracker are used to collect basic measurements of eye movement variability within a scene, or the duration of fixations in different driving conditions (Taylor et al., 2013).

#### 1.6.2.3 What Eye Movements can tell us about Visual Attention in Driving

Visual errors are responsible for a significant amount of crashes on the road, and even relatively brief glances away from the road can increase reaction times to safety-relevant behaviours such as braking (Zhang, Smith, & Witt, 2006). Section 1.6.2.1 highlights the fact that saccades and fixations are the primary measures of interest in eye movement data, whilst Section 1.6.2.2 makes it clear that head or vehicle mounted corneal reflective trackers are the most commonly used methods of eye movement data collection. This section will briefly

describe the emergence of eye movement research in driving, before describing some of the main areas of driving research that take measures of saccades and fixations.

The literature suggests that the first eye tracking systems that monitored and recorded eye movements were developed as early as the late 1960s (Kapitaniak et al., 2015; Shinar, 2008). However, the first major studies investigating the topic were from Mourant & Rockwell in the 1970s. In an initial study, they investigated the role of road familiarity and types of driving. When participants were asked to drive as they normally would, the majority of fixations were initially concentrated on road signs, but as road familiarity increased, fixations moved from here, towards the centre of the driving lane (Mourant & Rockwell, 1970). This was one of the first studies to show that in naturalistic driving, drivers use this visual information to maintain control of lane-keeping; this suggestion has been supported within subsequent research (Land & Horwood, 1995).

In a following study, Mourant and Rockwell compared the eye movements of drivers with varying levels of experience (Mourant & Rockwell, 1972). They found that those who were less experienced with driving had a narrower spread of fixations over the visual scene and a large proportion of these fixations were primarily on the road directly in front of the car. Since then, research has consistently demonstrated that whilst the most valuable information on potential dangers lies within the horizontal axis of vision, novices only narrowly scan this axis, and prioritise their spread of search within their vertical axis. Whilst this may help maintain lane control, this means that novices are less able to scan on-road dangers such as hazards (Pradhan et al., 2005). For example, in a study comparing the eye movements of police drivers, matched controls and novices, the findings suggested that police drivers have the highest levels of horizontal spread of search and a reduced mean fixation duration, whilst

novices showed the highest levels of vertical spread of search (Crundall, Chapman, Phelps, & Underwood, 2003). The authors argued that reduced fixation duration reflected the reduced processing time required for police drivers to process information. Along with greater levels of horizontal scanning, this results in a more optimal search strategy compared to novices. As a result of such research, attempts have been made to train novice drivers, within PC-based training programs, to increase their levels of horizontal scanning, with mixed results. Whilst some studies have suggested they are effective in orienting fixations towards areas where safety-relevant information is present (Pradhan, Pollatsek, Knodler, & Fisher, 2009), others have found that such training can increase horizontal spread of search, but only on a short-term basis (Chapman, Underwood, & Roberts, 2002).

More recent research has provided evidence for different search strategies according to experience; in a simulator study, driving instructors showed signs of shorter mean fixation durations and larger levels of spread of search compared to learner drivers (Konstantopoulos, Chapman, & Crundall, 2010). However, when decreasing levels of visibility by introducing weather conditions such as rain and fog, fixation durations increased for all drivers, indicating an increased processing time of the environment regardless of experience. This study is part of the large body of research that has used eye movement data to make inferences on the effects of cognitive and perceptual load on driving. The increasing availability of technologies such as mobile phones and in-car navigation systems have been suggested as causes of increased distraction and workload during driving, which could subsequently have negative effects on attentional deployment and accident rates. For example, increasing cognitive workload by giving a participant a riddle prior to viewing a hazard perception clip can result in a reduction in horizontal spread of search and slower response times to hazards (Savage, Potter, & Tatler, 2013). Performing an additional

cognitive task whilst driving has consistently found a reduction in spread of search and a tendency to gaze towards more central fixations (Harbluk, Noy, Trbovich, & Eizenman, 2007), indicating that extra demand can result in disadvantageous eye movements similar to those of novices. As well as this, studies into cognitive demand have demonstrated its effects on other types of eye movement data; for example an increase in cognitive demand can lead to increases in pupil diameter whilst driving (Niezgoda, Tarnowski, Kruszewski, & Kaminski, 2015). However, it is important to differentiate between cognitive and perceptual levels of demand. Cognitive load refers to increases in effort to perform a task due to competing demands for central resources, whereas increases in demand due to perceptual demand are due to increased information within the visual environment. Whilst perceptual demand increases result in changes such as increased blink rate (Richter, Wagner, Heger, & Weise, 1998) and diminished performance in peripheral detection tasks (Jahn, Oehme, Krems, & Gelau, 2005), it is only cognitive load that results in reduced scanning (Engstrom, Johansson, & Ostlund, 2005). Perhaps this is why no differences in spread of search were found in Konstantopoulos et al.'s (2010) study.

One study into cognitive load on driver performance found that when interacting with in-vehicle information systems, drivers were slower to react to a peripheral hazard even if they had initially fixed on it (Reyes & Lee, 2008). This consolidation failure was argued to be dependent on direct competition for processing resources. In turn, this suggestion highlights one of the main limitations of eye movement research. Whilst eye movement data such as fixations and saccades can tell us where a driver looks and the nature of their scanning patterns, it does not necessarily mean that the fixated information has been processed. For example, research conducted by Strayer and colleagues (Strayer, Drews, & Johnston, 2003) asked drivers to recall if they had seen any billboards they may have passed during a

simulated drive. They found that if a secondary task had been performed simultaneously, memory for billboards was worse, even if it had been glanced at during driving. Whilst this suggestion has been useful in looking into phenomena such as 'Look But Fail to See' driving errors (Crundall, Crundall, Clarke, & Shahar, 2012; White & Caird, 2010) , it is clear that eye movement data, whilst it useful in studying attentional allocation, cannot on its own tell us about the nature of attentional allocation in driving. It is a useful measure to be analysed alongside other variables such as skin conductance (Crundall et al., 2003) and hazard perception (Savage et al., 2013).

#### 1.6.2.4 Summary

What Section 1.6.2 has made clear is that eye movements and eye tracking are useful within the context of driving psychology. Saccades and fixations are the two most commonly studied types of eye movement in the field, and either head or vehicle-mounted trackers have been used to capture eye movement data. Since the initial studies on eye movements and driving in the 1970s, research has continually demonstrated how measures such as spread of horizontal and vertical search and fixation durations are indicative of processing and scanning patterns. In particular, studies have consistently demonstrated how limiting factors such as experience and levels of load can have detrimental effects on visual search in driving. However, eye movement data alone does not always indicate that a stimulus within the environment has been processed. With this in mind, eye movements have been measured alongside additional behavioural and physiological variables throughout the studies presented in this thesis.

### 1.6.3 Physiological measures

In the human body, the autonomic nervous system (ANS) is required to consistently maintain homeostasis of internal organs, and usually functions involuntarily. Thus, it continuously regulates areas such as the eyes, heart and muscles within the skin. The ANS consists of three separate nervous systems: the enteric nervous system, the sympathetic nervous system and the parasympathetic nervous system. The former regulates organs within the gut area, whilst the sympathetic and parasympathetic nervous systems are more important for the regulation of visceral organ activity within different types of situation or stressor.

These two nervous systems serve opposing functions. Sympathetic activity is common when energy needs to be exerted during 'fight-or-flight' situations, whereas parasympathetic activity is more apparent when energy needs to be conserved during rest (Sequeira, Hot, Silvert, & Delplanque, 2009). In both cases preganglionic neurons, located within the brainstem or spinal cord, secrete acetylcholine to peripheral neural centres. Postganglionic neurons then secrete either acetylcholine or norepinephrine to internal organs to promote either parasympathetic or sympathetic activity respectively. The exception to this is skin conductance, where sympathetic increases in skin conductance are said to be cholingerically mediated (Critchley, 2002). Sympathetic preganglionic nerves are located within the thoracic-lumbar regions of the spinal cord (Carpenter, 1915), whilst parasympathetic preganglionic nerves are located within the brainstem and sacral regions of the spinal cord (Sequeira et al., 2009). The classic model of the ANS proposes that a pattern of reciprocal coupling occurs during autonomic activity, in that one nervous system is activated whilst activity from the other is inhibited (Backs, Lenneman, Wetzel, & Green, 2003). However, taking into account the fact that reciprocal activity does not always occur, a multidimensional model of nervous system activity was proposed in the early 1990's (Berntson, Cacioppo, & Quigley, 1991).

This takes into account instances where, for example, increases in heart rate may be due to decreases in parasympathetic activity, without the expected increase in sympathetic activity (Hugdahl, 1996).

Nonetheless, what makes the study of sympathetic and parasympathetic activity particularly interesting is that autonomic responses can be dissociated from behavioural responses; for example, prosopagnosia patients can produce electrodermal responses to familiar faces without being able to behaviourally recognise them (Tranel & Damasio, 1985). This implies that whilst behavioural and self-report measures may be useful in the context of understanding driving behaviour, they may not always correlate with autonomic responses. However, measures such as skin conductance and heart rate, two variables that are commonly observed when studying autonomic activity (Hugdahl, 1996), may help us to understand the arousal and workload levels of a driver in the potential absence of behavioural effects. The next two sections discuss these measures in the context of the methods used, what general research using these measures suggests, and what they can tell us about arousal and workload levels in the context of driving.

### 1.6.4 Electrodermal Activity

#### 1.6.4.1 The Nature of Electrodermal Activity

When sympathetic activity is occurring, postganglionic neurons secrete acetylcholine to eccrine sweat glands, which are primarily found in the palms and soles of the feet (Sequeira et al., 2009). This causes activation of the glands, which affects the amount of sweat secreted in these areas. In turn, this affects the levels of conductance of an applied current, which can be measured at the surface of the skin (Critchley, 2002). This is also known as measuring

levels of electrodermal activity (EDA). EDA can be measured in short-term phasic recordings known as skin conductance responses (SCRs), or in long-term, tonic recordings known as skin conductance levels (SCL). Typically, skin conductance is measured in microSiemens, and one of these is equal to $10^{-6}$ siemens.

Due to the strong influence of sympathetic activity on EDA, measures of skin conductance have often been used to assess levels of autonomic arousal, orientation towards novel stimuli, and emotional reactivity to situations (Boucsein et al., 2012). In particular, levels of skin conductance have been measured within the context of threat (Critchley, 2002), a state which can induce high levels of sympathetic arousal and increase levels of tonic and phasic skin conductance. For example, early work into test anxiety suggested that higher levels of this also induced higher SCLs (Kissel & Littig, 1962). Additionally, SCLs have been shown to drop below baseline levels after anxious situations, supporting the idea that such increases in SCLs are related to the arousal associated with such an event (Croft, Gonsalvez, Gander, Lechem, & Barry, 2004). Inattentional blindness research also suggests that SCRs can indicate preferential processing of threat (Najstrom & Jansson, 2006), and can increase in response to fearful spider images, independent of reported levels of detection (Wiemer, Gerdes, & Pauli, 2013).

Whilst it is possible for skin conductance to be associated with arousal that is not specific to a certain state, and increased skin conductance can be associated with significance that is not specific to levels of arousal (Dindo & Fowles, 2008), neurological evidence supports the idea that skin conductance can elevate with increased levels of threat or fear. Lesions of the amygdala, an area of the brain associated with affective processing, have resulted in concurrent reductions in anxiety, skin conductance and heart rate (Masaoka, Hirasawa,

Yamane, Hori, & Homma, 2003). Furthermore, presentation of fearful faces to participants has shown an increase in amygdala, medial frontal cortex and primary motor cortex activity, which led the authors to suggest a preparatory motor state associated with increased levels of affective arousal (Williams et al., 2001). On this basis, two independent pathways of EDA control have been suggested; one of these is amygdala-based and reflects affective processes, whilst the other is cortical and basal-ganglia based, and is more reflective of general orienting and attention.

#### 1.6.4.2 Methods of Recording Electrodermal Activity

In an update on previous recommendations, Boucsein and colleagues created a recent committee report outlining recommendations for skin conductance measurement and recording (Boucsein et al., 2012). The most common method of skin conductance recording involves applying a small voltage to two electrodes placed on the palmar surface of the skin. Electrodes are applied to the fingertips, as these are the most reliable areas for the recording of EDA responses (Freedman et al., 1994). These electrodes are a silver-silver chloride (Ag/AgCl) metal disc set in a plastic casing, which is filled with an electrode gel and attached to the fingers using tape or a velcro strap to minimise movement artefacts. The electrode gel must contain a chloride salt, which is typically sodium chloride (NaCl), which does not significantly alter the concentration of surface sweat. The electrodes are usually attached to a differential amplifier, which is attached to a computer running data acquisition software that continuously records skin conductance. It is also noted within the guidelines that artefacts can arise due to factors such as loose electrodes, body movements, excessive sweating, speech and irregular breathing. Therefore, close visual inspection of the data is recommended after recording so that such artefacts can be manually removed prior to analysis.

#### 1.6.4.3 Research into Electrodermal Activity and Driving

The general literature on skin conductance research indicates that changes in electrodermal activity are reflective of at least some form of arousal, whether that be from threatening or non-threatening stimuli. Within the field of driving, the idea that skin conductance is reflective of arousal is widely supported. For example, significant increases in skin conductance have been found when listening to music with high levels of arousal, regardless of music valence (van der Zwaag, Fairclough, Spiridon, & Westerink, 2011). Furthermore, changes in skin conductance have been shown to more apparent when changes in stimuli, such as music, are abrupt rather than gradual (van der Zwaag et al., 2013).

More specifically, the idea that skin conductance is reflective of arousal has been supported in driving research looking at autonomic activity within the context of threatening or safety-critical situations. However, this research has made different implications depending on the measure of skin conductance used. For example, in one study, higher SCLs were found in drivers who performed well during a critical situation involving a car pulling into the driver's lane (Collet, Petit, Priez, & Dittmar, 2005). On the other hand, another study looking at simulated driving with a series of hazardous situations found that the frequency of SCRs was higher in hazardous situations that would eventually result in a driver failing a 'test' (Kuebler et al., 2014). Both make interesting implications for arousal whilst driving; whilst the former suggests that higher overall levels of electrodermal activity may be beneficial for resource mobilisation in critical situations, the latter suggests that too many responses in dangerous situations can make a driver unsafe. Whilst both implications are interesting, this highlights the need for careful consideration of electrodermal activity data when making inferences on subsequent driving behaviours.

This is not, however, to say that an increased amount of SCR cannot reflect levels of arousal that may be beneficial to driving contexts. For example, experienced drivers have been found to be twice as likely to produce an SCR in response to a dangerous situation such as a hazard. This is despite the fact that no differences were found in levels of appraisal of hazardous situations (Kinnear, Kelly, Stradling, & Thomson, 2013). Likewise, in Crundall et al.'s (Crundall et al., 2003) study of police drivers in comparison to novices, whilst no differences were found in hazard perception ratings, police drivers produced a greater number of SCRs. Along with the previously described differences in horizontal search, this may be indicative of arousal levels that allow more experienced drivers to allocate attentional resources more efficiently. Thus it could be argued that SCRs could be beneficial to dangerous driving situations, but too many SCRs could lead to more dangerous strategies in hazardous situations, such as those in Kuebler et al's (Kuebler et al., 2014) study.

Measures of electrodermal activity have also been taken in driving conditions where there are increased levels of workload, such as mobile phone conversations (Collet, Clarion, Morel, Chapon, & Petit, 2009). Early research into the relationship between increased workload, electrodermal activity and driving behaviour, in the context of environmental characteristics, suggested that increased skin conductance is due to an increase in mental effort rather than physical effort (Helander, 1978). Since then, research has consistently demonstrated that increases in workload can increase levels of skin conductance. Additionally, this finding seems to be consistent regardless of whether the changes in workload are due to increases in demand from environmental sources such as the rate of road curvature change (Richter et al., 1998), or due to cognitive increases in workload such as the addition of the n-back task whilst driving (Mehler, Reimer, & Coughlin, 2012). Regardless of the type of workload manipulation, it seems to increase levels of sympathetic activity. Furthermore, Mehler et al.'s

(Mehler et al., 2012) study found that whilst increases in workload result in increases in skin conductance, driving behaviours were not significantly affected. This led the authors to conclude that physiological measures may be more useful for observing changes in workload whilst driving; this supports the idea that physiological responses can be found even in the absence of a behavioural response (Tranel & Damasio, 1985).

#### 1.6.4.4 Summary

To summarise, the measurement of electrodermal activity is a useful physiological measure that is reflective of sympathetic activity. Data can be analysed in terms of either SCLs or SCRs, and both are reflective of levels of arousal, orientation towards stimuli or emotional reactivity. Within the field of driving, EDA has been measured particularly within the context of arousal in threatening situations, as well as levels of workload. However, careful consideration must be taken when choosing how to measure EDA, in terms of recording methods and dependent variables of choice. Additionally, whilst EDA is reflective of sympathetic activity, it does not provide information on levels of parasympathetic activity. By taking an additional measure, such as heart rate, it would be easier to assess whether reciprocal coupling of autonomic activity does occur with driving situations, or whether autonomic activity occurs on a more multidimensional level.

### 1.6.5 Heart Rate and Heart Rate Variability

#### 1.6.5.1 Heart Rate and the Cardiac Cycle

One critical function of the heart is to supply blood to the body in a relatively steady manner (Potter & Bolls, 2012). This is achieved by a combination of electrical and mechanical inputs,

which induce a series of contractions and relaxations of the heart muscle. Positively charged ions, which originate in the sinoatrial node, travel towards the atrioventricular nodes. This results in depolarisation of cells in the heart wall, and a contraction of the atria and ventricles of the heart respectively. The subsequent repolarisation of cells in the heart wall then result in the relaxation of the atria and ventricles. The former process is known as the systole phase of the cardiac cycle, and the latter is known as the diastole phase. The rate at which these contractions occur within a given time period is also known as heart rate, and is usually expressed as beats per minute (BPM).

It has been hypothesised from a cognitive perspective that one of the main reasons for a change in heart rate is, like skin conductance, due to an orienting response towards a stimulus. In a series of experiments, Lacey and colleagues found that whilst skin conductance increased in a non-specific manner, heart rate changes were more specific. Deceleration was observed in situations where participants were required to attend to simple stimuli, whilst acceleration was observed in contexts requiring stressful stimulation or cognitively challenging tasks (Carroll & Anastasiades, 1978). This led on to the formulation of the cardiac intake-rejection hypothesis (Lacey, Kagan, Lacey, & Moss, 1963). This hypothesis states that during heart rate deceleration, cortical excitation through a decreased firing of the baroceptors in the carotid artery allows the individual to take in more information from the environment, resulting in an 'orienting' response. On the other hand, an increased firing of carotid artery baroceptors results in cortical inhibition, which results in a 'rejection' of the environment in favour of internal processes, and subsequently heart rate acceleration. Both changes in heart rate are argued to prepare the individual to deal with expected, or potentially aversive, stimuli. For example, when experiencing stress exposure to something such as the

cold pressor test, heart rate may attenuate the impact of the cold pressor by reducing cortical sensitivity, resulting in an observed increase in heart rate (Öhman, Hamm, & Hugdahl, 2000).

Subsequent research has supported the idea that heart rate deceleration is reliably associated with an orienting response (Graham & Clifton, 1966). However, others have noted that the research has found mixed conclusions for the cardiac intake hypothesis. This can be dependent on the experimental paradigm. For example, research into the relationship between verbalisation and heart rate suggests that factors such as imagery, cognitive elaboration and motor actions and preparedness can all influence heart rate in addition to environmental rejection, as originally proposed. In terms of interpretation, it could also be argued that the primary cause of accelerated heart rate in a verbalisation task is cognitive processing, rather than environmental rejection (Carroll & Anastasiades, 1978). In addition to this, internal factors such as increased age, gender and physical fitness can all influence heart rate (Valentini & Parati, 2009). Therefore, whilst there is support for the cardiac intake hypothesis, factors such as experimental paradigm, internal factors and interpretation of key influences mean that care needs to be taken when studying heart rate and interpreting it within the context of orienting and defensive responses.

Whilst it is also acknowledged that heart rate can be influenced by mechanical, hemodynamic, humoral, neural and cortical inputs (Öhman et al., 2000), it is generally agreed that the frequency of heart rate is at least partially influenced by the autonomic nervous system (Kranjec, Begus, Gersak, & Drnovsek, 2014). Unlike skin conductance, which is primarily mediated by sympathetic activity, heart rate can be influenced by both sympathetic and parasympathetic fibers, resulting in an acceleration or deceleration of heart rate respectively (Valentini & Parati, 2009).

#### 1.6.5.2 Heart Rate Variability

As previously mentioned, heart rate is influenced by both sympathetic and parasympathetic activity, with increases of each either accelerating or decelerating heart rate respectively. However, heartbeats are rarely regular, even under resting conditions, and this factor is often overlooked when calculating measures such as mean heart rate. Measures such as heart rate variability (HRV) take into the count the variability of the time in-between heartbeats, and this in turn provides information on the relative contributions of sympathetic and parasympathetic activation to heart rate levels (Potter & Bolls, 2012). Analysis of HRV looks at the time intervals between beats, also known as the inter-beat-intervals; these are defined as the time between QRS-complex spikes in ECG recordings, or the time intervals between peaks in PPG recordings.

The two main ways of calculating HRV are either through time-domain or frequency-domain methods. Time-domain methods simply calculate the variation in inter-beat-intervals. Frequency-domain methods, on the other hand, takes inter-beat-intervals and places them into a Fast Fourier Transformation (FFT). The FFT decomposes a waveform into the amplitudes of the frequency band it makes up, and HRV variability is particularly interested in the strength of low frequency (LF) and high frequency (HF) bands. HF bands (0.15-0.4Hz) are often reflective of vagal activity, whilst LF bands (0.04-0.15Hz) are argued to be a possible combination of both sympathetic and parasympathetic activity. This makes interpretation of the LF/HF ratio slightly more controversial; whilst most argue that an increased LF/HF ratio is a reflection of sympathetic activity, the ambiguity of the function of the LF band means this reflection must be interpreted with caution (Shaffer, McCraty, & Zerr, 2014). Measurements of LF and HF are usually made in either absolute values of power ($ms^2$) or normalized units (n.u.), but it is recommended that both values are reported (Camm et al.,

1996). When the European and North American Task Force provided their initial recommendations regarding HRV recording and analysis, they also provided normal values of LF and HF power, as well as LF/HF ratios; however, these were based on a small sample of studies, and this has recently been updated to include more studies (Nunan, Sandercock, & Brodie, 2010). These values are available in Table 1.2.

**Table 1.2: Reported normal values for LF power, HF power, and the LF:HF ratio (Nunan et al., 2010)**

| | | **Mean(*sd*)** | **Range** |
|---|---|---|---|
| **LF** | $ms^2$ | 519 (291) | 193-1009 |
| | n.u. | 52 (10) | 30-65 |
| **HF** | $ms^2$ | 657 (777) | 82-3630 |
| | n.u. | 40 (10) | 16-60 |
| **LF:HF ratio** | | 2.8 (2.6) | 1.1-11.6 |

Other recommendations provided suggest that recordings of HRV can be between 2 minutes to 24 hours in length, and that data must be acquired at a sampling rate of at least 100Hz (Camm et al., 1996). Whilst HRV is also typically calculated from ECG recordings, and others question the reliability of HRV values derived from PPG recordings due to vulnerability to motion artifacts (Kranjec et al., 2014), recent studies have found a high correlation between values derived from ECG and PPG recordings, suggesting that the use of PPG data is acceptable when calculating HRV (Lu, Yang, Taylor, & Stein, 2009; Selvaraj, Jaryal, Santhosh, Deepak, & Anand, 2008).

Within the context of anxiety, the research suggests overall that higher levels of anxiety result in lower levels of HF power and higher levels of LF power (Friedman, 2007). According to

the Polyvagal Theory of HRV (Porges, 2007), the vagus influences the sinoatrial artery node to increase or decrease the level of engagement in social and emotional behaviours, thus an increase in HF power is indicative of an increased ability to regulate emotions. Neurovisceral models of HRV also suggest that HRV functions at both state and trait levels (Thayer, Ahs, Fredrikson, Sollers, & Wager, 2012; Thayer, Hansen, Saus-Rose, & Johnsen, 2009), indicating that any differences in HRV, particularly in HF power, may be apparent at both state and trait levels of negative emotions such as anxiety. Recent research shows that by inducing a negative state of emotion such as worry (Aldao, Mennin, & McLaughlin, 2013) or threat (Elliot, Payen, Brisswalter, Cury, & Thayer, 2011) can reduce levels of HF power. Research has also suggested that higher levels of trait anxiety can result in lower levels of HF power regardless of threat (Miu, Heilman, & Miclea, 2009). Moreover, lower levels of HF power have been observed in varying types of pathological anxiety, such as general anxiety disorder (Kemp et al., 2014), panic disorder (Pittig, Arch, Lam, & Craske, 2012) or social anxiety disorder (Gaebler, Daniels, Lamke, Fydrich, & Walter, 2013).

It has also been suggested that regulation of HF-HRV can lead to better performance on cognitive tasks; for example, decreases in HF-HRV have been associated with decreases in IQ test performance (Elliot et al., 2011), and those who show high levels of HF power also perform more accurately on tasks, regardless of whether they are under threatening conditions (Hansen, Johnsen, & Thayer, 2009). Neurovisceral models also argue that higher levels of HF power also lead to better performance on tasks that require executive functioning (Thayer et al., 2009). Taken together, this suggests that higher levels of HF power in HRV are associated with higher levels of autonomic and cognitive flexibility in environments with different levels of demand. Those higher in either state or trait anxiety show lower levels of flexibility to cope with environmental demands, hence lower levels of HF power.

#### 1.6.5.3 Methods for recording cardiac measures

One of the most common methods used for recording cardiac activity is by using electrocardiography (ECG). ECG is a method of recording that measures the changes in the cardiac cycle due to electrical activity (Potter & Bolls, 2012). A total of three electrodes are typically placed onto the participant's body; they can be placed in several locations, but their pattern must form an Einthoven's triangle, an equilateral triangle with the heart at its centre. However, ECG is highly sensitive to movement artifacts, and whilst it may be possible to place electrodes on the chest to improve this, this can be seen as invasive to the participant.

A less invasive method of recording heart rate, and the method used to obtain heart data throughout this thesis, is using photoplethysmography (PPG). Whilst ECG records heart rate by measuring electrical changes in cardiac activity, PPG is an optical method of recording that records pulse rate from a peripheral location. Unlike ECG, recordings are usually taken from single PPG locations, such as the finger or the earlobe (Allen, 2007). A PPG sensor consists of a light source emitting red or near infrared light at a wavelength of around 900nm (Elgendi, 2012), and a photodetector that receives the light reflected back. Human tissue is relatively transparent to near infrared (NIR) light, and a series of optical processes, such as scattering and absorption, occur when tissue and light interact (Anderson & Parrish, 1981). The photodetector can measure changes in reflected NIR light that are due to blood volume and blood absorption changes.

During the cardiac cycle, an increase in light absorption, as measured by the PPG signal, is present during the systole phase, and lower levels of light absorption reflect the diastole

phase (Kranjec et al., 2014). Thus, the pulsatile component of the PPG signal is synchronous with heartbeat, meaning that it can be a useful measure of heart rate. Like ECG, the leads from PPG sensors are connected to a bioamplifier, which can then record the pulse signal in a physiological software program and convert the pulse signal into heart rate. When the pulse signal is recorded, the signal's appearance differs to that of the ECG. The two main components of the PPG waveform are the anacrotic phase (the rising edge) and the catacrotic phase (the falling edge) (Allen, 2007), sometimes with the appearance of a dicrotic notch during the catacrotic phase (Elgendi, 2012).

Whilst PPG is a useful tool for measuring heart rate, and a non-invasive alternative to techniques such as ECG, there are several factors that can have an effect on both reproducibility and interpretation. These include movement artifact, posture, breathing patterns, wakefulness and room temperature (Zhang & Zhang, 2006). Thus, like other physiological, careful visual inspection of the data is required prior to analysis in order to identify potential artifacts, and manually remove them when necessary.

#### 1.6.5.4 Research investigating the Relationship between Heart Rate and Driving

Research investigating the relationship between cardiovascular activity and driving has taken place primarily within the context of mental workload. It is argued within the literature that an increase in workload whilst driving leads to an increase in heart rate and a decrease in HRV. This pattern of cardiovascular activity is said to be reflective of a defensive response to increasing demands (Brookhuis & de Waard, 2010). If Lacey's (Lacey et al., 1963) cardiac-intake-rejection hypothesis is taken into account, it could be argued that when the demands of the driving environment or situation are too high for the driver, they will then use internal

resources in order to cope with the increasing demands, thus an increase in heart rate is observed.

This idea could be supported by research into curve navigation that separates perceptual from internal processing demands (Backs et al., 2003). In their study, Backs and colleagues asked drivers to navigate around curves with varying degrees of radii. They found a negative correlation between calculated scores of visual demand, and mean heart rate, in that higher levels of visual demand were associated with a lower heart rate. In this case, when perceptual demands were higher, the driver was required to take in more visual information, thus heart rate decreases. This idea has been supported in previous research, where it has been argued that an increase in curvature change has led to decreases in heart rate, which could also be indicative of the increase in external processing demands (Richter et al., 1998). A decrease in heart rate has also been found due to increases in oncoming traffic (Dijksterhuis, Brookhuis, & De Waard, 2011).

Sometimes, elevations in heart rate have been found in response to typical driving events such as cars pulling out of side roads and traffic lights changing colour (Johnson et al., 2011). This behaviour could reflect an internal, prepared response by the driver to deal with the situation. However, it has been consistently demonstrated that when levels of internal demand are too high, the pattern of heart rate increase and HRV decrease is often found, and is sometimes associated with changes in performance. Within driving research, these effects are found in both simulator and on-road research, and workload is often manipulated by increasing levels of central processing demand with tasks such as the *n*-back task. For example, Lenneman and Backs (Lenneman & Backs, 2009) asked drivers to complete 0 and 3-back tasks whilst completing a simulated driving task, and found greater increases in heart

rate associated with the more difficult *n*-back task. Mehler and colleagues (Mehler et al., 2012) also asked participants to complete a delayed digit recall task whilst driving in a simulator, and found that with increased levels of difficulty, there were incremental increases in heart rate. In both cases, effects were found in the absence of any obvious changes in driving performance. Mehler argues that it is possible that this can be expected if resources are still available to complete both tasks at the same time. However, if we accept this theory, it is interesting to note that these autonomic changes occurred even with sufficient resources, and it could indicate that an increase in heart rate may function as an internal awareness that mental demands have increased. Nonetheless, heart rate increases have also been found when driving for a longer duration (Apparies, Riniolo, & Porges, 1998) and when completing cellphone tasks during simulated driving (Liu & Lee, 2006). In both cases, these heart rate increases have been attributed to increased mental workload; the former associates heart rate to increased workload using subjective measures, and the latter argues that increased heart rate is due to increased workload as it results in compensatory strategies such as speed reduction.

It is important to note that increases in heart rate and decreases in HRV do not always occur simultaneously; for example, changes in demand by increasing traffic density and fog have resulted in decreases in HF-HRV, without any effects on mean heart rate (Stuiver, Brookhuis, de Waard, & Mulder, 2014). It is argued in driving research that changes in levels of workload are also associated with decreases in HRV, specifically within the mid-frequency band (MF; 0.07-0.14 Hz). The act of driving alone, compared to a rest condition, can reduce levels of MF power (Mesken et al., 2007), indicating that the MF band is sensitive to changes in mental load. Interestingly, Dijksterhuis et al. found decreases of MF power, alongside decreases in heart rate and a reduction in standard deviation of lane position (Dijksterhuis et

al., 2011). Whilst it has previously been suggested a decrease in heart rate is associated with an increased intake of perceptual information, an additional decrease in MF-HRV power could also suggest that an increase in mental effort is required to intake more perceptual information, and this combination of increased mental effort and perceptual intake leads to compensatory strategies such as reduced SDLP. However, it should also be noted that research has also found decreases in LF and HF bands, that have in turn been associated with increased workload (Mullen, Faull, Jones, & Kingston, 2012; Stuiver et al., 2014; Tozman, Magdas, MacDougall, & Vollmeyer, 2015).

It is also important to note that any studies looking at cardiovascular activity and driving should also take measures of driving performance and subjective workload, in order to assess whether changes in heart rate and HRV are truly due to changes in workload. There are, for example, occasions where self-reported increases in workload are not associated with cardiovascular changes. In Dijksterhuis's (Dijksterhuis et al., 2011) study, subjective measures suggested that manipulations in workload due to reductions in lane width did increase levels of workload, yet no effects of lane width resulted in changes in heart rate or HRV. Additionally, subjective increases in workload have also been associated with increases in MF-HRV power (Brookhuis, van Driel, Hof, van Arem, & Hoedemaeker, 2009). It has been argued that such findings reflect an over-evaluation of how much workload is required to complete each driving task (Paxion, Galy, & Berthelon, 2014). Nonetheless, such findings highlight the importance of collecting subjective, objective and physiological data simultaneously whilst completing tasks that manipulate workload levels.

#### 1.6.5.5 Summary

In summary, the nature of cardiovascular activity is said to be reflective of both sympathetic and parasympathetic activity. Heart rate increases are influenced by sympathetic activity, whereas heart rate decreases and decreases in HRV are due to parasympathetic influences. Methods of recording heart rate include ECG and PPG, both of which are subject to artifacts in movement and respiration, meaning that data must be closely checked prior to analysis. The research looking into the relationship between cardiovascular activity and driving is primarily focused on the relationship between workload and driving; specifically, it suggests that decreases in heart rate reflect the increased intake of perceptual information, whilst increases in heart rate and decreases in HRV are associated with increases in mental workload. Whilst some information is known about the relationship between cardiovascular activity and anxiety, little is known about the effects of anxiety on cardiovascular activity whilst driving. The influence of anxiety on HF-HRV power has been noted in the driving literature (Mullen et al., 2012), however, with the exception of heart rate increases reported as a function of increased anxiety or fear (Mesken et al., 2007; Muhlberger et al., 2007), little is reported on anxiety's effects on cardiovascular activity whilst driving.

## 1.7 Aims of the Thesis

What is clear from this review is that negative emotions and traits have the potential to be dangerous to driving. Whilst a significant proportion of the driving research focuses on the relationship between anger and driving behaviours, there has been considerably less focus on the effects of anxiety. It may be important for research to provide further details on whether anxiety makes someone a more dangerous driver, considering that drivers have the potential

to be involved in accidents due to nerves or panic (Department for Transport, 2014). Studies that have looked at anxiety's effects on driving have so far been either primarily questionnaire-based, or they have provided mixed conclusions. It is important that this research topic is expanded within laboratory and simulator studies, in order to provide more concrete conclusions. In particular, it is important that research also investigates the physiological effects of anxiety on driving; with this information, it may be possible to discuss implications of how anxiety affects autonomic activity, and how this autonomic activity may affect levels of arousal, attentional patterns, and levels of workload.

This is not to say, however, that questionnaire methods should be disregarded. As noted in Section 1.6.5.4, subjective measures should be used alongside physiological and driving performance measures, in order to provide a comprehensive picture of anxiety's effects on driving. Therefore, the overall aim of this thesis is to use these methods in a series of laboratory and simulator studies, in order to assess how anxiety in both state and trait forms may affect driving performance and autonomic activity.

Firstly, however, it is important to provide a picture of how anxiety may affect driving behaviours within the general population. Section 1.6.1 highlights how questionnaires can provide a rich dataset of such behaviour across a large number of participants. In Chapter 2, the wide variety of questionnaires within driving research will be discussed; however, it will also be noted that a large majority of questionnaires within driving research often focus on patient or student populations. Subsequently, the study presented in Chapter 2 will use the STICSA, as well as a variety of driving questionnaires and demographic, to assess effects of driving and trait anxiety on subjective perceptions of driving behaviour within the general population.

Chapter 3 will discuss a laboratory study which aimed to assess the effects of trait anxiety on perceptions of risk, attention and autonomic activity whilst watching a series of driving clips with varying levels of danger. The chapter argues that anxiety's effects on driving are inconclusive on the basis that it is often mislabelled and mistaken in the research for another emotion, fear (Taylor, Deane, & Podd, 2008). It is argued that anxiety is based on top-down cognitive thought processes, whilst fear arises as a result of bottom-up environmental influences. The study presented attempted to investigate this theory by asking participants with varying levels of trait anxiety to watch driving clips with varying levels of danger.

Another laboratory study is presented in Chapter 4, using the same video clips as those from the study in Chapter 3. In this chapter, it is suggested that those with higher levels of trait anxiety may perceive clips with different levels of danger as more challenging, or as if they as the driver would have to work harder to cope with the demands of the presented environment. This study looks at self-perceived driving abilities, alongside the effects of driving clips on levels of self-reported and autonomic workload.

In Chapter 5, it is reiterated that further research in the field needs to look at driving performance alongside autonomic and self-reported measures. As the remainder of studies presented in the thesis take place in driving simulators, this chapter provides an overview of the use of simulators in driving research, along with practical and ethical considerations that may need to be taken into account.

Chapter 6 outlines the first of the studies conducted within the driving simulator. In this study, attempts to manipulate state anxiety are made in-between completing a series of drives

along the motorway. Driving performance, as well as measures of skin conductance and heart rate, are discussed.

Chapter 7 discusses a study that extends the suggestions made in Chapter 6. Here, it is emphasised that emotional state manipulations often need to have personal relevance to the driver. Additionally the possibility that levels of environmental demand may have an effect on driving behaviour and autonomic activity is explored.

The final study of the thesis is presented in Chapter 8, which is a simulator study into how trait anxiety may influence driving performance or levels of processing efficiency. Based on Attentional Control Theory (Eysenck, Derakshan, Santos, & Calvo, 2007), it is argued that those with higher levels of trait anxiety may not perform any differently on a given driving task, yet due to differences in central executive demands and processing efficiency levels, they may be required to make more effort in such tasks. This study examines this theory within the driving context, using functional near infra-red spectroscopy to measure levels of blood oxygenation within the frontal lobes.

The final chapter will discuss the implications of the findings from all six studies, within the context of driving. It will discuss what the findings imply about the relationship between anxiety and driving from a behavioural and autonomic perspective, and it will also discuss potential implications for future research within the field.

# Chapter 2. How does anxiety affect every day driving? An online questionnaire study within the general population.

## 2.1 Introduction

Chapter 1 highlighted how questionnaires are useful in general research, and what points should be taken into consideration when conducting such studies. They are a particularly useful, and often desirable, research tool on the basis that they are easy to administer and a large number of responses can be collected over a short period of time. Additionally, for driving research, questionnaire research allows insight into demographic or personality groups that may be particularly dangerous on the roads without requiring them to drive. Thus, a wide variety of questionnaires are used within driving research to measure the types of behaviours carried out by road users. For example, the Driver Behaviour Questionnaire (DBQ- Reason, Manstead, Stradling, Baxter, & Campbell, 1990) is a widely used questionnaire that measures the amount or errors, lapses and violations drivers make. It has been referenced in over 400 subsequent studies, its factor structure is supported across cultures (Lajunen, Parker, & Summala, 2004) and it has been suggested as a useful tool for road safety practitioners for the purposes of predicting future accidents (de Winter & Dodou, 2010).

It is particularly important that questionnaires looking into the relationship between emotions and driving are established as valid measures on the basis of practical implementations. If established as valid, road safety practitioners could use information to predict the types of accidents or violations a driver is likely to be involved in, and clinicians may be able to understand the specific driving behaviours that may either result from an emotional response, or be caused by an emotional response. Examples of such questionnaires include the Dula

Dangerous Driving Index, which measures the rate of aggressive and risky behaviours committed by a driver, and has been established as a measure which could be useful to employers or clinicians (Dula & Ballard, 2003). Another example is the Driving Situations Questionnaire (Ehlers, Hofmann, Herda, & Roth, 1994) that asks participants to rate their discomfort or fear of specific driving situations, and to what degree they would avoid such situations.

The original Driving Situations Questionnaire was constructed and validated using a sample of participants reporting a phobia of driving. It has been suggested as a useful tool for measuring levels of anxiety and avoidance within the phobic population. However, whilst driving phobia is specified within the DSM-IV and the DSM-V (da Costa, de Carvalho, Cantini, da Rocha Freire, & Nardi, 2014; American Psychiatric Association, 2013), it would also be useful for driving questionnaires to assess the degrees of anxiety and anxiety-related behaviours within the general population. A variety of recently constructed questionnaires have attempted to do this. For example, the Driving and Riding Avoidance Scale (DRAS- Stewart & Peter, 2004) is a 20-item scale that measures the degree to which drivers avoid certain situations. The authors originally constructed it to measure avoidance behaviours in drivers who had previously been involved in an accident, however it was also suggested to measure behaviours in those who express a general fear of driving. Two recent questionnaires that measure the degree of concerning thoughts or behaviours related to anxious driving situations are the Driving Cognitions Questionnaire (DCQ- Ehlers et al., 2007) and the Driving Behaviour Survey (DBS- Clapp, Olsen, Beck, et al., 2011) respectively.

The DCQ is a 20-item questionnaire that is designed to assess the frequency of socially-related, accident-related and panic-related concerns people feel during the task of driving.

Social concerns include statements such as ‘People I care about will criticise me’, accident concerns include statements such as ‘I will die in an accident’, and panic concerns include statements such as ‘I will tremble and not be able to steer’. Six items address social concerns, seven items address accident concerns, and seven items address panic concerns. Items are administered on a 5-point Likert scale, with “0” meaning that a respondent “Never” has a certain concern, and “4” meaning a respondent “Always” has a specific concern when driving. A minimum score of 0 and maximum score of 28 can be obtained for accident and panic concerns, whilst a minimum score of 0 and maximum score of 24 can be obtained for social concerns. An overall minimum score of 0 and maximum score of 80 can be obtained for the DCQ, which addresses general concerns when driving. The three-factor structure of the DCQ was supported in research that was conducted over three different countries, and subscales correlated with measures of both driving phobia and trait anxiety, supporting its use as a measure of driving concerns in both phobic and general populations. Further research using the questionnaire has found higher scores on the DCQ in phobic populations in comparison to non-phobics (da Costa et al., 2014), and has found strong correlations between DCQ subscales and subscales on the DBS (OliSan, Cantini, de Carvalho, & Cardoso, 2015).

The DBS (Clapp, Olsen, Beck, et al., 2011) was constructed in order to look more specifically at the behavioural consequences of encountering a driving situation that induces anxiety. It asks participants to state how frequently they perform a series of 21 items when they personally encounter a stressful driving situation. These items assess the degree of anxiety-based performance deficits, exaggerated safety-cautious behaviours and aggressive or hostile reactions, and seven items are assigned to each factor. Anxiety-based performance deficits (ABPD) are related to changes in driving performance that are the result of an increase in cognitive load due to anxious thoughts, and include behaviours such as drifting

into other lanes and not making appropriate speed adjustments. Exaggerated safety-cautious behaviours (ESCB) are behaviours that aim to increase the safety of the situation from the driver's perspective, and increase their perceptions of control. Such behaviours include maintaining a larger headway distance and slowing down at traffic lights regardless of their colour. Aggressive behaviours measure the 'fight' aspect of the fight-or-flight response, and include behaviours such as swearing and pounding on the steering wheel (Baker et al., 2014). Items are administered on a 7-point Likert scale, with 1 meaning "Never" and 7 meaning "Always". For each subscale, item scores are averaged, meaning that for each subscale participants can obtain a minimum score of 1 and a maximum score of 7; this same principle is applied to the overall DBS score. Since its construction the scale has been effective in finding positive relationships between its factors and subjective levels of accident distress (Clapp, Olsen, et al., 2011a), and has been suggested as a useful measure of trauma-related behavioural responses to motor vehicle accident (MVA) post-traumatic stress disorder (Baker et al., 2014; Clapp, Baker, Litwack, Sloan, & Beck, 2014). The initial construction of the DBS also found positive correlations between DBS and DCQ scores (Clapp, Olsen, Beck, et al., 2011).

Overall, the research conducted on the DCQ and DBS so far provides support for their use in driving research; correlational findings also suggest that the two questionnaires measure a similar construct, anxiety. As the DCQ measures thoughts and the DBS measures behaviours, the two may complement each other and be useful for road safety practitioners to understand the thoughts concerning those that are anxious, and how anxious drivers may be likely to react. However, whilst these may be useful research tools within the general population, the small body of research conducted using the two questionnaires has been conducted within phobic populations, or those with PTSD. It is important to investigate the psychometric

properties of each questionnaire within a non-clinical population, in order to increase their validity and provide further support for their use in both research and clinical practice. For example, a recent study investigating the psychometric properties of the DRAS used a sample of undergraduate students, and not only found an alternative factor structure, but also higher scores on questions in comparison to Stewart & St Peter's (2004) original research (Taylor & Sullman, 2009). This led the authors to suggest that this may be due to the fact that the questionnaire does not specifically ask participants to rate their avoidance of situations due to anxiety, and that motivations behind avoidance may be due to other factors. For example, subsequent research used the DRAS amongst a student population to investigate the effects of social desirability on responding, and found that participants reported higher scores in public settings for putting off a brief driving trip and choosing to cycle or walk instead of driving. The authors argued that such items may reflect avoidance due to environmental concerns rather than due to anxiety (Sullman & Taylor, 2010).

Whilst some of the research validating the DCQ and DBS has found positive correlations between subscale scores and trait anxiety (Ehlers et al., 2007), this was found with relatively small sample sizes; therefore, further research should also seek to find relationships between the two questionnaires and trait anxiety. This is particularly important if questionnaire research has already suggested that higher levels of trait anxiety are indicative of more dangerous driving behaviours, as measured by the Dula Dangerous Driving Index (Dula et al., 2010) and the DBQ (Pourabdian & Azmoon, 2013; Shahar, 2009). It has been specifically suggested that trait anxiety should be measured separately from driving anxiety (Dula et al., 2010). Whist the literature is mixed on the effects of anxiety on driving, the effects of state, trait and general driving anxiety all seem to suggest behaviours that may be dangerous on the roads. However, the individual contributions of trait and driving anxiety could be assessed by

attempting to measure the degree to which both trait and driving anxiety predict specific thoughts and behaviours.

Therefore, the two main aims of the current study were to investigate the psychometric properties of the DCQ and DBS in a non-clinical and primarily non student population, and to establish the contributions of trait anxiety and driving anxiety to anxious thoughts and behaviours whilst driving. A series of hierarchical regression models were used to establish whether STICSA trait and driving anxiety scores (based on an adapted version of the state part of the STICSA) were significant predictors of scores on each of the DCQ and DBS subscales. Additionally, to address concerns from previous research that ratings of avoidance may not necessarily be due to anxiety (Taylor & Sullman, 2009), participants were also asked to rate the degree to which they felt anxiety towards, and would aim to avoid, a series of specific driving situations. These scores were also placed within a hierarchical regression model to measure how strongly STICSA trait and driving scores predicted anxiety and avoidance ratings. Based on the previous literature, it was hypothesised that anxiety, either state or trait, would contribute to both DCQ and DBS scores, and that an investigation of their psychometric properties would provide support for the use of each questionnaire within a wider population.

## 2.2 Methods

### 2.2.1 Participants

A total of 320 participants expressed interest in the survey; however, only 227 completed their responses, resulting in a 71% retention rate. For those who completed the entire survey, their ages ranged from 17-81, and the average respondent age was 35 (*sd*=18.44). A total of 149 females (59.5%) and 76 males (40.5%) completed the survey. Eighty-two participants

were currently undergraduate or postgraduate students (36.1%). On average, respondents had held their full driving licence for 15.19 years (*sd*=16.79), and drove an average of 6229.22 miles per year (*sd*=5904.19). The majority of participants reported driving every day or at least a few times a week (69.46%). Ninety-five participants reported previous involvement in an accident in which they were the driver of the car (41.85%), and 42 reported previously receiving a conviction (18.5%); out these, 32 offences were for speeding (76.2%). Of those previously involved in an accident as the driver of the car, they reported being in an accident at any time from the previous week, to 37 years prior.

### 2.2.2 Materials

The entire survey was conducted online. It was compiled and distributed to participants using LimeSurvey version 2.05, an online open source software tool which can be used to create and publish surveys, as well as compile respondent statistics and collate responses for analysis.

The survey initially consisted of a standard information sheet and consent form outlining the details of the survey. After this, a series of questions were asked regarding demographics and general driving behaviour. This included questions on licence duration, annual mileage and accident history. These demographics are discussed in more detail in Section 2.3. Two final questions were asked regarding how people feel about driving. The first of these asked, on a Likert Scale from 1-10, how much fear the respondent feels whilst driving. The second asked, on the same scale, how much anxiety someone feels whilst they are driving. Whilst these could be perceived as the same question, it has been argued in the driving anxiety literature that fear and anxiety can, and should, be seen as separate entities (Schmidt-Daffy, 2013; Taylor et al., 2008). Dictionary definitions were provided to make these terms clear for

respondents; fear was defined as “an unpleasant emotion caused by the threat of danger, pain or harm”, whilst anxiety was defined as “the feeling of worry, nervousness or unease about an event with an uncertain outcome”.

#### 2.2.2.1 State-Trait Inventory for Cognitive and Somatic Anxiety

Both parts of the STICSA were administered to participants. However, to measure the effects of anxiety on driving, the phrasing of the state part of the STICSA was changed in the current study; instead of asking participants how they felt “at this moment”, they were asked how they felt during driving. Average driving state anxiety scores were 29.43 (*sd*=10.93) and average trait anxiety scores were 31.8 (*sd*=11.3) Cronbach’s α for driving state anxiety was .946, and .941 for trait anxiety, indicating good internal consistency.

#### 2.2.2.2 Driving Cognitions Questionnaire

The DCQ (Ehlers et al., 2007) was administered to investigate the concerns that respondents feel whilst they are driving (See Appendix ‘B’). Average scores for social, panic and accident concerns were 5.17 (*sd*=4.9), 1.98 (*sd*=3.48) and 6.34 (*sd*=5.26) respectively, whilst the overall average score was 13.49 (*sd*=12.26). Overall Cronbach’s α for the current study was .941. Cronbach’s α for social, accident and panic concerns were .866, .897, and .888 respectively.

#### 2.2.2.3 Driving Anxiety and Avoidance

In order to investigate which specific driving behaviours induce anxiety and avoidance, participants were asked to rate to what degree specific driving situations cause the individual

anxiety, and are subsequently avoided (See Appendix 'C'). A series of 11 items were selected based on driving situations mentioned in questionnaires such as the DRAS (Stewart & Peter, 2004), the Driving Situations Questionnaire (Ehlers et al., 1994), the Driver Stress Inventory (Matthews, Desmond, Joyner, Carcary, & Kirby, 1997) and the Travel Anxiety Questionnaire (Blanchard & Hickling, 2006). These situations included: performing manoeuvres, running errands that require driving, driving on country roads, driving in bad weather, driving in heavy traffic, driving at night-time, driving in an unfamiliar location, driving along city streets, driving along residential roads, driving along the motorway and driving to a recreational activity. Items were administered on a 5-point Likert scale ranging from 0-4, with 0 meaning "Not anxiety at all" or "Do not avoid at all", and 4 meaning "Severe anxiety" or "Always avoid". This scale is similar to the one used in the Driving Situations Questionnaire, and was thus deemed appropriate for the current survey.

#### 2.2.2.4 Driving Behaviour Survey

The DBS (Clapp, Olsen, Beck, et al., 2011) was administered to measure the degree to which participants carried out maladaptive behaviours when encountering a stressful driving situation (See Appendix 'D'). Average scores for anxiety-based performance deficits (ABPD), exaggerated safety-cautious behaviours (ESCB) and aggression were 2.09 (*sd*=0.9), 3.52 (*sd*=1.25) and 2.2 (*sd*=1.12) respectively, whilst the average overall score was 2.6 (*sd*=0.84). Overall, Cronbach's α in the current study was .885; Cronbach's α for anxiety-based performance deficits, exaggerated safety-cautious behaviours and aggressive reactions were .835, .846, and .862 respectively.

### 2.2.3 Procedure

Participants were approached and recruited using a series of social media invitations, as well as advertising online on a local newspaper website and a local study recruitment website, and inviting participants from the School of Psychology volunteer database. All participants were required to hold a full driver's licence before taking part. After consenting to take part in the study, respondents completed the online survey, which took approximately 10-15 minutes to complete. A chance to win £50 in shopping vouchers was offered as inconvenience allowance. The survey was available online for approximately 12 months. Approval for the study was obtained from the University of Nottingham's Ethics Committee.

## 2.3 Results

### 2.3.1 Gender differences and ratings of anxiety and fear

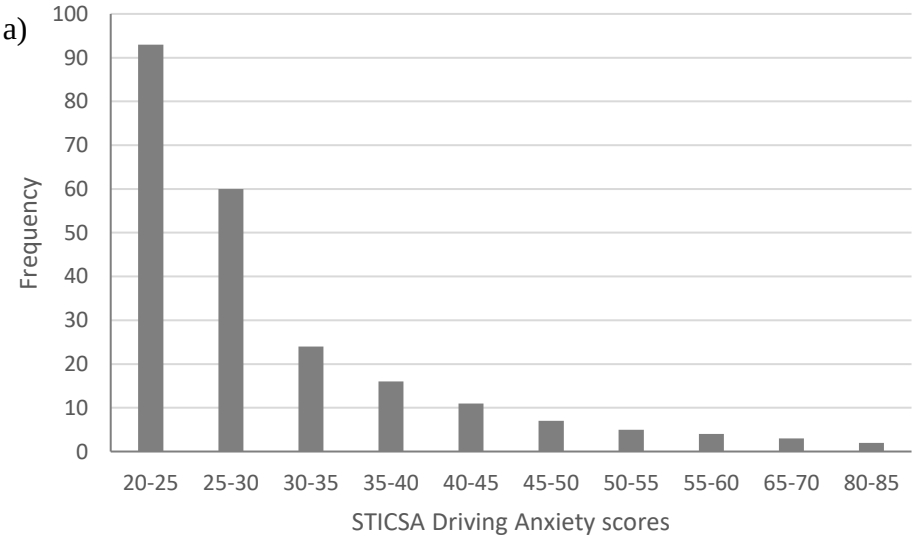
Based on findings from the literature, a series of Welch's *t*-tests were conducted to assess the effects of gender on self-reported driving fear and anxiety, DCQ scores and DBS scores. Welch's test was chosen to account for any differences in variance across groups due to uneven sample sizes. These tests found significant differences between groups on all variables apart from exaggerated safety-cautious behaviours ($t$ (161.2)=.336, $p$=.563), aggression ($t$ (149.6)=.374, $p$=.542) and total DBS scores ($t$ (154.4)=.76, $p$=.39). In all other cases, females reported significantly higher levels of driving fear and anxiety, higher driving and trait scores on the STICSA, higher DCQ scores, and higher levels of anxiety-based performance deficits. Ratings for this are provided in Table 2.1 and distribution graphs of STICSA driving and trait anxiety scores are presented in Figure 2-1.

**Table 2.1 Descriptive statistics for ratings by gender. Standard deviations are presented in brackets.**

| | Males | Females |
|---|---|---|
| **Driving fear (out of 10)** | 2.4 (1.58) | 3.09 (1.99)** |
| **Driving anxiety (out of 10)** | 2.8 (1.9) | 3.85 (2.39)** |
| **STICSA Driving Score** | 26.61 (7.49) | 31.24 (11.77)** |
| **STICSA Trait Score** | 29.15 (8.4) | 33.43 (12.14)** |
| **DCQ-Panic** | 1.2 (2.01) | 2.41 (3.98)** |
| **DCQ-Accident** | 5.19 (4.16) | 6.99 (5.66)** |
| **DCQ-Social** | 3.62 (3.96) | 6.01 (5.15)** |
| **DCQ-Total** | 10.01 (9.04) | 15.43 (13.26)** |
| **DBS-ABPD** | 1.9 (.84) | 2.2 (.92)* |
| **DBS-ESCB** | 3.47 (1.18) | 3.57 (1.27) |
| **DBS-Aggression** | 2.27 (1.13) | 2.17 (1.12) |
| **DBS-Total** | 2.55 (.82) | 2.65 (.84) |

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

a)



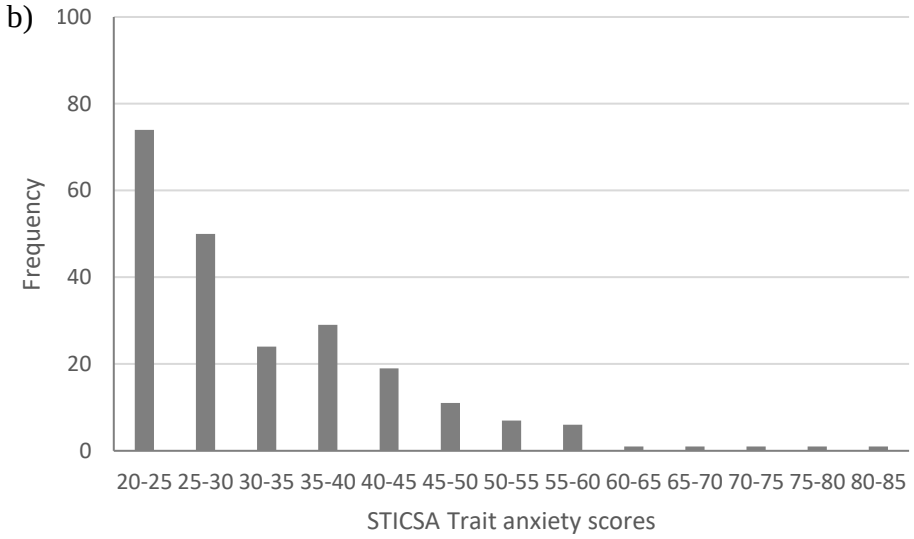



*Figure 2-1: Distribution graphs of a) STICSA driving anxiety, and b) STICSA trait anxiety scores,*

Additionally, a paired samples *t*-test was conducted across all participants to compare ratings of fear and anxiety; this found a significant difference between ratings ($t$ (224)=7.92, $p$<.001). Ratings of driving anxiety were significantly higher ($m$=3.49) than ratings of driving fear ($m$=2.85).

### 2.3.2 Correlations between variables

Data providing correlations between demographic variables, ratings of driving fear and anxiety, STICSA driving and trait scores, DCQ scores and DBS scores are provided in Table 2.2. Age and experience negatively correlated with ratings of anxiety, DCQ and DBS scores. This indicated that overall, increases in age, experience and mileage resulted in lower levels of anxiety, driving related concerns and a lower frequency of anxiety-related driving behaviours. There were, however, some exceptions. Age and licence duration did not significantly correlate with the frequency of exaggerated safety-cautious behaviours, and annual mileage did not correlate with trait anxiety, panic-related concerns, exaggerated

safety-cautious behaviours, aggressive behaviours or total DBS score. Otherwise, the remaining variables had at least moderate positive correlations with each other. These suggest that increasing levels of both STICSA driving and STICSA trait scores are associated with greater ratings of both fear and anxiety, a greater frequency of driving concerns, and a greater frequency of anxiety-related behaviours. STICSA driving scores were generally more positively correlated with all DCQ and DBS scores than trait scores were; the exception to this was for DCQ social and DBS aggression scores.

**Table 2.2: Correlations between demographic variables, anxiety ratings, DCQ Scores and DBS Scores**

| | Age | Years with licence | Annual mileage | Driving fear ratings | Driving anxiety ratings | STICSA Driving | STICSA Trait | DCQ Panic | DCQ Accident | DCQ Social | DCQ Total | DBS ABPD | DBS ESCB | DBS Aggression | DBS Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Age | | .961** | .132* | -.209** | -.262** | -.271** | -.328** | -.14* | -.273** | -.402** | -.318** | -.249** | -.072 | -.194** | -.212** |
| Years with licence | | | .149* | -.233** | -.297** | -.294** | -.322** | -.163* | -.289** | -.427** | -.341** | -.271** | -.08 | -.151* | -.204** |
| Annual mileage | | | | -.235** | -.225** | -.138* | .04 | -.06 | -.148* | -.167* | -.146* | -.218** | -.11 | .05 | -.11 |
| Driving fear ratings | | | | | .847** | .636** | .408** | .500** | .618** | .571** | .636** | .460** | .401** | .09 | .410** |
| Driving anxiety ratings | | | | | | .638** | .462** | .452** | .624** | .664** | .662** | .461** | .405** | .081 | .404** |
| STICSA Driving | | | | | | | .656** | .661** | .725** | .665** | .765** | .558** | .394** | .339** | .551** |
| STICSA Trait | | | | | | | | .585** | .610** | .704** | .709** | .519** | .312** | .391** | .518** |
| DCQ Panic | | | | | | | | | .765** | .648** | .872** | .558** | .423** | .244** | .521** |
| DCQ Accident | | | | | | | | | | .703** | .928** | .611** | .482** | .323** | .605** |
| DCQ Social | | | | | | | | | | | .886** | .628** | .425** | .233** | .542** |
| DCQ Total | | | | | | | | | | | | .672** | .497** | .301** | .624** |
| DBS ABPD | | | | | | | | | | | | | .501** | .396** | .787** |
| DBS ESCB | | | | | | | | | | | | | | .257** | .795** |
| DBS Aggression | | | | | | | | | | | | | | | .717** |
| DBS Total | | | | | | | | | | | | | | | |

*$p$<.05; **$p$<.01

### 2.3.3 The contribution of driving state and trait anxiety to DCQ and DBS factors

In order to measure the contribution of both STICSA driving and STICSA trait scores towards predicting the frequency of driving concerns and anxiety-related driving behaviours, a hierarchical regression model was applied to DCQ and DBS subscales and total scores. For the purposes of each model, step one of each model contained demographic predictors that have previously been associated with driving anxiety. These included age, experience (operationalised by the amount of years a participant held a full driver's licence), gender and previous accident involvement (which was measured in a binary fashion). Step two of each model then contained STICSA driving and trait scores, to measure the degree to which each of these predicted DCQ and DBS scores.

Step one of models for each of the DCQ subscales and total scores found that each model was a significant overall predictor of scores (all *p*s<.05). In particular, DCQ social scores were significantly predicted by experience ($\beta$=-.539, $sr^2$=0.022) (*t* (218)=-2.49, *p*=.014) and accident involvement ($\beta$=-.206, $sr^2$=0.034) (*t* (218)=-3.11, *p*=.002). These suggested that before placing STICSA driving and trait scores into the model, experience negatively predicted social concerns, and those with previous accident involvement were less likely to show socially-related concerns about their driving. Placing STICSA driving and trait scores into the model significantly improved the model's ability to predict all DCQ scores (all *p*s<.001), and both STICSA driving and trait scores acted as significant individual predictors of DCQ scores (all *p*s<.001). Experience also remained a significant negative predictor of DCQ social scores in step two of the model ($\beta$=-.179, $sr^2$=0.026) (*t* (216)=-3.84, *p*<.001). When comparing standardised $\beta$ values across DCQ scores, STICSA driving anxiety has

more impact in predicting panic and accident-related concerns, as well as total DCQ score, compared to trait anxiety. However, trait anxiety is a better predictor of socially-related concerns than driving anxiety scores (See Table 2.3).

Step one of models for DBS scores were significant overall predictors of scores for all scales apart from the ESCB subscale ($F(4,217)=1.07$, $p=.375$). Specifically, age was a significant negative predictor of scores on the aggression subscale ($\beta=-.53$, $sr^2=0.024$) ($t$ (217)=-2.21, $p$=..028). Placing STICSA driving and trait scores into step two significantly improved each model's ability to predict DBS scores (all $p$s<.001). Driving anxiety scores acted as significant individual predictors across all scales (all $p$s<.001), whilst trait anxiety was a significant predictor of all scales apart from the ESCB subscale ($t$ (215)=1.56, $p$=.121). Comparison of standardised $\beta$ scores suggests that driving anxiety was a stronger predictor of DBS scores on the ABPD subscale and on the total DBS score. However, trait anxiety acted as a better predictor of aggression scores than driving anxiety scores. Additionally, age was still a significant negative predictor of aggression ($\beta=-.569$, $sr^2=0.024$) ($t$ (215)=-2.57, $p$=.011), whilst experience acted as a positive predictor of aggression ($\beta=.483$, $sr^2=0.017$) ($t$ (215)=-2.16, $p$=.032) and gender differences suggested that females were less likely to report aggression in comparison to males ($\beta$=--.151, $sr^2=0.02$) ($t$ (215)=-2.35, $p$=.002) (See Table 2.4).

To summarise, the addition of STICSA driving and trait scores into step two of each regression suggests that they both significantly improve the predictability of DCQ and DBS scores. Whilst a comparison of standardised $\beta$s would suggest that driving anxiety scores are a better predictor than trait anxiety scores in the majority of cases, trait anxiety scores are

better at predicting levels of social concern and levels of aggression in response to an anxiety-inducing driving situation.

**Table 2.3: Hierarchical regression models for the Driving Cognitions Questionnaire subscales and total score.**

| | | Step 1 | | | | Step 2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | *B* | *SE B* | *β* | $sr^2$ | *B* | *SE B* | *β* | $sr^2$ |
| DCQ Panic | | | | | | | | | |
| | Age | 0.055 | 0.046 | 0.286 | 0.006 | 0.030 | 0.034 | 0.158 | 0.002 |
| | Licence Duration | -0.078 | 0.051 | -0.369 | 0.010 | -0.011 | 0.038 | -0.051 | 0.000 |
| | Gender | 0.990 | 0.512 | 0.134 | 0.016 | 0.275 | 0.383 | 0.037 | 0.001 |
| | Accident Involvement | -0.498 | 0.524 | -0.070 | 0.004 | -0.224 | 0.389 | -0.032 | 0.001 |
| | STICSA Driving Score | | | | | 0.158 | 0.021 | 0.484*** | 0.129 |
| | STICSA Trait Score | | | | | 0.090 | 0.021 | 0.288*** | 0.046 |
| | | $R^2$=.053* | | | | $R^2$=.486*** | $\Delta R^2$=.433*** | | |
| DCQ Accident | | | | | | | | | |
| | Age | 0.016 | 0.068 | 0.057 | 0.000 | -0.028 | 0.048 | -0.096 | 0.001 |
| | Licence Duration | -0.096 | 0.075 | -0.303 | 0.007 | 0.012 | 0.053 | 0.038 | 0.000 |
| | Gender | 1.157 | 0.758 | 0.104 | 0.010 | 0.017 | 0.534 | 0.002 | 0.000 |
| | Accident Involvement | -0.140 | 0.775 | -0.013 | 0.000 | 0.336 | 0.543 | 0.031 | 0.001 |
| | STICSA Driving Score | | | | | 0.282 | 0.030 | 0.573*** | 0.180 |
| | STICSA Trait Score | | | | | 0.104 | 0.029 | 0.220*** | 0.027 |
| | | $R^2$=.09*** | | | | $R^2$=.56*** | $\Delta R^2$=.471*** | | |
| DCQ Social | | | | | | | | | |
| | Age | 0.066 | 0.058 | 0.243 | 0.004 | 0.045 | 0.041 | 0.166 | 0.002 |
| | Licence Duration | -0.158 | 0.064 | -0.539* | 0.022 | -0.078 | 0.045 | -0.267 | 0.005 |
| | Gender | 1.147 | 0.645 | 0.111 | 0.011 | 0.257 | 0.458 | 0.025 | 0.001 |
| | Accident Involvement | -2.049 | 0.660 | -0.206** | 0.034 | -1.784 | 0.465 | -0.179*** | 0.026 |
| | STICSA Driving Score | | | | | 0.138 | 0.026 | 0.302*** | 0.050 |
| | STICSA Trait Score | | | | | 0.191 | 0.025 | 0.436*** | 0.104 |
| | | $R^2$=.22*** | | | | $R^2$=.615*** | $\Delta R^2$=.391*** | | |
| DCQ Total | | | | | | | | | |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Age | 0.137 | 0.154 | 0.203 | 0.003 | 0.047 | 0.097 | 0.070 | 0.000 |
| Licence Duration | -0.332 | 0.169 | -0.451 | 0.015 | -0.077 | 0.107 | -0.105 | 0.001 |
| Gender | 3.294 | 1.711 | 0.127 | 0.015 | 0.549 | 1.079 | 0.021 | 0.000 |
| Accident Involvement | -2.686 | 1.751 | -0.108 | 0.009 | -1.672 | 1.097 | -0.067 | 0.004 |
| STICSA Driving Score | | | | | 0.577 | 0.061 | 0.505*** | 0.140 |
| STICSA Trait Score | | | | | 0.385 | 0.058 | 0.351*** | 0.067 |
| | $R^2$=.142*** | | | | $R^2$=.668*** | $\Delta R^2$=.526*** | | |

*$p$<.05

**$p$<.01

***$p$<.001

**Table 2.4: Hierarchical regression models for the Driving Behaviour Survey subscales and total scores.**

| | Step 1 | | | | Step 2 | | | |
|---|---|---|---|---|---|---|---|---|
| | *B* | *SE B* | *β* | $sr^2$ | *B* | *SE B* | *β* | $sr^2$ |
| DBS ABPD | | | | | | | | |
| Age | 0.009 | 0.012 | 0.177 | 0.002 | 0.004 | 0.010 | 0.086 | 0.001 |
| Licence Duration | -0.020 | 0.013 | -0.371 | 0.010 | -0.007 | 0.011 | -0.125 | 0.001 |
| Gender | 0.167 | 0.130 | 0.087 | 0.007 | 0.021 | 0.110 | 0.011 | 0.000 |
| Accident Involvement | -0.210 | 0.133 | -0.114 | 0.010 | -0.162 | 0.113 | -0.088 | 0.006 |
| STICSA Driving Score | | | | | 0.030 | 0.006 | 0.358*** | 0.070 |
| STICSA Trait Score | | | | | 0.021 | 0.006 | 0.255** | 0.036 |
| | $R^2$=.096*** | | | | $R^2$=.365*** | $\Delta R^2$=.269*** | | |
| DBS ESCB | | | | | | | | |
| Age | 0.004 | 0.017 | 0.063 | 0.000 | -0.001 | 0.016 | -0.019 | 0.000 |
| Licence Duration | -0.009 | 0.018 | -0.118 | 0.001 | 0.005 | 0.017 | 0.073 | 0.000 |
| Gender | 0.086 | 0.185 | 0.033 | 0.001 | -0.067 | 0.173 | -0.025 | 0.001 |
| Accident Involvement | -0.224 | 0.190 | -0.089 | 0.006 | -0.167 | 0.177 | -0.066 | 0.003 |
| STICSA Driving Score | | | | | 0.037 | 0.010 | 0.318*** | 0.055 |
| STICSA Trait Score | | | | | 0.014 | 0.009 | 0.131 | 0.009 |
| | $R^2$=.019 | | | | $R^2$=.169*** | $\Delta R^2$=.149*** | | |
| DBS Aggression | | | | | | | | |
| Age | -0.032 | 0.015 | -0.530* | 0.021 | -0.035 | 0.014 | -0.569* | 0.024 |
| Licence Duration | 0.021 | 0.016 | 0.319 | 0.008 | 0.032 | 0.015 | 0.483* | 0.017 |
| Gender | -0.228 | 0.162 | -0.097 | 0.009 | -0.354 | 0.151 | -0.151* | 0.020 |
| Accident Involvement | -0.046 | 0.167 | -0.020 | 0.000 | -0.017 | 0.154 | -0.008 | 0.000 |
| STICSA Driving Score | | | | | 0.017 | 0.008 | 0.162* | 0.014 |
| STICSA Trait Score | | | | | 0.030 | 0.008 | 0.299*** | 0.049 |
| | $R^2$=.058* | | | | $R^2$=.213*** | $\Delta R^2$=.155*** | | |
| DBS Total | | | | | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Age | -0.006 | 0.011 | -0.139 | 0.001 | -0.011 | 0.009 | -0.230 | 0.004 |
| | Licence Duration | -0.003 | 0.012 | -0.053 | 0.000 | 0.010 | 0.010 | 0.205 | 0.003 |
| | Gender | 0.008 | 0.121 | 0.005 | 0.000 | -0.133 | 0.101 | -0.076 | 0.005 |
| | Accident Involvement | -0.160 | 0.124 | -0.095 | 0.007 | -0.115 | 0.103 | -0.068 | 0.004 |
| | STICSA Driving Score | | | | | 0.028 | 0.006 | 0.361*** | 0.072 |
| | STICSA Trait Score | | | | | 0.022 | 0.005 | 0.291*** | 0.046 |
| | | $R^2$=.061** | | | | $R^2$=.365*** | $\Delta R^2$=.304*** | | |

*$p$<.05

**$p$<.01

***$p$<.001

### 2.3.4 The contribution of driving state and trait anxiety to specific anxiety and avoidance situations

To measure the contributions of STICSA driving and STICSA trait scores towards the degree of anxiety and avoidance behaviours, data from each of the 11 specified situations was also placed into a hierarchical regression model. Steps one and two were the same as those used for the analysis of DCQ and DBS scores.

Step one of each model could only predict levels of anxiety in situations involving manoeuvres, country driving, bad weather, night-time driving, driving in an unfamiliar location, city driving and motorway driving (all *p*s<.05). However, in all 11 situations, step two of the model significantly improved its ability to predict levels of anxiety (all *p*s<.001). Specifically, levels of STICSA driving positively predicted levels of anxiety across all situations (all $\beta$s>.27, all *p*s<.001). However, some of these models included additional significant predictors. For example, gender was still a significant predictor of anxiety during manoeuvres ($\beta$=.173, $sr^2$=0.027) (*t* (211)=2.86, *p*=.005), bad weather ($\beta$=.262, $sr^2$=0.06) (*t* (215)=4.25, *p*<.001), unfamiliar driving ($\beta$=.165, $sr^2$=0.024) (*t* (208)=2.58, *p*=.011), and motorway driving ($\beta$=.183, $sr^2$=0.029) (*t* (202)=2.98, *p*=.004). Whilst they do not have as much of an impact on each model, they do suggest that females show significantly higher levels of anxiety in these contexts. Additionally, trait anxiety also had a significant influence in certain contexts. It was a significant predictor of reported anxiety during residential driving ($\beta$=..225, $sr^2$=0.03) (*t* (210)=2.93, *p*=.004), and a marginally significant predictor of anxiety in city driving ($\beta$=.126, $sr^2$=0.01) [*t* (207)=.126, *p*=.099]. Anxiety regarding night-time driving was also predicted by trait anxiety ($\beta$=.235, $sr^2$=0.033) (*t* (207)=3.09, *p*=.002), and was also additionally predicted by age ($\beta$=.544, $sr^2$=0.022) (*t* (207)=2.51, *p*=.013) and gender

($\beta$=.205, $sr^2$=0.036) ($t$ (207)=3.24, $p$=.001). Overall, this suggests that whilst trait anxiety is not as strong a predictor as driving anxiety, it can positively predict anxiety in these contexts. Age and gender were also significant predictors of night-time driving, in that females show higher levels of anxiety regarding night-time driving, and this anxiety can also be positively predicted by age. Additionally, the standardised beta values regarding age ($\beta$=.544) compared to driving anxiety ($\beta$=.279) may indicate that age is a stronger predictor of driving anxiety during night-time driving (See Table 2.5 for a summary of significant predictors at steps one and two).

Step one of each model could only predict degree of avoidance for driving situations involving manoeuvres, bad weather, heavy traffic, driving in an unfamiliar location, and motorway driving (all $p$s<.05). However, step two significantly improved each model's ability to predict levels of driving avoidance (all $p$s<.001). Specifically, across all 11 situations levels, STICSA driving anxiety scores were a significant positive predictor of avoidance (all $\beta$s>.21, all $p$s<.001). However, there were additional predictors for specific situations. Gender was a significant predictor of avoidance of manoeuvres ($\beta$=.189, $sr^2$=0.032) ($t$ (177)=2.72, $p$=.007), bad weather ($\beta$=.201, $sr^2$=0.036) ($t$ (183)=3.07, $p$=.002) and driving in an unfamiliar location ($\beta$=.205, $sr^2$=0.038) ($t$ (179)=3.17, $p$=.002). In all cases, females were significantly more likely to report avoidance of these situations. Accident history also significantly predicted avoidance of manoeuvres ($\beta$=-.15, $sr^2$=0.032) ($t$ (177)=-.199, $p$=.048) and heavy traffic ($\beta$=-.177, $sr^2$=0.023) ($t$ (177)=-2.33, $p$=.021). However, these were negative associations, meaning that those who were previously involved in an accident were less likely to avoid these situations compared to those with no previous accident involvement. Experience was a predictor of avoidance of residential driving ($\beta$=.43, $sr^2$=0.015) ($t$ (179)=1.99, $p$=.048), in that greater experience was positively associated with a

greater degree of avoidance. Finally, trait anxiety was significantly associated with avoidance of driving in residential areas ($\beta$=.218, $sr^2$=0.028) ($t$ (179)=2.67, $p$=.008) and night-time driving ($\beta$=.295, $sr^2$=0.028) ($t$ (180)=3.63, $p$<.001), and was marginally associated with avoidance of performing manoeuvres ($\beta$=.16, $sr^2$=0.01) [$t$ (177)=1.92, $p$=.057]. In all cases, trait anxiety positively predicted avoidance of these situations. In particular, standardised beta values for trait anxiety were larger for night-time driving ($\beta$=.295) than for driving anxiety scores ($\beta$=.233), indicating that trait anxiety was a stronger predictor in this case (See Table 2.6 for a summary of significant predictors at steps one and two).

To summarise, step two of each model significantly predicted the degree of anxiety and avoidance for each of the specified driving situations. In all cases, this was primarily due to a strong influence of STICSA driving scores. However, in some cases, demographic variables and levels of trait anxiety also significantly predicted anxiety and avoidance. In particular, some examples suggest that additional demographic variables may be better predictors than levels of STICSA driving anxiety.

## Table 2.5: Hierarchical regression models for the degree of anxiety reported in specific driving situations

| | Step 1 | | | | | Step 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Significant predictor | *B* | SE B | *β* | $sr^2$ | *B* | SE B | *β* | $sr^2$ |
| Manoeuvres | Gender | 0.537 | 0.152 | 0.234** | 0.05 | 0.397 | 0.139 | 0.173** | 0.027 |
| | STICSA driving score | | | | | 0.043 | 0.008 | 0.410*** | 0.1 |
| | | $R^2$=.149*** | | | | $R^2$=.313*** | $\Delta R^2$=.163*** | | |
| Errands | STICSA driving score | | | | | 0.036 | 0.006 | 0.488*** | 0.137 |
| | | $R^2$=.031 | | | | $R^2$=.283*** | $\Delta R^2$=.252*** | | |
| Country | STICSA driving score | | | | | 0.043 | 0.008 | 0.437*** | 0.011 |
| | | $R^2$=.097*** | | | | $R^2$=.275*** | $\Delta R^2$=.178*** | | |
| Bad Weather | Gender | 0.727 | 0.149 | 0.335*** | 0.101 | 0.569 | 0.134 | 0.262*** | 0.06 |
| | STICSA driving score | | | | | 0.042 | 0.008 | 0.404*** | 0.127 |
| | | $R^2$=.117*** | | | | $R^2$=.309*** | $\Delta R^2$=.192*** | | |
| Heavy Traffic | Gender | 0.404 | 0.176 | 0.162* | 0.024 | 0.256 | 0.162 | 0.103 | 0.009 |
| | STICSA driving score | | | | | 0.047 | 0.009 | 0.396*** | 0.096 |
| | | $R^2$=.027 | | | | $R^2$=.201*** | $\Delta R^2$=.174*** | | |
| Night-time driving | Age | 0.037 | 0.014 | 0.629** | 0.030 | 0.032 | 0.013 | 0.544* | 0.022 |
| | Experience | -0.034 | 0.016 | -0.53* | 0.021 | -0.020 | 0.014 | -0.315 | 0.007 |
| | Gender | 0.616 | 0.156 | 0.274*** | 0.068 | 0.460 | 0.142 | 0.205** | 0.037 |
| | STICSA driving score | | | | | 0.030 | 0.008 | 0.279*** | 0.048 |
| | STICSA trait score | | | | | 0.024 | 0.008 | 0.235** | 0.034 |
| | | $R^2$=.092*** | | | | $R^2$=.273*** | $\Delta R^2$=.181*** | | |
| Unfamiliar Location | Gender | 0.589 | 0.176 | 0.231** | 0.049 | 0.420 | 0.163 | 0.165* | 0.024 |
| | STICSA driving score | | | | | 0.050 | 0.009 | 0.405*** | 0.099 |
| | | $R^2$=.091*** | | | | $R^2$=.247*** | $\Delta R^2$=.155*** | | |
| City driving | STICSA driving score | | | | | 0.045 | 0.009 | 0.392*** | 0.097 |
| | | $R^2$=.045* | | | | $R^2$=.243*** | $\Delta R^2$=.197*** | | |
| Residential driving | STICSA driving score | | | | | 0.028 | 0.006 | 0.358*** | 0.077 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | STICSA trait score | | | | | | 0.016 | | 0.005 | 0.225** | 0.030 |
| | | $R^2$=.022 | | | | $R^2$=.26*** | | $\Delta R^2$=.239*** | | | |
| Motorway driving | Gender | | 0.668 | 0.186 | 0.251*** | 0.056 | 0.486 | | 0.169 | 0.183** | 0.029 |
| | STICSA driving score | | | | | | 0.050 | | 0.010 | 0.388*** | 0.093 |
| | | $R^2$=.113*** | | | | $R^2$=.291*** | | $\Delta R^2$=.178*** | | | |
| Recreational driving | STICSA driving score | | | | | | 0.046 | | 0.006 | 0.579*** | 0.205 |
| | | $R^2$=.017 | | | | $R^2$=.357*** | | $\Delta R^2$=.34*** | | | |

*$p$<.05

**$p$<.01

***$p$<.001

## Table 2.6: Hierarchical regression models for the degree of avoidance reported in specific driving situations

| | Step 1 | | | | | Step 2 | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Significant predictor | *B* | SE B | *β* | $sr^2$ | *B* | SE B | *β* | $sr^2$ |
| Manoeuvres | Gender | 0.561 | 0.169 | 0.241** | 0.053 | 0.441 | 0.162 | 0.189** | 0.032 |
| | Accident Involvement | -0.385 | 0.174 | -0.175* | 0.023 | -0.330 | 0.166 | -0.150* | 0.017 |
| | STICSA driving score | | | | | 0.021 | 0.009 | 0.212* | 0.027 |
| | | $R^2$=.137*** | | | | $R^2$=.234*** | $\Delta R^2$=.097*** | | |
| Errands | STICSA driving score | | | | | 0.034 | 0.007 | 0.441*** | 0.109 |
| | | $R^2$=.012 | | | | $R^2$=.25*** | $\Delta R^2$=.238*** | | |
| Country | STICSA driving score | | | | | 0.037 | 0.007 | 0.474*** | 0.122 |
| | | $R^2$=.034 | | | | $R^2$=.221*** | $\Delta R^2$=.188*** | | |
| Bad Weather | Gender | 0.647 | 0.180 | 0.26*** | 0.062 | 0.501 | 0.163 | 0.201** | 0.036 |
| | STICSA driving score | | | | | 0.039 | 0.008 | 0.376*** | 0.080 |
| | | $R^2$=.109*** | | | | $R^2$=.293*** | $\Delta R^2$=.184*** | | |
| Heavy Traffic | Licence Duration | -0.039 | 0.019 | -0.498* | 0.021 | -0.023 | 0.018 | -0.298 | 0.007 |
| | Accident Involvement | -0.522 | 0.196 | -0.217** | 0.036 | -0.427 | 0.183 | -0.177* | 0.023 |
| | STICSA driving score | | | | | 0.037 | 0.009 | 0.345*** | 0.069 |
| | | $R^2$=.101** | | | | $R^2$=.232*** | $\Delta R^2$=.130*** | | |
| Night-time driving | Gender | 0.310 | 0.156 | 0.150* | 0.021 | 0.203 | 0.141 | 0.098 | 0.009 |
| | STICSA driving score | | | | | 0.021 | 0.007 | 0.233** | 0.034 |
| | STICSA trait score | | | | | 0.026 | 0.007 | 0.295*** | 0.056 |
| | | $R^2$=.042 | | | | $R^2$=.24*** | $\Delta R^2$=.198*** | | |
| Unfamiliar Location | Gender | 0.738 | 0.193 | 0.278*** | 0.070 | 0.545 | 0.172 | 0.205** | 0.038 |
| | STICSA driving score | | | | | 0.047 | 0.009 | 0.418*** | 0.102 |
| | | $R^2$=.125*** | | | | $R^2$=.33*** | $\Delta R^2$=.205*** | | |
| City driving | STICSA driving score | | | | | 0.032 | 0.008 | 0.347*** | 0.070 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $R^2$=.046 | | | | $R^2$=.202*** | $\Delta R^2$=.156*** | | |
| Residential driving | Licence Duration | 0.007 | 0.011 | 0.159 | 0.002 | 0.019 | 0.010 | 0.430* | 0.015 |
| | STICSA driving score | | | | | 0.025 | 0.005 | 0.413*** | 0.096 |
| | STICSA trait score | | | | | 0.013 | 0.005 | 0.218** | 0.027 |
| | | $R^2$=.015 | | | | $R^2$=.31*** | $\Delta R^2$=.295*** | | |
| Motorway driving | Gender | 0.394 | 0.199 | 0.149* | 0.020 | 0.274 | 0.190 | 0.104 | 0.010 |
| | STICSA driving score | | | | | 0.031 | 0.010 | 0.274** | 0.043 |
| | | $R^2$=.061* | | | | $R^2$=.168*** | $\Delta R^2$=.107*** | | |
| Recreational driving | STICSA driving score | | | | | 0.036 | 0.006 | 0.474*** | 0.144 |
| | | $R^2$=.007 | | | | $R^2$=.248*** | $\Delta R^2$=.241*** | | |

*$p$<.05

**$p$<.01

***$p$<.001

### 2.3.5 DCQ and DBS construct validity

In order to evaluate the psychometric properties of the DCQ and DBS within the current sample, a principal components analysis was conducted for each questionnaire. Prior to analysis, a parallel analysis was conducted and scree plots were created to deicide the number of factors that were to be retained. Whilst a scree plot provides a visual indication of what factors need be kept based on a point of inflection, parallel analysis compares eigenvalues from the current dataset against a set of eigenvalues based on a randomly simulated dataset with the same number of items; parallel analysis identifies which eigenvalues from the current dataset are significantly higher than chance, and on this basis suggests how many factors should be retained. Parallel analysis was conducted in SPSS based on a pre-made syntax file (O'Connor, 2000). On the basis of previous research, it was expected that factors would be theoretically related to each other, therefore a principal components analysis with a direct oblimin rotation was used. Based on previous criteria (Stevens, 2002), factor loadings of 0.4 or over were considered significant.

### 2.3.5.1 Driving Cognitions Questionnaire

Parallel analysis suggested that three eigenvalues were greater than 1; only two of these were considered significant. However, the scree plot provided was less clear, suggesting that that either a 2 or 3-factor solution could be interpreted (See Figure 2-2). Therefore, two PCAs were conducted to explore both types of model.

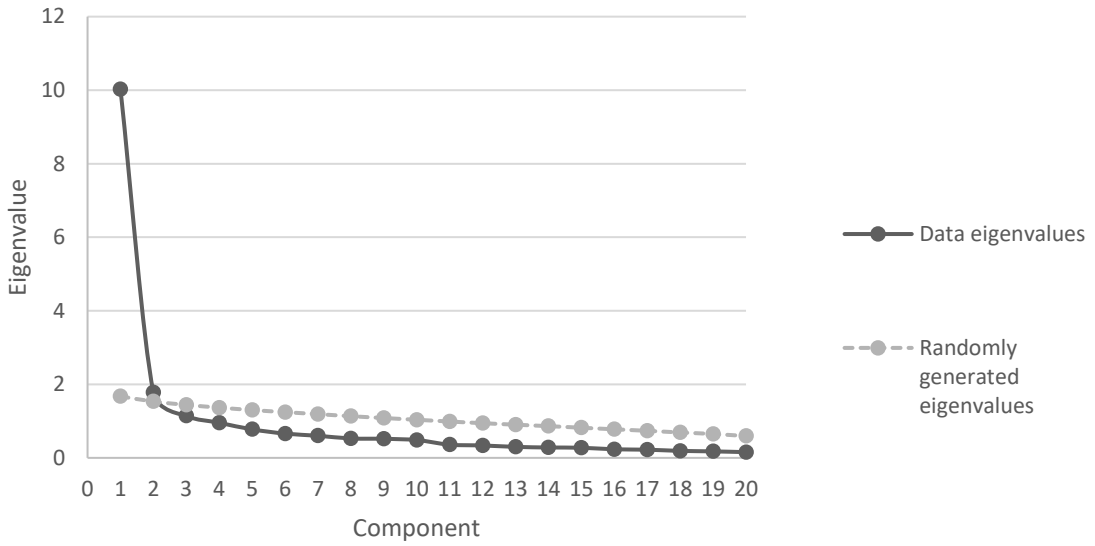



*Figure 2-2: Eigenvalues generated from the DCQ data compared to randomly generated eigenvalues from the parallel analysis. The scree plot suggests there may be points of inflection after 2 or 3 components.*

The Kaiser-Meyer-Olkin (KMO) test of sampling adequacy and Barltett's test of sphericity suggested that the data were suitable for a PCA, as these values were .928 and <.001 respectively. The components associated with the 2-factor solution explained 50.13% and 8.89% of variance in the data respectively. The pattern matrix suggested a clear 2 component solution with no items loaded onto more than one variable and no items that did not load on either component. However, the interpretation of these components was less clear. Component 1 consisted primarily of panic and accident-related factors, and one item from the social concern subscale. This could be interpreted as concerns related to negative reactions to driving situations and the accident-related consequences of this. Component 2 consisted

primarily of socially-related concerns, along with two items from the accident concerns subscale. Based on the phrasing of each item, this component was interpreted as related to concerns regarding the reactions of others.

When considering the 3-factor solution, the components explained 50.13%, 8.89% and 5.73% of the variance, respectively. The pattern matrix provided a three factor solution, which broadly supported the original DCQ subscales. Component 1 reflected panic-related concerns, component 2 reflected social concerns, and component 3 reflected accident-related concerns. However, item 12 significantly loaded onto both the panic-and accident-related components. Additionally, items 10 and 20 did not significantly load onto any component. Item 10 was close to loading onto panic (.38) and social components (.374), whilst item 20 was close to loading onto the accident-related component (-.341). The item communalities also suggested that item 20 did not share a lot of variance with other items, which may explain why it did not load onto any components (See Table 2.7). On this basis, whilst support for the 3-component solution was found, some of the items may not have loaded onto their respective components; this may be due to ambiguity of the items in question.

**Table 2.7: A comparison of 2 and 3-component solutions for the Driving Cognitions Questionnaire**

| Item | | 2-component model | | 3-component model | | | Communalities |
|---|---|---|---|---|---|---|---|
| | | Component 1 | Component 2 | Component 1 | Component 2 | Component 3 | |
| 12 | I will be trapped. | **0.87** | -0.07 | **0.54** | -0.11 | **-0.49** | 0.69 |
| 14 | I will be stranded. | **0.85** | -0.18 | **0.72** | -0.04 | -0.16 | 0.63 |
| 16 | My heart will stop beating. | **0.83** | -0.22 | **0.88** | 0.08 | 0.14 | 0.71 |
| 18 | I will not be able to move. | **0.76** | 0.01 | **0.61** | 0.11 | -0.19 | 0.61 |
| 11 | I will die in an accident. | **0.71** | 0.10 | 0.27 | -0.10 | **-0.69** | 0.65 |
| 6 | I will tremble and not be able to steer. | **0.71** | 0.09 | **0.61** | 0.22 | -0.12 | 0.63 |
| 3 | I will be unable to catch my breath. | **0.69** | 0.07 | **0.46** | 0.06 | -0.36 | 0.54 |
| 7 | I will be injured. | **0.64** | 0.24 | 0.27 | 0.08 | **-0.60** | 0.66 |
| 19 | People riding with me will be hurt. | **0.61** | 0.24 | 0.12 | -0.03 | **-0.78** | 0.68 |
| 9 | I will injure someone. | **0.58** | 0.34 | 0.15 | 0.11 | **-0.70** | 0.72 |
| 10 | I will not be able to think clearly. | **0.57** | 0.38 | 0.38 | 0.37 | -0.30 | 0.70 |
| 13 | I will cause an accident. | **0.50** | 0.38 | 0.06 | 0.12 | **-0.71** | 0.67 |
| 20 | I will lose control of myself and will act stupidly or dangerously. | **0.49** | 0.23 | 0.27 | 0.18 | -0.34 | 0.41 |
| 8 | People will think I am a bad driver. | -0.09 | **0.93** | -0.10 | **0.89** | -0.06 | 0.81 |
| 2 | People I care about will criticise me. | -0.13 | **0.87** | -0.11 | **0.86** | -0.01 | 0.69 |
| 15 | I will hold up traffic and people will be angry. | 0.04 | **0.81** | -0.02 | **0.77** | -0.13 | 0.71 |
| 5 | Other people will notice that I am anxious. | 0.30 | **0.56** | 0.26 | **0.62** | -0.07 | 0.63 |
| 17 | People will laugh at me. | 0.29 | **0.52** | 0.34 | **0.66** | 0.08 | 0.63 |
| 4 | I cannot control whether other cars will hit me. | 0.18 | **0.50** | -0.29 | 0.11 | **-0.79** | 0.57 |
| 1 | I will not be able to react fast enough. | 0.36 | **0.46** | -0.04 | 0.18 | **-0.67** | 0.59 |

### 2.3.5.2 Driving Behaviour Survey

Parallel analysis found four eigenvalues greater than 1, but only three of these were deemed significant. However, the produced scree plot indicated a potential 4-factor solution based on its point of inflection (See Figure 2-). Both solutions were explored using a PCA.

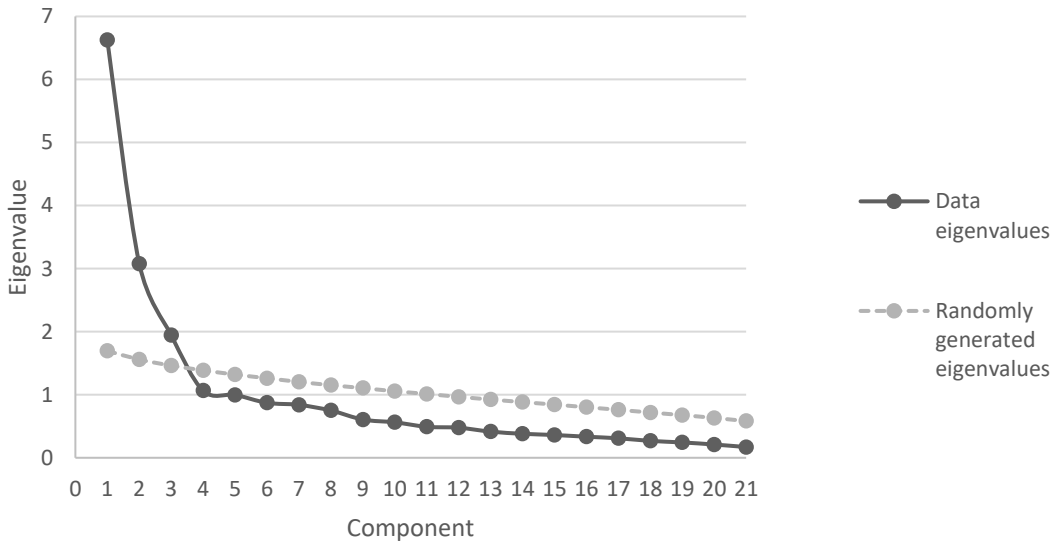



*Figure 2-3: Eigenvalues for the DBS data compared to randomly generated eigenvalues for the parallel analysis. The data from this plot suggests points of inflection at either 3 or 4 components.*

The KMO and Barlett's tests indicated that the date were suitable for a PCA, as these values were .854 and <.001 respectively. The three-component solution explained 31.54%, 14.66% and 9.26% of the variance respectively. The pattern matrix associated with this data indicated a clear 3-component solution that supported the DBS subscales; component 1 was made up of exaggerated safety-cautious behaviours, component 2 consisted of aggressive or hostile behaviours, and component 3 was made up of anxiety-based performance deficits. Whilst item 15 did not significantly load onto any component, it was close to loading onto the aggressive behaviours subscale (.392). The 4-factor solution explained an additional 5.07% of

the variance, however the interpretation of components was slightly less clear. Whilst components 1, 2 and 3 were reflective of exaggerated safety-cautious behaviours, aggressive behaviours and anxiety based performance deficits respectively, a fourth component consisted of items 1, 9 and 15, whilst item 16 did not significantly load onto any component. The fourth component could potentially be interpreted as a loss of attentional control, however item 15 (“I pound on the steering wheel when I’m nervous”) may not necessarily fit this interpretation. Therefore, these findings indicated support for the original 3-factor solution.

**Table 2.8: A comparison of 3 and 4-component solutions for the Driving Behaviour Survey**

| Item | | 3-component model | | | 4-component model | | | | Communalities |
|---|---|---|---|---|---|---|---|---|---|
| | | Component 1 | Component 2 | Component 3 | Component 1 | Component 2 | Component 3 | Component 4 | |
| 11 | I try to put distance between myself and other cars. | **0.90** | 0.00 | 0.16 | **0.92** | -0.03 | 0.14 | 0.05 | 0.76 |
| 13 | I try to stay away from other cars. | **0.79** | -0.03 | -0.11 | **0.77** | -0.03 | -0.16 | 0.03 | 0.70 |
| 8 | I maintain a large distance between myself and the driver in front of me. | **0.76** | 0.01 | 0.12 | **0.84** | -0.04 | 0.18 | 0.21 | 0.63 |
| 12 | I maintain my speed in order to calm myself down. | **0.71** | 0.04 | -0.07 | **0.70** | 0.04 | -0.10 | 0.04 | 0.57 |
| 19 | During bad weather, I drive more cautiously than other vehicles on the road. | **0.70** | 0.07 | -0.02 | **0.56** | 0.12 | -0.23 | -0.32 | 0.59 |
| 3 | I slow down when approaching intersections, even when the light is green. | **0.55** | 0.09 | -0.09 | **0.50** | 0.11 | -0.16 | -0.07 | 0.38 |
| 16 | I decrease my speed until I feel comfortable. | **0.47** | -0.02 | -0.24 | 0.34 | 0.03 | -0.40 | -0.23 | 0.41 |
| 10 | I make gestures at the driver/drivers who made me nervous. | 0.00 | **0.90** | 0.12 | 0.03 | **0.89** | 0.20 | 0.10 | 0.77 |
| 17 | I honk my horn at the driver who made me nervous. | -0.07 | **0.80** | -0.02 | -0.10 | **0.82** | -0.01 | -0.02 | 0.64 |
| 7 | I let the driver who has made me nervous know that I am upset. | -0.09 | **0.77** | -0.14 | -0.08 | **0.77** | -0.06 | 0.12 | 0.66 |
| 20 | I swear/use profanity when I am driving. | 0.15 | **0.76** | 0.16 | 0.07 | **0.79** | 0.08 | -0.21 | 0.61 |
| 18 | I try to find ways to let other drivers know that they are making me nervous. | 0.00 | **0.72** | -0.13 | -0.04 | **0.74** | -0.12 | -0.02 | 0.61 |
| 2 | I yell at the driver/drivers who make me nervous. | 0.14 | **0.67** | -0.08 | 0.13 | **0.68** | -0.07 | 0.03 | 0.55 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 15 | I pound on the steering wheel when I'm nervous. | 0.01 | 0.39 | -0.32 | 0.12 | 0.36 | -0.12 | **0.41** | 0.44 |
| 5 | I drift into other lanes. | -0.10 | 0.01 | **-0.88** | -0.12 | 0.05 | **-0.79** | 0.26 | 0.73 |
| 4 | I have trouble staying in the correct lane. | 0.02 | -0.07 | **-0.85** | -0.04 | -0.03 | **-0.83** | 0.14 | 0.70 |
| 1 | I lose track of where I am going. | 0.02 | 0.05 | **-0.69** | 0.09 | 0.04 | **-0.51** | **0.42** | 0.57 |
| 6 | I forget to make appropriate adjustments to speed. | -0.04 | 0.20 | **-0.63** | -0.07 | 0.23 | **-0.58** | 0.16 | 0.50 |
| 14 | I have trouble finding the correct lane. | 0.27 | -0.05 | **-0.59** | 0.17 | 0.01 | **-0.68** | -0.07 | 0.57 |
| 21 | I have difficulty merging into traffic. | 0.34 | -0.14 | **-0.57** | 0.16 | -0.05 | **-0.76** | -0.27 | 0.69 |
| 9 | I forget where I am driving to. | -0.01 | 0.10 | **-0.52** | 0.18 | 0.03 | -0.20 | **0.70** | 0.63 |

## 2.4 Discussion

There were two main aims to the current study. The first aim was to establish the psychometric properties of two established driving anxiety questionnaires, the DCQ and the DBS. The second aim was to investigate the specific contributions of both driving anxiety and trait anxiety to DCQ and DBS scores, as well as the degrees of anxiety and avoidance of specific situations. Overall, results provided support for the use of the DBS and DCQ as measures of anxiety-related thoughts and behaviours. Specifically, driving and trait anxiety were found to make specific contributions to scores on both scales as well as anxiety and avoidance of specific situations. Along with individual contributions of demographic variables such as gender, age and experience, these findings could be useful in tailoring individual training and exposure programs for drivers in the general population who experience anxiety, or avoid certain driving situations due to anxiety.

### 2.4.1 Findings

#### 2.4.1.1 The effects of gender, age and experience

Firstly, findings regarding demographic variables provide overall support for the previous literature. Females reported greater levels of driving anxiety and fear, as well as greater DCQ scores and a greater degree of anxiety based-performance deficits. In addition, regression analyses found that females were still less likely to report using aggressive reactions, even when STICSA driving and trait scores were considered. This supports previous research that has found that males not only score higher on scales on aggression related scales such as the Propensity for Angry Driving Scale, but also found a decreasing number of males in groups when they were separated into trait anxiety groups (Dula et al., 2010). Additionally, females

were more likely to report greater levels of anxiety in driving situation involving manoeuvres, bad weather, night-time driving, driving in unfamiliar locations and motorway driving. With the exception of night-time and motorway driving, females were also more likely to show greater levels of avoidance in these situations. Thus the findings suggest that future programs tailored to reduce anxiety would particularly benefit females if training was conducted in such environments. Additionally, the fact that females reported a greater degree of anxiety-based performance deficits suggests that training should focus on maintaining cognitive focus during anxiety-provoking driving situations.

One discrepancy that is perhaps less easy to explain is the difference between t-test and regression results regarding gender differences in response to DBS aggression scores. Whilst the regression model suggested that females were less likely to show aggressive behaviours in response to an anxiety-provoking situation, no significant differences were found when conducting t-tests. The spread of driving state and trait anxiety scores, as shown in Figure 2-1, suggested that scores may have been positively skewed. This effect was common across both genders; however, a small proportion of females reported driving and state anxiety levels that ranged from 70-84, whilst males did not. This explains the significant mean differences in driving and trait anxiety scores across genders; however, if the distribution frequencies of DBS aggression scores may also aid the interpretation of these discrepancies. Like the driving and trait anxiety scales, these distributions are positively skewed, which may explain the lack of mean differences between groups (See Figure 2-4). However, a slightly higher proportion of males provide a score of 3 or higher on the scale (24%) compared to females (22%). This may explain why the regression suggests that males may be more likely to show aggressive behaviours; due to the positive skew of scores, these effects may be cancelled out in a simple t-test. However, these findings are based on unequal sample sizes,

and future research should aim to explore this assumption with a higher proportion of males compared to the current study.

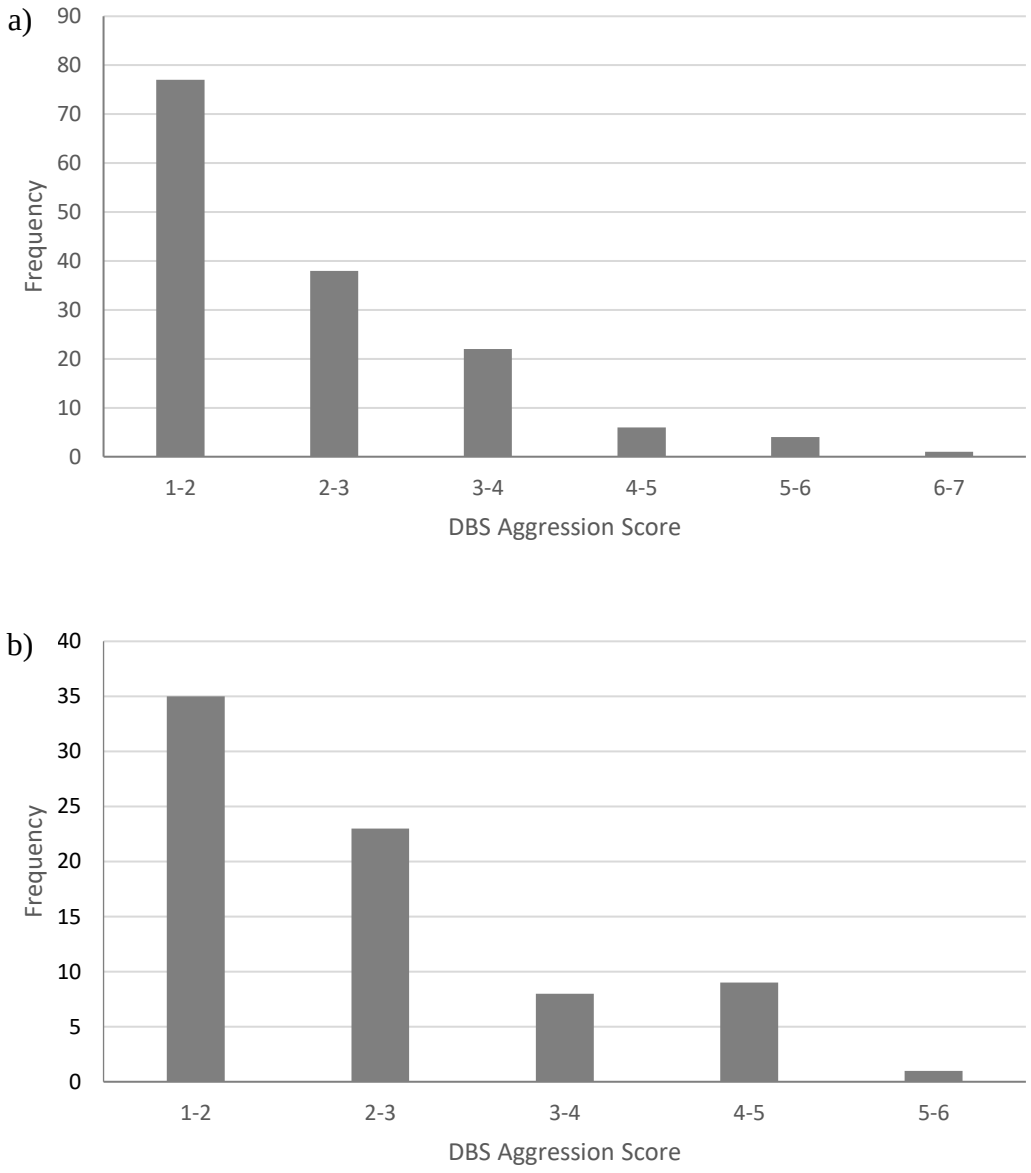



*Figure 2-4: Distributions of DBS aggression scores across a) females, and b) males.*

Age and experience negatively correlated with levels of anxiety, DCQ scores and DBS scores, which suggests that future programs would be particularly beneficial to younger drivers with less experience. In particular, training may wish to focus on reducing the amount

of aggressive reactions in younger drivers, as age was a significant negative predictor of DBS aggression scores. This finding supports previous research that has found a negative relationship between age and aggression (Garrity & Demick, 2001; Przepiorka et al., 2014), however, it does not explain why younger drivers are more likely to show aggressive behaviours. It has been suggested that glorification of risky or aggressive driving behaviours in the media may justify greater aggression levels (Fischer et al., 2012; Przepiorka et al., 2014), and the fact that the current findings support previous research means that such explanations should be investigated in further detail in future research.

Age was also a negative predictor of reported anxiety during night-time driving, suggesting that younger drivers may benefit to additional exposure to driving in darker conditions. It is possible to suggest that there is an increased anxiety towards night-time driving due to a lack of exposure to such conditions in driver training. However, on this basis, we would also expect experience to negatively predict night-time driving anxiety, which it does not. It is also interesting that experience positively predicted levels of aggression and avoidance of driving in residential areas. It is possible that with increased experience, drivers are more likely to expect others to show courtesy, or to possess a greater level of driving skill, hence there may be greater levels of aggression when this is not the case. Additionally, more experienced drivers may choose to avoid driving in residential areas on the basis that alternative road types make it easier to reach a destination. Both explanations could be explored in future research; the use of more detailed questionnaires or focus groups could provide richer information on such issues. This type of dataset may also provide rich information on some of the more unexpected findings regarding accident involvement, which was a negative predictor of social concerns and avoidance of certain driving situations.

#### 2.4.1.2 The contribution of driving and trait anxiety to anxiety-related thoughts and actions

The fact that DCQ and DBS scores positively correlated with each other, as well as with STICSA driving and trait scores, strongly supports the claim that each scale is related to a similar construct, anxiety. Regression analyses also suggested that both driving and trait anxiety were strong predictors of subscale and total scores. Overall, driving anxiety scores were stronger predictors than trait anxiety; however there were some exceptions to this. Firstly, trait anxiety was a stronger predictor of DCQ social concerns. Secondly, trait anxiety was a stronger predictor of DBS aggression scores. Not only does this support previous research that has associated trait anxiety with levels of aggression (Deffenbacher et al., 2000), but it also suggests that the driving worries and behaviours associated with higher levels of trait anxiety may be more emotionally-based.

It is also worth noting that trait anxiety was a significant predictor of anxiety-based performance deficits, but not exaggerated safety-cautious behaviours. This suggests that any performance changes associated with higher anxiety levels of trait anxiety may be attentional-based, and such changes could be particularly due to a preoccupation on socially-focused worries whilst driving. This may support theories such as processing efficiency theory (Eysenck & Calvo, 1992), which suggest that preoccupation with worrisome thoughts may lead to changes in processing efficiency, if driving performance itself is not affected. It may also explain why mixed conclusions have been found in simulator research regarding trait anxiety and driving performance; research may need to focus on behaviours more closely related to those specified on the anxiety-based performance deficits subscale, such as drifting into other lanes and remembering where the driver is travelling to.

Levels of STICSA driving anxiety were also a strong, positive predictor of anxiety and avoidance ratings across all 11 specified driving situations. Overall, the fact that it remains a strong predictor of avoidance ratings suggests that those with higher levels of driving anxiety may use avoidance as a coping strategy in order to avoid more difficult driving tasks. However, trait anxiety was also a predictor of ratings of anxiety and avoidance of night-time driving and driving in residential areas. In particular trait anxiety was a stronger predictor of avoidance of night-time driving avoidance than driving anxiety. This, alongside results from the DCQ and DBS subscales, suggest that whilst driving anxiety may be an overall better predictor of specific levels of anxiety, trait anxiety also provides a significant contribution in specific contexts. Nonetheless, the overall impact of driving anxiety on avoidance ratings provides support for the use of exposure therapy to more difficult or anxiety-provoking driving situations.

These findings also extend previous discussions which have suggested ratings of avoidance may not necessarily be due to anxiety (Taylor & Sullman, 2009). Whilst the current findings do not directly imply that anxiety is one of the main reasons for driving avoidance, they do suggest that anxiety is at least a strong predictor of avoidance across a wide variety of situations. They do, nonetheless, provide some support for the original claim that avoidance ratings may not necessarily be due to anxiety. This is on the basis that demographic variables such as age, gender, accident history, and experience make individual contributions in certain circumstances. The fact that contributions towards driving avoidance are not consistent across all situations highlights the complex nature of driving avoidance; future research should seek to use more extensive information on driving history and driving skill in order to provide a greater assessment of the contributions towards driving avoidance.

#### 2.4.1.3 The construct validity of the DCQ and DBS

A series of PCAs were conducted on both the DCQ and DBS questionnaires, and overall these demonstrated evidence of construct validity. Whilst both 3 and 4-component solutions were found for the DBS, this was also the case when the scale was originally constructed (Clapp, Olsen, Beck, et al., 2011). The original study also found 4 and 5-component solutions, which contained few salient loadings that made interpretation of each component ambiguous. On this basis, the three-component solution was chosen on the grounds of conceptual clarity. The same issue was found in the current study, but the overall clarity of the 3-component solution supports the original scale's construction. However, the opposite pattern was found for the DCQ. Parallel analyses and scree plots suggested 2 and 3-component solutions, the former of which provided a large amount of loadings onto one component, making interpretation ambiguous. When the 3-component solution was explored, clearer support for the original scale was found; however, items 10 and 20 did not significantly load onto any component. It is suggested that this may be due to the ambiguity of the items in question. For example, item 10 suggests that "I will not be able to think clearly". The original DCQ suggests this is a panic-related item, whilst in the current study it was close to loading onto both panic and social components. Item 20 also states that "I will lose control of myself and act stupidly or dangerously". The original scale suggests this is an item addressing social concerns, but the act of losing control of the car or acting dangerously may be more relevant to accident concerns. This would explain why item 20 was close to loading onto the accident component in the current study. The initial construction also found that some items loaded significantly onto more than one component (Ehlers et al., 2007), meaning that this issue is not specific to the current study. Overall, this suggests that there is stronger evidence of construct validity for the DBS than for the DCQ, and that there is an issue with ambiguity of items on the DCQ.

### 2.4.2 Limitations

Some of the findings in the current research have implications particularly for road safety practitioners, as training programs could be made to target individuals within a non-clinical population, in specific demographic groups and with different types of anxiety. However, one limitation of the current research is the use of self-report data. Whilst recent research has found positive relationships between self-report responses and driving performance in a simulated task (Taubman-Ben-Ari, Eherenfreund-Hager, & Prato, 2016), this does not mean that the behaviours suggested in the current study would necessarily translate into real-road behaviour. This case is particularly true for the current study, as the driving concerns and behaviours expressed by the DCQ and DBS have not been explored within simulated or real-road contexts. Therefore it would be important for future research to investigate the effects of anxiety-provoking situations on reactions outlined in the DBS, or to perhaps investigate whether specific types of driving situation invoke different types of driving concern, and whether effects in either case are exacerbated by either driving or state anxiety.

Secondly, the current research was targeted at members of the general population as opposed to patient groups or students. Age, experience and annual mileage varied greatly in the data, suggesting that a more representative group of everyday drivers completed the survey compared to previous research. Additionally, only a small percentage of drivers were students, whilst the remaining participants varied in employment status. However, the majority of participants were female. Whilst this has previously been the case in questionnaire research (Sullman & Taylor, 2010), statistics on UK drivers suggest that a greater proportion of drivers are male (Department for Transport, 2015a). Additionally, participants in the current study had a higher annual mileage across all age groups when

compared with national statistics (Department for Transport, 2015b). Future driving research using questionnaire methods may wish to attempt targeting a greater proportion of male respondents, in order to obtain a more representative sample of participants.

One possible result that should perhaps be taken with caution in this study is the contribution of accident involvement, as it was measured in a binary fashion. This means that participants may have reported being in an accident of any degree of severity, ranging from a minor bump with another car to a large-scale collision with severe injuries. As previous research has demonstrated that accident severity can have an impact on subscale scores such as the DBS (Clapp, Olsen,et al., 2011a), this issue should perhaps be considered in future research. Additionally, when participants who had previously been involved in an accident were asked how long ago it had taken place, responses ranged from the previous week to around 37 years ago. This large range of responses could be seen as problematic for two reasons. Firstly, as already discussed, these accidents could be ranging in severity. Secondly, research has demonstrated that despite the high arousal associated with the pain and personal trauma of being in an accident, memory for the occurrence and severity of driving events can be surprisingly poor (Groeger, 2000). Over time, research has shown that there are systematic distortions in the recall of accident occurrence to the degree that around a quarter of accidents are forgotten per year (Maycock, Lockwood & Lester, 1991). Subsequent research has also demonstrated that when asked to rate the severity of accident or near-accident in question, these ratings are inflated when recalling over a period of two weeks in comparison to reporting immediately after a journey (Chapman & Underwood, 2000). Thus, memory of accidents occurring and the severity of these accidents can be forgotten or distorted over time. This, along with the fact that accident involvement was treated as a binary measure, suggests that the current results may need to be interpreted with these issues in mind.

### 2.4.3 Conclusions

The current research sought to investigate the psychometric properties of the DCQ and DBS, as well as investigate the specific contributions of driving and trait anxiety to these scores, as well as ratings of anxiety and avoidance. The study was also unique on the basis that it was investigating the psychometric properties of these scales in a non-clinical sample, who widely ranged in age, experience and driving history. Results suggested that ratings of driving anxiety specifically were strongly related to driving concerns, reactions and anxiety and avoidance ratings. However, there were instances in which those with higher trait anxiety showed greater levels of social concerns, aggressive reactions, and avoidance of night-time driving. Additionally, a series of demographic variables contributed towards levels of anxiety and avoidance in specific situations. Overall, these findings are useful for road safety practitioners in providing information on how to tailor interventions for those with higher levels of driving and trait anxiety, depending on specific demographic groups. Overall, levels of internal consistency and construct validity provided support for the use of the DBS and DCQ within driving research. However, the issue of item ambiguity on the DCQ may need to be explored in future research.

Additionally, whilst not discussed in detail here, results suggested that there were significant differences between ratings of anxiety and fear. This suggests that in self-report research, when given a detailed definition of the meaning of each term, differences can be found between the two ratings. To explore whether differences between fear and anxiety can be found in a more immersive context, the next chapter discusses a study attempting to find differences in fear ratings, according to different levels of trait anxiety, in a laboratory study.

# Chapter 3. A laboratory study of the behavioural, physiological and attentional markers of negative affect.

## 3.1 Introduction

What should be evident from Chapter 1 is the importance of studying negative affect in the field of driving. In particular, there is a need for further empirical research into the relationship between driving and anxiety. There seems to be a considerable gap in the literature on this subject, despite the fact that anxiety is one of the more prevalent feelings reported during driving (Roidl, Frehse, Oehl, & Hoeger, 2013). Chapter 1 highlighted how variables such as skin conductance, heart rate and eye movements have been measured within the context of driving and anxiety, and the use of such measurements should increase.

The lack of consensus over whether anxiety does affect driving behaviours could be due to confusion between anxiety and other negatively valenced emotions and dispositions. It has been noted in the literature that feelings such as anxiety are often misleadingly labelled in the literature. For example, one recent paper looking into the effects of emotions on driving consistently interchanges the terms 'anxiety' and 'fear' (Jeon et al., 2014). It is possible for both anxiety and fear to have similar effects. Research labelling drivers as 'fearful' suggests that such drivers rate themselves as poorer drivers (Taylor et al., 2007b), whilst other research that labels drivers as anxious has suggested that this subtype may be classified as more risky drivers (Ulleberg & Rundmo, 2003). However, it has also been highlighted that whilst fear is the result of a known, definite threat, anxiety in driving is experienced as a result of dangers that are less clear and obvious (Taylor et al., 2008). This distinction is important, as most people tend to perceive fear and anxiety as similar concepts within the driving field (Taylor & Paki, 2008); whilst both 'fearful' and 'anxious' drivers can be seen as

risky, the consequences of the actions of both types of driver, in behavioural and physiological terms, could differ from one another.

Some attempt has already been made to look at the effects of both anxiety and fear within the driving environment. In 2013, Schmidt-Daffy and colleagues had participants complete a computerised driving task (Schmidt-Daffy, 2013). It was acknowledged that fear and anxiety could occur within driving simultaneously to varying degrees, thus making it hard to distinguish between the two. However, it was proposed that fear can be induced because of task demands, such as those invoked within the environment, whilst anxiety may manifest because of internal conflict. Therefore, in the study's driving task, participants were required to continuously press a space bar to drive along a road, and occasionally brake at the presence of the silhouette of a deer. Task demand was manipulated by lowering levels of visibility on screen, in order to simulate fog, and internal conflict was manipulated by increasing levels of monetary penalty if a participant either crashed into a deer or did not complete a condition in sufficient time. They found that increases in subjective anxiety were dependent on the type of task performed. Anxiety levels increased in conditions of fixed speed when road visibility was reduced, whereas in conditions where the participant could choose their speed, anxiety only increased with increasing levels of internal conflict.

The results from this study, and the theory behind it, could complement the original theory about the difference between fear and anxiety, that fear is the result of known environmental demands, whilst anxiety is the result of unknown, more internal sources of threat. From a cognitive perspective, this could imply that fear and anxiety manifest because of simultaneous bottom-up and top-down influences respectively. In turn, this could support a transactional model of stress (Lazarus & Folkman, 1984). As discussed in Chapter 1, the

transactional model of stress is a dynamic model that suggests the environment imposes demands on the individual, but it is the degree of the individual's own coping resources that determines the response produced. This transactional model has been supported in previous driving research (Trimpop, Austin, & Kirkcaldy, 2000), and arguably it could apply to research into emotion and driving. For example, a traffic jam may impose demands on an individual, but it is the driver's individual levels of anger, whether state or dispositional, that determine whether an aggressive response is produced (Harris & Houston, 2010).

This seems to be the approach taken within the Scmhidt-Daffy paper, and this is the approach taken within the current study, however, one criticism of the previous study is that it lacked ecological validity. For example, the 'road' participants were required to drive on was in fact a grey background, and the participant had to brake at the silhouette of an object rather than an actual object. Thus, whilst the current study was also a computer-based task, participants were instead required to respond to clips of real driving events, such as hazards and crashes. This approach of responding to recorded driving events is often seen in tests or observations of hazard perception. Hazard perception often requires a participant to watch a video of a driving event, and respond when they believe a hazardous event is occurring. The advantage of researching hazard perception is that attentional and physiological data can be reliably recorded, to assess where drivers prioritise their attention and how they react to dangerous events. For example, early research into hazard detection suggested that drivers' spread of horizontal search narrows when they locate a potential threat (Chapman & Underwood, 1998). Further research indicates that these effects can differ according to factors such as increased demands and experience. For example, preoccupation whilst completing a hazard perception task results in reduced horizontal search and a greater rate of blinks per minute, which could indicate the effects of an increased use of cognitive resources (Savage et al.,

2013). Chapter 1 also noted an increase in skin conductance levels with police drivers despite reporting similar hazard ratings (Crundall et al., 2003).

The findings from Crundall et al.'s (2003) study highlight the importance of studying physiological as well as attentional data in this kind of task, as it suggests that more experienced drivers are more prepared in dealing with hazardous driving situations. Therefore, in the current study, as well as taking behavioural and attentional variables, physiological variables were also taken to assess participants' reactions to different levels of danger within driving clips. As described in Section 3.2.2, physiological measures that were taken included skin conductance, heart rate and blood pressure. Whilst skin conductance and heart rate measures have been described as useful within the driving context (Johnson et al., 2011), blood pressure results are conflicting within the anxiety literature, and have been rarely studied within the field of driving, making it more difficult to predict what effects demand and anxiety would have on blood pressure variables.

To summarise, the aim of the first study was to assess how participants would react to videos of genuine driving situations, each with differing levels of driving threat. Participants were required to watch these videos, imagining they were the driver of the car, and continuously rate how much fear they would feel if they were the driver in the given situation. Additionally, unlike the previous research, anxiety was measured from a dispositional perspective; this approach was chosen on the basis that questionnaire research suggests that those with higher trait anxiety are more dangerous drivers (Dula et al., 2010; Shahar, 2009). Two questions were being addressed by the current study. Firstly, can videos with increasing levels of threat affect behavioural, attentional and physiological responses? Secondly, can this effect be influenced by levels of trait anxiety? It was predicted that increasing levels of

threat produced in the videos would be reflected by increasing levels of fear, which would in turn be reflected by changes in attentional and physiological measures. It was also predicted that trait anxiety would have an additional influence on responses.

## 3.2 Methods

### 3.2.1 Participants

Fifty-nine participants were initially recruited for this study; however, data from two of the participants had to be discarded prior to analysis, leaving a total of 57 in the final analysis. They ranged in age from between 18-42 years (*m*= 22.75; *sd* = 4.54). Forty-one were female and 16 were male. They were all either students or employees from the University of Nottingham, who were recruited using a poster advertisement. All participants had been in possession of a full driver's licence for an average of 4.59 years (*sd*=4.58) and drove an average of 6929.8 miles per year (*sd*=3867.7). Fifteen had been in a minor road accident in the past three years, one had been in a major road accident and one had been convicted of driving offences. Ethical approval was obtained from the University of Nottingham's Ethics Committee prior to commencing testing, and participants signed a consent form prior to participation stating their willingness to take part. All participants were compensated with an inconvenience allowance at the end of the study. At the same time, they were also made aware of the potential risks to driving after completing a study involving the viewing of car accidents. Participants acknowledged this and subsequently signed a post-trial consent form stating that they were willing to wait for at least half an hour before driving on real roads again.

### 3.2.2 Design

This study had a mixed design including one continuous variable and two within-subjects factors. The continuous variable was the level of trait anxiety expressed by the participants, according to STAI-Y2 scores (See Section 3.2.3).

The first within-subjects variable was the level of environmental arousal shown in driving clips, all of which were taken from the driver's point of view. Clips contained either low, moderate or high levels of arousal. In the lowest level, a car would be driving down a road and no negative events would occur, making this a 'safe' clip. Moderate and high arousal clips were considered 'dangerous' clips on the basis that they contained an event that was dangerous for the driver in the clip. Clips with moderate levels of arousal were practice Hazard Perception clips provided by the Driving Vehicle Standards Agency (DVSA); in these clips a car would be driving along a road, and an event would happen so that the driver had to stop or take evasive action to avoid a crash. Clips with high levels of arousal included a crash that would happen to the driver. For ethical purposes none of these crash clips contained any fatalities or evidence of visual harm to groups such as pedestrians and animals. In the dangerous clips, only one event was shown, so in moderate arousal clips, only one hazard or crash occurred. Six clips were shown in total for each level of arousal, leaving a total of 18 clips. To control for effects of clip time (as video clips of crashes were significantly shorter than Hazard Perception clips ($t$ (10)=8.514, $p$<.0001)), half of the safe clips matched the average length of time of Hazard Perception clips and the other half matched the average length of time for crash clips. Clip order was also counterbalanced across participants.

The second within-subjects variable was the time window in which measurements were taken, so that the effects of driving events on the chosen variables could be assessed across time. There were three time periods measured of this: a 'precursor window' measured between the onset of a hazard or crash, until this event had occurred, a 'control' window before this (the period of time from the start of the clip until the beginning of the precursor window) and an 'outcome' window (the period of time from the end of precursor window until the end of the video clip). Clips provided by the DVSA already contain defined precursor windows that mark the start and end of each hazard. These precursor windows begin the moment the stimulus that causes the hazard appears on screen and end once the hazard has fully developed. Responses from the participant before or after this window indicated a response that was either too early or too late. This same criteria were applied for crash clips. Thus in these instances, the precursor window began on the first appearance of the vehicle that eventually results in the crash, and ended at the point of impact between cars. To create comparable windows within safe clips, these windows were matched for time by taking the average start and end frame of hazardous and crash clips, and using these as windows for the safe clips that were the same length as the hazardous and crash clips respectively.

A series of behavioural, physiological and attentional dependent variables were taken in this study. Scores on the Driver Stress Inventory and Driver Coping Questionnaire (Matthews et al., 1997) were also measured, although this was only analysed with regards to anxiety levels.

Behavioural variables included mean perceptions of fear and changes in responses (delta response) made on a variable response transducer (VRT) measured on a scale between 0 and 9. A measure of reaction time was also taken; however, rather than using a discrete button

press, as would be expected in the standard Hazard Perception Test, responses in this study were defined as the time in which there was a significant upturn in the recorded VRT trace (Pelz & Krupat, 1974). In order to control for the length of each precursor window, these times were subsequently converted into 'Hazard Perception' scores (a diagram describing this calculation, as well as the study's overall design, can be found in Figure 3-1). As hazardous clips contain a genuine hazard, this score is reflective of the one they would receive in an actual Hazard Perception Test. However, for safe and crash clips, this score is more reflective of the likelihood of a participant responding to levels of fear, and how soon this response is made.

Physiological measures included mean and changes in skin conductance (in microSiemens, or μS), the amount of electro dermal responses (EDRs) produced per second, heart rate (in BPM), and blood pressure (including mean arterial pressure, systolic and diastolic mmHg). Whilst it is possible to measure the total amount of EDRs for each time window, this measure could be confounded due to the fact that time windows were different (in seconds) for each clip. Therefore, EDRs per second were chosen as a standardised measure. Attentional variables included saccadic amplitude (in degrees) and number of fixations per second.

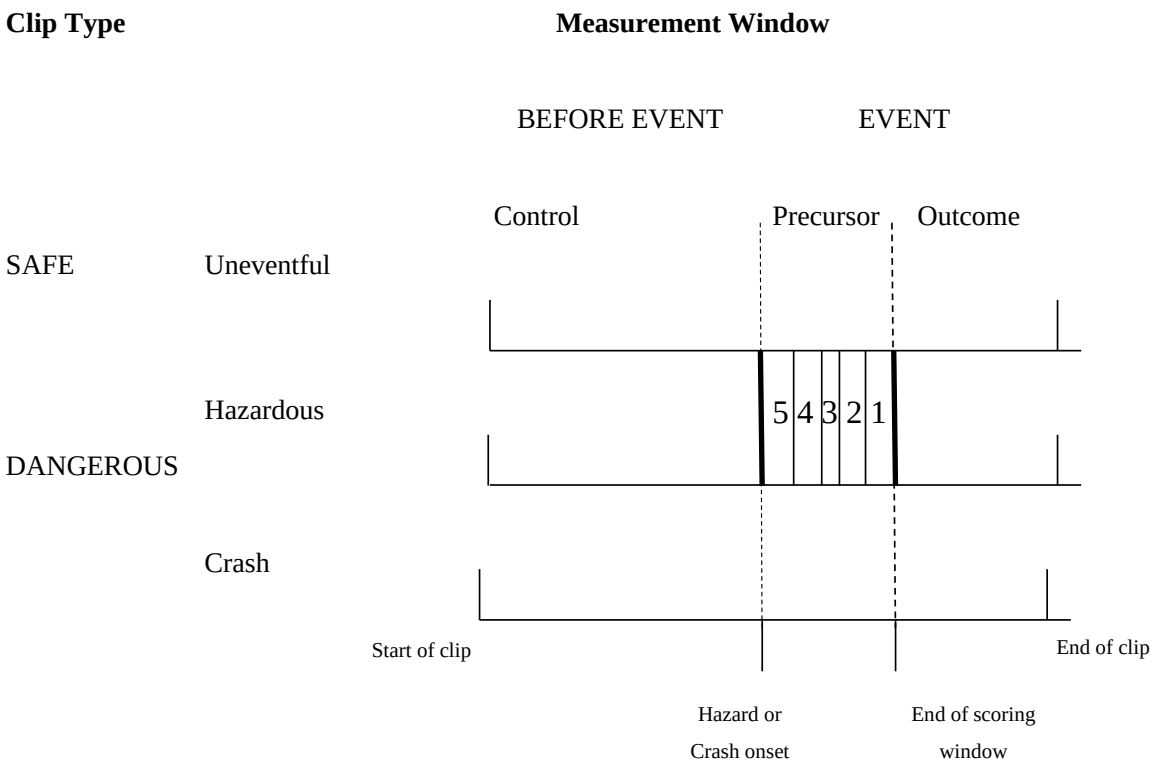



*Figure 3-1: Diagram of the study's design. This shows the types of safe (uneventful) and dangerous (hazardous or crash) clips that were shown to participants, along with the types of windows (control, precursor or outcome) that measurements were taken in. During each precursor window, scores of either 5,4,3,2 or 1 were given according to whether the participant made a response up to 20,40,60,80 or 100% of the way into the window respectively; any responses made after this window, or no responses at all, obtained a score of 0. This criterion is based on the UK Driver and Vehicle Standards Agency's Hazard Perception Test.*

### 3.2.3 Materials & Stimuli

#### 3.2.3.1 Questionnaires

To measure anxiety, both parts of the State-Trait Anxiety Questionnaire were used (STAI; Spielberger, 1983). Scoring was completed according to instructions provided within the STAI manual, and as described in Chapter 1, participants could score a minimum of 20 and a maximum of 80 on the scale. In the present study, the average trait score was 37.79 (*sd*=7.77)

and the average state score was 31.33 (*sd*=6.12). Reliability of both state and trait aspects of the scale were also high (Cronbach's α= .853 and .894 respectively).

To look at the effects of anxiety on the participant's driving, the Driver Stress Inventory (DSI- Matthews et al., 1997) was also issued (See Appendix 'E'). The inventory consists of two sections; section 'A' is a 12 item questionnaire looking at demographic driving information, and section 'B' is a questionnaire consisting of 41 items all measured on an 11 point scale. These items look at the role of general driver stress through five dimensions: Dislike of Driving, Aggression, Thrill Seeking, Fatigue Proneness and Hazard Monitoring. Responses given can range from '0' to '10', which means the participants either agree 'very much' with the statement or 'not at all', depending on the framing of the question. The scale has been useful in predicting driver outcomes in several studies (Rowden, Matthews, Watson, & Biggs, 2011; Susilowati & Yasukouchi, 2012). The Driver Coping Questionnaire was also included in this (See Appendix 'F'). This is a 35-item questionnaire measuring responses on a 6 point scale. The items look at the role of specific stressful driving events, recalled by the participant, through another five dimensions: confrontive coping, task focus, emotion focus, reappraisal and avoidance. Responses range from '0' to '5', with '0' meaning someone agrees with the statement 'not at all', to '5' meaning they agree with the statement 'very much'. On both questionnaires, subscale scores range from 0 to 100, with higher scores implying a greater likelihood of committing a specific behaviour. Cronbach's α indicated that reliability scores on the DSI ranged from .634 (for the 'Hazard Monitoring' subscale) to .843 (for the 'Aggression' subscale). Reliability scores for the Driver Coping Questionnaire ranged from .61 (for the 'Avoidance' subscale) to .874 (for the 'Emotional Focus' subscale).

### 3.2.3.2 Driving clips and physiological equipment

Stimuli consisted of nine hazard perception video clips taken from the Driving Vehicle Standards Agency (DVSA), and nine videos taken from various internet sources. Due to the fact that hazard perception clips did not contain any audio, sound was removed from all clips to remove possibility of this becoming a confound. The 18 clips were then edited into one video using Final Cut Pro working on a Mac PC, according to the various counterbalancing orders that had been decided. To recognise the beginning and end of each video clip in the software packages used during the study, one second of white noise was placed at the beginning and end of each driving clip. Two seconds prior to viewing each clip participants would see message saying 'Clip 'X'' written in white Arial font on a black background, with 'X' representing the appropriate clip number. After these videos had been created they were then recorded onto Sony MiniDV video cassettes using a Sony video recorder.

Cassettes were then played back onto an 18 inch Sony monitor via a Sony DVCam. To track eye movements, a fixed head & chin rest was placed approximately 60cm away from the Sony monitor, and eye movements were tracked using a SensoMotoric Instruments IView X RED eye tracker. The tracker had a sampling rate of 50 Hz and a spatial resolution better than 0.5 degrees. Eye movement calibration was enabled using WinCAL and IViewX software, both of which were operated using separate computers. Perceptions of fear were measured using a Biopac variable response transducer TSD115, and galvanic skin response was measured on the non-dominant hand using two finger straps attached to the ring and little fingers, with the finger straps filled with skin conductance gel (GEL101, Biopac Systems Inc., Goleta, CA, USA). Blood pressure and heart rate were measured using Cnap Monitor 500; prior to experimentation the participants were fitted with appropriately sized arm and

finger cuffs provided with the Cnap monitor. All of these devices were attached to a Bipoac MP150 amplifier, which was linked to a third computer recording these responses using Acqknowledge version 4.1, recording at a sampling rate of 1000Hz.

### 3.2.4 Procedure

After consenting to take part in the study, participants completed the STAI, DSI and Driver Coping Questionnaire, which took 10 minutes. The physiological equipment was then placed on the participant's non-writing hand and arm, before eye tracking calibration took place. Blood pressure calibration then took place, before the instructions for the experiment were explained to them. They were told that they would be watching a series of driving clips, all taken from the driver's point of view. They were to watch the videos as if they were the driver of the car, and as best as possible give a continuous rating, using their writing hand, of how much fear they would feel if they were the driver in the situation, using the variable response transducer provided to them. The scale ranged from 0 to 9, with 0 indicating that no fear would be felt and 9 indicating the maximum amount of perceived fear. The scale started at 0 for the start of each clip to control for starting position on the transducer. After practising looking at the screen and moving the transducer scale at the same time, the task then took place; this lasted approximately 15 minutes, after which equipment was removed, debriefing took place and inconvenience allowance was provided.

## 3.3 Results

Prior to analysis, behavioural and physiological data were copied and pasted into an Acqknowledge journal, before being converted to an Excel file, which was later uncounterbalanced and averaged to obtain descriptive data for each participant. Then this was entered into IBM SPSS Statistics 21 to conduct a series of 3x3 (Clip type x measurement window) ANCOVAs. Eye movement data were extracted from iViewX into an iViewX Events file. Using a script created in MATLAB R2012a, this file was parsed into its appropriate measurement windows and uncounterbalanced to obtain descriptive data, before inputting into SPSS for analysis.

Recent literature emphasises that prior to conducting an ANCOVA in a study that contains within-subject variables, covariates of interest need to be centred in order to avoid distorting any within-subjects effects or obtaining a Type I error (Schneider, Avivi-Reich, & Mozuraitis, 2015). Therefore, all trait anxiety scores were centred prior to ANCOVA analyses by subtracting individual scores from the grand mean of STAI Y-2 scores.

All *F* values and results of significance can be seen in Table 3.2. When reporting results for VRT scores, eye movements, skin conductance, heart rate and blood pressure measures only within-subjects effects and interactions have been reported, on the basis that no significant effects of trait anxiety were found for these variables (all *p*s>.05). Partial eta squared is reported as a measure of effect size, and where there have been violations of Mauchley's assumption of sphericity, Greenhouse-Geisser corrected values have instead been reported. Where there are significant effects, planned a priori contrasts have been made, comparing safe to dangerous clips and hazardous to crash clips. Additional contrasts also compare

measures taken before the event to during the event, and the precursor of the event to its outcome (see Figure 3-1).

### 3.3.1 DSI and Driving Cognitions Questionnaire Responses

Two participants failed to complete the DSI, therefore their scores were excluded from analysis. Scores for each factor were calculated according to recommendations from Matthews et al. (Matthews et al., 1997). Pearson's correlational analyses found a significant relationship between aggression and thrill seeking ($r$=.319, $n$=55, $p$=.018), aggression and confrontational coping ($r$=.408, $n$=55, $p$=.002), dislike of driving and fatigue proneness ($r$= .386, $n$=55, $p$=.004), dislike of driving and emotional focus ($r$= .636, $n$=55, $p$<.0001), hazard monitoring and task focus ($r$= .387, $n$=55, $p$=.004), and hazard monitoring and reappraisal ($r$= .404, $n$=55, $p$=.002). Taking into consideration these moderate positive correlations and previous recommendations (Tabachnick & Fidell, 2007), the decision was made to conduct a MANCOVA on this data, with a centred trait anxiety score as a continuous covariate on all factors.

Results from the MANCOVA suggested that trait anxiety had a significant influence on the dislike of driving ($F$(1,53)=17.38, $p$<.001, $\eta_p^2$=.247) and fatigue ($F$(1,53)=4.42, $p$=.04, $\eta_p^2$ =.077) subscales of the DSI, and the task focus ($F$(1,53)=5.02, $p$=.029, $\eta_p^2$=.087), emotional focus ($F$(1,53)=40.08, $p$<.001, $\eta_p^2$=.431), and reappraisal ($F$(1,53)=6.19, $p$=.012, $\eta_p^2$=.114) subscales of the Driver Coping Questionnaire. A series of simple linear regression analyses were then performed on each of these significant relationships to assess the degree of influence trait anxiety has on each of the factors Table 3.1.

**Table 3.1: Simple linear regression analyses of Driver Stress Inventory and Driver Coping Questionnaire Factors significantly influenced by trait anxiety.**

| | $R^2$ | *B* | *SE B* | *B* |
|---|---|---|---|---|
| **Dislike of Driving** | . | | | |
| (Constant) | | 17.33 | 8.151 | |
| Trait Anxiety | .247 | .884 | .212 | .497** |
| **Fatigue** | | | | |
| (Constant) | | 27.28 | 9.16 | |
| Trait Anxiety | .077 | .501 | .238 | .277* |
| **Task Focus** | | | | |
| (Constant) | | 56.95 | 8.63 | |
| Trait Anxiety | .087 | .503 | 3.224 | .294* |
| **Emotional Focus** | | | | |
| (Constant) | | -29.12 | 12.27 | |
| Trait Anxiety | .431 | 2.02 | .319 | .656** |
| **Reappraisal** | | | | |
| (Constant) | | 20.45 | 12.19 | |
| Trait Anxiety | .114 | .829 | .317 | .338* |

*$p$<.05; **$p$<.001

**Table 3.2: *F* values and degrees of freedom for all dependent variables according to main effects (Clip Type and Measurement Window) and interaction**

| | Clip Type (*F*) | Measurement Window (*F*) | Clip Type*measurement window (*F*) |
|---|---|---|---|
| **Behavioural data** | | | |
| Mean fear perception | 307.9 (1.6,88.01)*** | 238.4 (2,110)*** | 81.52 (2.97,163.4)*** |
| Delta fear perception | 14.64 (2,110)*** | 9.96 (2,110)*** | .423 (3.24,178.36) |
| Mean hazard perception score | 76.36 (2,110)*** | 13.28 (2,110)*** | 20.73 (3.36, 184.7)*** |
| **Skin conductance** | | | |
| Mean skin conductance (μS) | 19.93 (2,108)*** | 17.78 (1.32,71.18)*** | 48.51 (1.54, 83.36)*** |
| Delta skin conductance | 18.86 (2,108)*** | 9.89 (15.79,96.84)*** | 6.44 (2.66,148.9)*** |
| EDR's per second | 31.09 (2, 108)*** | 10.85 (1.46, 78.99)*** | 6.24 (2.27, 122.78)** |
| **Heart Rate and Blood Pressure** | | | |
| Mean heart rate (BPM) | 2.99 (1.48, 78.25) | 16.24 (2, 106)*** | .71 (3.38, 179.1) |
| Systolic pressure | 3.75 (1.25, 66.3)* | 1.85 (1.77, 94.22) | .275 (2.8, 148.39) |
| Diastolic Pressure | .205 (1.13, 60.18) | 3.12 (1.64, 87.15) | 2.16 (2.63, 139.55) |
| **Eye movements** | | | |
| Saccadic amplitude (º) | 3.39 (2, 56)* | 12.95 (1.45, 40.52)*** | 12.61 (3.05, 85.34)*** |
| Fixations per second | 5.98 (2, 56)** | 69.9 (1.59, 44.72)*** | 9.98 (2.97, 83.18)*** |

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

### 3.3.2 Behavioural variables: Mean and delta fear perception, and mean hazard scores

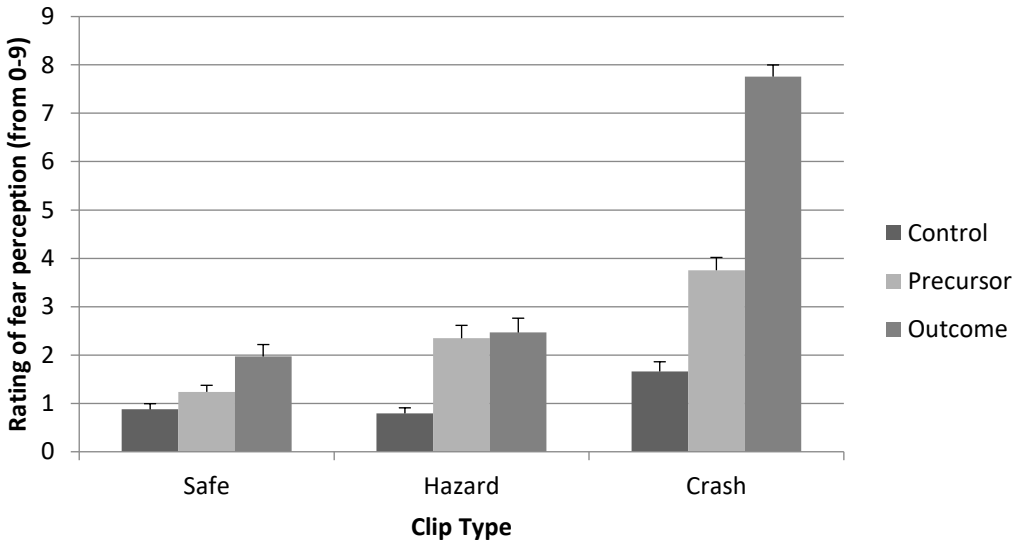
Results presented in Table 3.2 suggest that for all of the behavioural variables, there were significant main effects of clip type and measurement window, as well as a significant interaction. This is with the exception of a significant interaction on delta fear perception.

For mean fear perception, higher fear ratings were found in dangerous than in safe clips ($p<.001$, $\eta_p^2=.899$), and higher fear ratings were also found in crash clips than in hazardous clips ($p<.001$, $\eta_p^2=.818$). Main effects of measurement window also suggested an increase in fear across time; higher fear ratings were found in event windows than in control windows ($p<.001$, $\eta_p^2=.882$), and also in outcome windows compared to precursor windows ($p<.001$, $\eta_p^2=.687$). Analysis of the interaction suggests that the difference between event and control windows was smaller for safe clips ($m=0.73$) than in dangerous clips ($m=3.66$, $p<.001$, $\eta_p^2=.829$), and the difference between precursor and outcome windows was also smaller for safe clips ($m=0.73$) than for dangerous clips ($m=2.12$, $p<.001$, $\eta_p^2=.235$). When comparing hazardous to crash clips, smaller differences were found between control and event windows for hazardous clips ($m=0.12$) than for crash clips ($m=0.4$, $p<.001$, $\eta_p^2=.54$), and the difference between precursor and outcome windows was also smaller for hazardous clips ($m=0.12$) than for crash clips ($m=4$, $p<.001$, $\eta_p^2=.71$) (See Figure 3-2a).

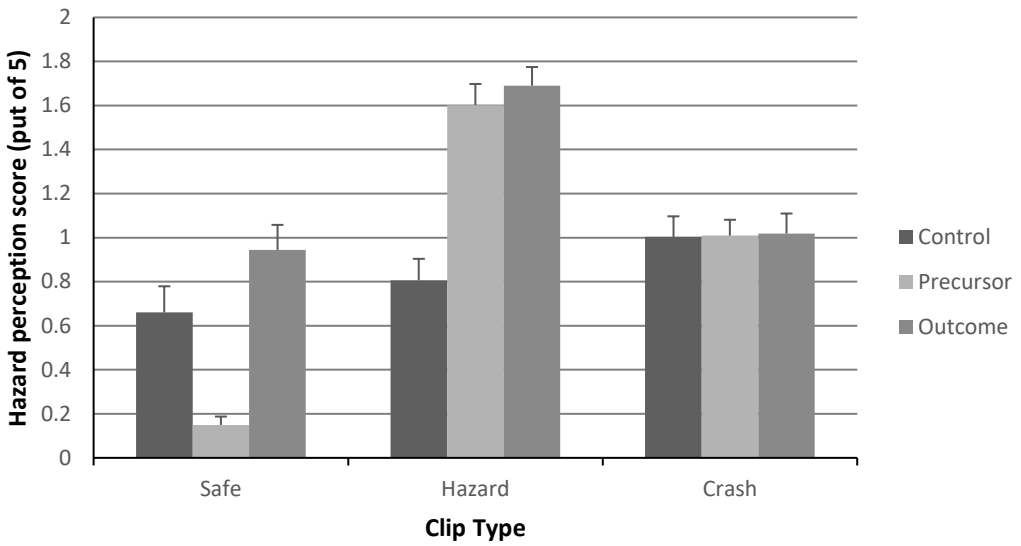
Contrasts found that delta fear perception was significantly smaller in safe clips than dangerous clips ($p<.001$, $\eta_p^2=.251$), and significantly smaller for hazard clips than for crash clips ($p=.001$, $\eta_p^2=.176$). Across clips, delta fear perception was significantly smaller during control windows than event windows ($p<.001$, $\eta_p^2=.222$), but significantly higher during precursor windows than during outcome windows ($p=.029$, $\eta_p^2=.084$).

Higher hazard perception scores were found in dangerous clips compared to safe clips ($p$<.001, $\eta_p^2$=.765), but scores were higher in hazard clips compared to crash clips ($p$<.001, $\eta_p^2$=.209). Higher hazard scores were also found in event windows compared to control windows ($p$=-.001, $\eta_p^2$=.186). Further analysis of the interaction suggested that the difference between control and event windows was smaller for safe clips ($m$=0.11) than for dangerous clips ($m$=0.85, $p$<.001, $\eta_p^2$=.375), but the difference in score between precursor and outcome windows was larger for safe clips ($m$=0.8) than for dangerous clips ($m$=0.09, $p$<.001, $\eta_p^2$=.339). When comparing hazardous to crash clips, differences between the control and event windows were larger for hazardous ($m$=0.84) than for crash clips ($m$=0.01, $p$<.001, $\eta_p^2$=.395) (See Figure 3-2b).

a)



b)




*<u>Figure 3-2:</u> Mean ratings of fear perception (a), and mean hazard perception scores (b) according to clip type and measurement window.*

### 3.3.3 <u>Skin conductance</u>

Due to an inability to record data from one participant, the ANCOVA on skin conductance contained data from 56 participants. Data from these participants was initially smoothed according to recommendations from Kim et al. (Kim, Bang, & Kim, 2004) prior to analysis. This was achieved by removing any values of skin conductance that were less than 10% below the mean value of skin conductance across the entire dataset. This method of smoothing was also used throughout the remaining studies conducted in the thesis.

Significant main effects and interactions were found for mean skin conductance, delta skin conductance and the number of EDRs per second. Mean skin conductance was significantly lower in safe clips than dangerous clips ($p<.001$, $\eta_p^2=.223$), and was also lower in hazardous clips compared to crash clips ($p<.001$, $\eta_p^2=.316$). Mean conductance was also lower in precursor windows than in outcome windows ($p<.001$, $\eta_p^2=.376$). The interaction suggested that the difference in mean skin conductance between control and event windows was larger

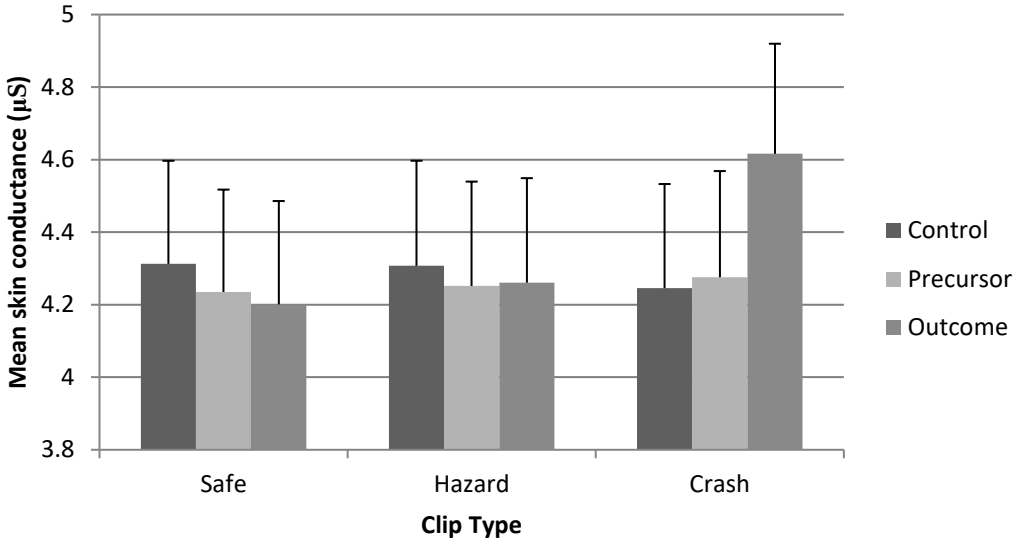
for safe clips (*m*=-0.095 μS) than for dangerous clips (*m*=0.049 μS, *p*<.001, $\eta_p^2$=.466). However, for safe clips the difference between precursor and outcome windows was smaller (*m*=-0.03 μS) than for dangerous clips (*m*=0.18 μS, *p*<.001, $\eta_p^2$=.448). Differences between the control and event windows were smaller for hazardous clips (*m*=-0.051 μS) than for crash clips (*m*=0.2 μS, *p*<.001, $\eta_p^2$=.525). The difference in mean conductance between precursor and outcome windows was also smaller for hazardous clips (*m*=0.009 μS) than for crash clips (*m*=0.34 μS, *p*<.001, $\eta_p^2$=.467) (See Figure 3-3a).

Delta skin conductance was lower for safe than for dangerous clips, (*p*=.018, $\eta_p^2$=.1), and also lower for hazardous than for crash clips (*p*<.001, $\eta_p^2$=.384). Across clips, delta conductance was also lower for control windows compared to event windows (*p*=.001, $\eta_p^2$=.195), and lower for precursor windows than for outcome windows (*p*=.042, $\eta_p^2$=.074). Contrasts on the interaction found that the difference in delta conductance between control and event windows was smaller for safe clips (*m*=0.04) than for dangerous clips (*m*=0.21, *p*=.048, $\eta_p^2$=.071). When comparing hazardous to crash clips, differences between the control and event windows were larger for hazardous (*m*=0.18) than for crash clips (*m*=0.05, *p*=.036, $\eta_p^2$=.079), but smaller differences were found between the precursor and outcome windows for hazardous (*m*=0.13) than for crash clips (*m*=0.16, *p*=.003, $\eta_p^2$=.152).

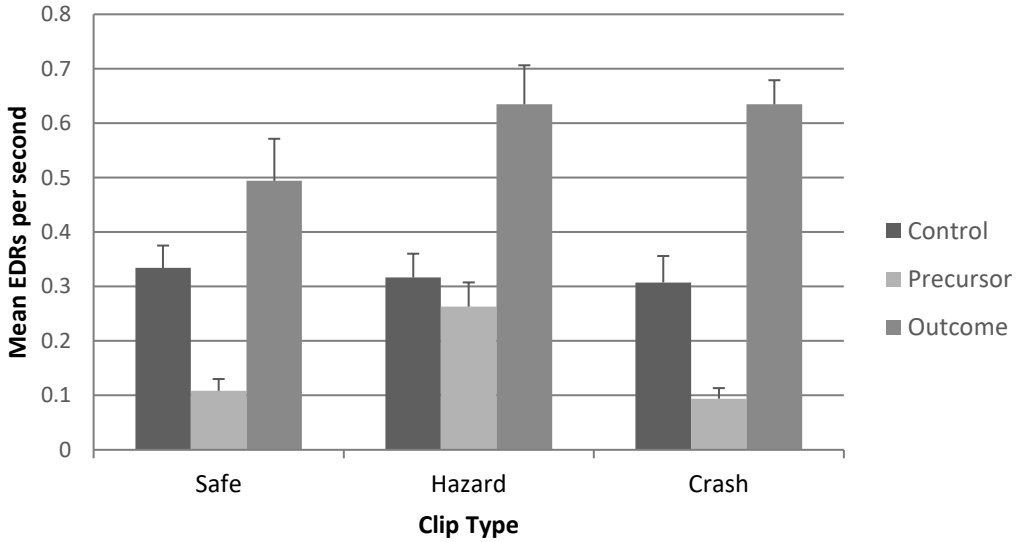
The amount of EDRs per second was smaller for safe than for dangerous clips (*p*<.001, $\eta_p^2$=.231), but larger for hazardous clips than for crash clips (*p*<.001, $\eta_p^2$=.452). There was also a smaller amount of EDRs per second during control windows than during event windows (*p*<.001, $\eta_p^2$=.357). Contrasts on the interaction found significant differences between hazardous and crash clips. The difference in EDRs per second between control and event windows was larger for hazardous clips (*m*=0.13) than for crash clips (*m*=0.05, *p*=0.13,

$\eta_p^2$=.109), but the difference between precursor and outcome windows was smaller for hazardous clips (*m*=0.37) than for crash clips (*m*=0.54, *p*<.001, $\eta_p^2$=.249) (See Figure 3-3b).

a)




b)




*<u>Figure 3-3:</u> Mean skin conductance (a) and number of electro dermal responses per second (b) according to clip type and measurement window.*

### 3.3.4 Heart rate and blood pressure

Data was discarded from two participants, meaning that data from 55 participants was included in the ANCOVA on heart rate and blood pressure.

For heart rate, the only effect of significance was a main effect of measurement window. Contrasts suggested that heart rate was significantly higher in control windows than event windows ($p<.001$, $\eta_p^2=.394$). For blood pressure, no significant within-subjects effects were found, with the exception of a significant main effect on clip type for systolic pressure. Contrasts suggested that systolic pressure was significantly smaller during safe clips than during dangerous clips ($p=.024$, $\eta_p^2=.092$).

### 3.3.5 Eye movements

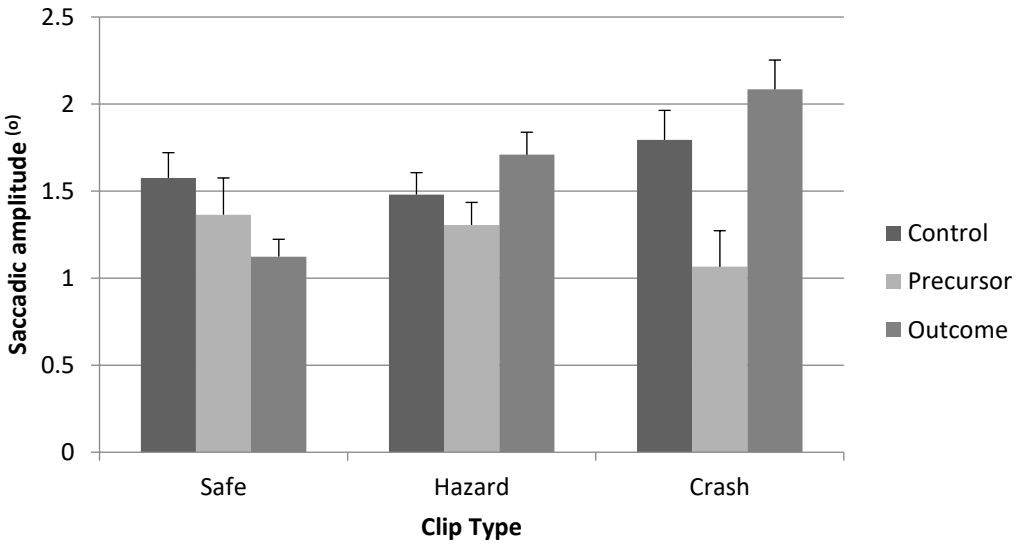
Due to problems with hardware, there were some issues with recording reliable attentional variables. Thus after close visual inspection, data from 27 participants had to be discarded. This left a total of 30 sets of eye movement data for ANCOVA analysis.

Significant main effects and interactions were found for both saccadic amplitude and the amount of fixations per second. Saccadic amplitude was significantly smaller during safe clips than dangerous clips ($p=.01$, $\eta_p^2=.214$). Amplitude was also smaller during event windows compared to control windows ($p=.015$, $\eta_p^2=.193$), and also smaller during precursor windows than outcome windows ($p<.001$, $\eta_p^2=.382$). With regards to the interaction, the difference in saccadic amplitude between control and event windows was greater for safe clips ($m= .033$) than for dangerous clips ($m=0.1$, $p=.013$, $\eta_p^2=.201$). Amplitude difference between precursor and outcome windows was smaller for dangerous clips ($m=-0.71$) than for

safe clips ($m$=0.24, $p$<.001, $\eta_p^2$=.465). When comparing hazards to crashes, differences in amplitude between precursor and outcome windows were smaller for hazardous clips ($m$=-0.4) than for crash clips ($m$=-1.02, $p$=.01, $\eta_p^2$=.214) (See Figure 3-4a).

Contrasts suggested that there were more fixations per second for hazardous than for crash clips ($p$=.005, $\eta_p^2$=.246). There were also more fixations per second for control windows than event windows ($p$<.001, $\eta_p^2$=.675), but fewer for precursor windows than outcome windows ($p$<.001, $\eta_p^2$=.527). The difference in fixations per second between control and event windows was smaller for safe clips ($m$=0.12) than for dangerous clips ($m$=0.22, $p$=.032, $\eta_p^2$=.154). When comparing hazardous to dangerous clips, differences in fixations per second between control and event windows were smaller for hazardous clips ($m$=0.13) than for crash clips ($m$=0.31, $p$=.002, $\eta_p^2$=.288), and differences between precursor and outcome windows were also smaller for hazardous clips ($m$=-0.19) than for crash clips ($m$=-0.55, $p$<.001, $\eta_p^2$=.527) (See Figure 3-4b).

a)



b)

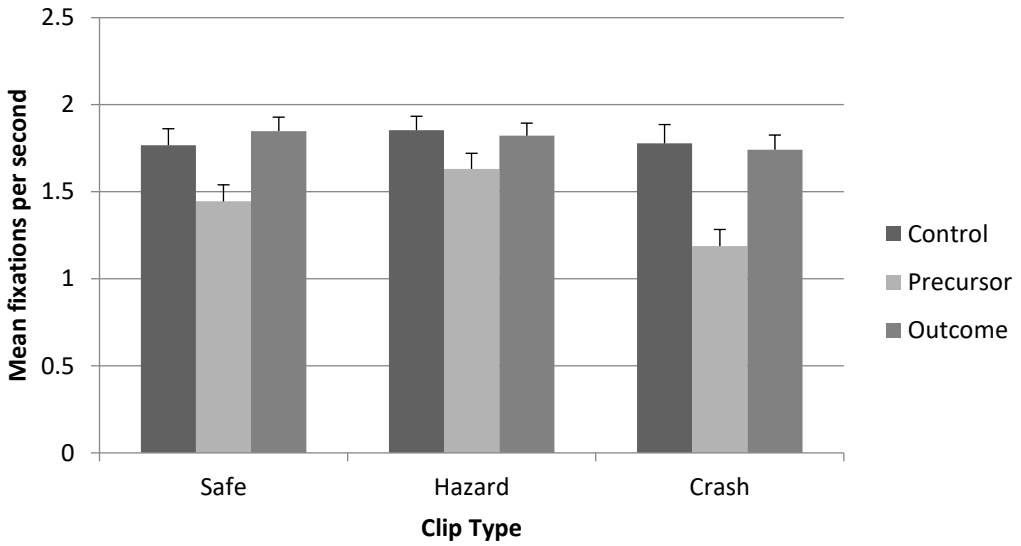



*Figure 3-4:Saccadic amplitude (a) and mean fixations per second (b), both according to clip type and measurement window.*

## 3.4 Discussion

The aim of the current study was to assess whether driving clips would increase levels of perceived fear, and whether these perceptions of fear and any associated attentional and physiological reactions were modulated by anxiety. The findings suggested that whilst there was considerable support for the first hypothesis, none of these effects were influenced by trait anxiety.

### 3.4.1 Findings

Firstly, as predicted, levels of perceived fear did increase with increasing levels of threat from the environment, and across time. This supports the idea that fear is a correlate of risk perception (Schmidt-Daffy, 2013) within a more dynamic and genuine driving environment. Interestingly, measures of skin conductance seemed to correspond to this increase in fear. During dangerous driving situations, mean and delta skin conductance increased in

comparison to safe clips, but this effect was more pronounced in crash clips compared to hazardous clips. This could suggest that changes in skin conductance were a reflection in the simultaneous changes in fear. Whilst some suggest that skin conductance is only a reflection of general arousal (Fuller, 2005), these results at least provide support for the idea that an increase in levels of threat can increase physiological activity (Palomba, Sarlo, Angrilli, Mini, & Stegagno, 2000; Tomaka, Blascovich, Kelsey, & Leitten, 1993) but extends it by suggesting this effect can occur when viewing dynamic stimuli as well as static stimuli. The fact that skin conductance and behavioural measures complemented each other in this way could also suggest that skin conductance acts as some sort of somatic marker guiding fear perception (Damasio, 1996). This inference has been supported in previous driving research (Kinnear et al., 2013), and could also explain previous findings regarding the relationship between skin conductance and hazard perception (Collet et al., 2005; Crundall et al., 2003).

Evidence from attentional findings also suggested increased vigilance according to the level of danger in a driving situation. In dangerous driving situations, a 'U' shaped pattern of amplitude was found across time, albeit this was to a smaller degree in hazardous compared to crash clips. There were more overall fixations per second in hazardous compared to crash clips, but differences between precursor and outcome windows were smaller for hazardous than for crash clips. Overall, these findings provide support for the notion of cognitive tunnelling during dangerous situations (Chapman & Underwood, 1998). The fact that this was to a lesser degree in hazardous clips could suggest that the source of threat was detected more quickly in hazardous clips, as indicated by higher calculated hazard perception scores in hazardous precursor windows, and participants may have been searching more of the environment to ensure there were no other potential sources of threat (Kimble et al., 2014).

This suggestion could be further supported by the overall increase in fixations per second in hazardous compared to crash clips, which could suggest an increase in vigilance.

There is however, the issue that calculated hazard perception scores were low overall. As with previous research, if participants had been completing a genuine Hazard Perception test and gaining scores reflecting those within the previous study, nobody would pass the test (Jones, Chapman, & Bailey, 2014). It could reflect the fact that in a genuine Hazard Perception Test, participants are aware that they should expect a hazard. However, in the current study there were a combination of uneventful and crash events, possibly reflecting a more representative range of driving situations. The low scores in precursor windows could also reflect the fact that these windows are simply shorter than control or outcome windows. Nonetheless the reliability of a hazard perception score as a standardised method of reaction time, at least within the context of this research, may need to be questioned.

The cardiovascular findings, on the other hand, provide some mixed findings. Firstly, the only significant finding from the heart rate data was that average heart rate was greater during control windows in comparison to event windows. This could potentially be seen as evidence of an orienting response (Bradley, Codispoti, Cuthbert, & Lang, 2001), which could increase levels of attention and information intake. Such an orienting response within the field of driving has been associated with a need to take in road information (Backs et al., 2003) and for the current study, this could provide support for the idea of increased attention and vigilance in dangerous situations to deal with a potentially threatening situation. However, the main problem with this theory is that there was no significant main effect of clip type. If we were to suggest an increased orienting response that supported the attentional data, this orienting response would surely be more evident in hazardous compared to crash clips, in

order to support the increased vigilance across precursor and outcome windows. It also does not explain why deceleration was also found in safe clips, when there were no threatening events to induce an orienting response.

The findings from the blood pressure are less conclusive. Systolic pressure was smaller in safe clips compared to dangerous clips. This could reflect lower levels of arousal; however, this does not necessarily support findings from previous driving research (Fairclough et al., 2014; Stuiver et al., 2014). It should also be noted that blood pressure can be seen as a measure with a longer latency, therefore future research may want to measure blood pressure over a longer period than what was recorded in this study. For example in Stuiver et al's study (Stuiver et al., 2014), participants completed six one hour sessions whilst cardiovascular measures were taken.

These findings suggest that these effects are independent of trait anxiety. However, this does not mean that anxiety cannot interact with increasing levels of threat or environmental demand. Dispositional anxiety was chosen as a measure for the current study, but previous research has also suggested a potential influence of state anxiety on driving behaviours; this issue is discussed in further detail in subsequent chapters. Additionally, findings from the DSI and Driver Coping Questionnaires suggest that higher levels of trait anxiety can indicate higher levels of disliking driving, and using emotional focus as a means of coping with dangerous situations. Both of these are vulnerability factors in driving. In particular, emotionally focused coping is a method used when people feel they have little control over a given situation and cannot manage the external source of the problem. In the context of driving, this method of coping could perhaps be used because those with higher trait anxiety dislike driving. Nonetheless, higher dislike of driving scores have been associated with higher

levels of driving accidents and convictions (Öz, Özkan, & Lajunen, 2010). If it is accepted that higher trait anxiety scores are associated with a greater dislike of driving, then it is still possible that those with higher trait anxiety are in fact dangerous drivers.

### 3.4.2 Limitations

Whilst previous research has suggested that greater levels of trait anxiety result in more dangerous driving, this is based on questionnaire research and needs to be investigated in higher fidelity paradigms. This was attempted in the current study; however, the lack of conclusive findings suggest that it may need to be investigated in a more immersive environment, such as simulated driving, in order to find a genuine effect. This possibility is explored in further detail in Chapters 5-8. Additionally, it is noted that the nature of the current task, watching a video and imagining the participant is the driver, is a passive task in itself and may lack some ecological validity.

It is also noted that there were some issues with sample size. Firstly, sample sizes were fairly low. Post-hoc observed power analyses suggested that the average observed effect size due to trait anxiety was a Cohen's f of 0.1, which is considered to be small. For any anxiety comparisons to be significant, achieving a power of 0.8 in the design would have required 273 participants. If future research were to use a similar design it would need to consider using a larger sample size. Additionally, the majority of participants in this study were young females who were either students or worked within a University environment. Research has previously demonstrated that women in particular profess a more anxious style of driving (Gwyther & Holland, 2012; Mesken et al., 2007). Whilst not directly related to driving anxiety, in the current study males had an average trait score of 33.4 whilst females had an

average trait score of 39.5. This highlights the need for a more representative sample in future research, and attempts to address this issue have been made in the subsequent studies.

### 3.4.3 Conclusion

In summary, increasing levels of threat in driving clips resulted in increasing levels of fear, and attentional and skin conductance measures seemed to reflect this. Whilst there were some mixed findings with the cardiovascular data, skin conductance may have been acting as a somatic marker, and eye movements may have been reflecting an increased level of vigilance in dangerous situations. Whilst there were no effects of trait anxiety within the current study, this does not mean that it does not have an effect on driving or hazard perception. Chapter 4 looks at trait anxiety within a similar paradigm, albeit using alternative measures that are said to be more reflective of workload. Chapter 8 also investigates the relationship between trait anxiety and driving; however this measures the effects of trait anxiety on central executive processing during simulated driving performance. Measures of processing efficiency and workload, alongside measures of actual driving performance, may provide a better indication of whether trait anxiety does influence a more dangerous style of driving.

# Chapter 4. Trait anxiety, task capability and autonomic measures of workload whilst viewing driving clips.

## 4.1 Introduction

The study described in Chapter 3 found no effects of trait anxiety on behavioural, physiological or attentional responses. This does not mean, however, that trait anxiety may not have an effect on driving behaviours and perceptions. For example, participants were asked how much fear they would feel if they were the driver in question within each clip. It is possible that effects may be found when asking about perceptions of capability within each task, using questions such as those based on the Task Capability Interface model (Fuller, 2005).

When discussing self-assessment of driver capability, a distinction is often made between driving skill and driving style. Driving style refers to the way an individual chooses to drive, and can be motivated by personality and lifestyle. Driving skill, on the other hand, refers to the quality of performance on various driving manoeuvres (Sundstrom, 2008). Often when asked to assess capability, drivers often inflate their estimations. Early research indicates that when asked to rate their overall skills, drivers place themselves higher on a visual analogue scale than the 'average' driver (Svenson, 1981). Several reasons have been proposed for this effect. Some argue that drivers still judge the average driver's skill favourably by placing them above the median on Likert scales, which would support a self-enhancement bias (McKenna, Stanier, & Lewis, 1991). Others argue that drivers negatively evaluate the skills of other drivers, which would indicate a downward comparison (Walton & Bathurst, 1998). Others suggest that there is an enhanced 'illusion of control' when evaluating skills, by suggesting that drivers perceive their peers as more likely to be involved in an accident

(Dejoy, 1989, 1992). Video-based methods have also found that when asked to imagine themselves as the driver or the passenger of the car, drivers claimed they would choose to drive at a faster speed than their hypothetical other driver (Horswill & McKenna, 1999). This effect is presumably down to a belief that the individual is more able to cope with situational demands than the hypothetical other driver.

However, it has been noted in the literature that comparing selves to the 'average driver' may be a difficult task. This is due to the fact that the term 'average' is rather ambiguous. Some may even perceive the term 'average' as a negative rather than a neutral descriptor (Groeger, 2000). As an extension of Svenson's (1981) original paper, McCormick and colleagues (McCormick, Walkey, & Green, 1986) asked drivers to rate their perception of driver skills in reference to themselves, the average driver and a very good driver. Additionally, they included a list of bipolar scales on which to make their judgements (these are discussed in more detail in Section 4.2.3). They found that whilst individuals still rated themselves as better than average, they did not rate themselves as highly as a very good driver. It has been argued that this makes the term 'average' less ambiguous and may potentially improve the quality of driver capability ratings (Sundstrom, 2008).

Recent research has also explored perceptions of driver capability in comparison to objective measures, such as driver performance and accident history. Some of this has shown that regardless of accident history or measures of driver performance, drivers still rate themselves as equally or more skilled than their peers (Marottoli & Richardson, 1998). Some simulator research, however, indicates that inflation of individual capability or underestimation of risk could potentially be dangerous. For example, poorer performance in the simulator has been associated with higher ratings of perceived skill (Freund, Colgrove, Burke, & McLeod,

2005), and an underestimation of subjective risk perception has been found when driving past scenarios and incidents such as intersections and roadside hazards (Charlton, Starkey, Perrone, & Isler, 2014). The study of driver capability has led to suggestions for training programs that help drivers accurately assess their capabilities. This may be particularly relevant and of interest for younger drivers (Gabriel Molina, Sanmartin, & Keskinen, 2013), who may have a greater illusion of control that places them more at risk of having an accident (Matthews & Moran, 1986).

There has been some research conducted on the relationship between personality and driver capability, but this field is limited. Findings so far suggest that perceptions of driver skill are negatively correlated with a dislike of driving (Lajunen & Summala, 1995), and perceptions of safety skills are negatively correlated with aggression and Type A behaviour (Lajunen, Corry, Summala, & Hartley, 1998). Additionally, higher levels of confidence, sensation-seeking and extraversion have been associated with higher ratings of driver skill (McPeek, Nichols, Classen, & Breiner, 2011). Whilst the driving research has not specifically focused on anxiety, we may expect that higher levels of anxiety may result in lower perceptions of capability. The general literature on this relationship has found that increases in state anxiety can lead to more conservative judgements about abilities in tasks such as grasping objects (Graydon, Linkenauger, Teachman, & Proffitt, 2012) as well as higher ratings of risk (Constans, 2001).

The perception of risk is also discussed within the Task Capability Interface (TCI) model (Fuller, 2005); however, this argues that overall ratings of risk are not as important as ratings of task difficulty. The TCI model suggests that task difficulty and subsequent performance are due to an interaction between the demands of the task and the capabilities of the driver.

Demands may include factors such as the driving environment, operational demands and demands over which the individual has control. Driver capability, on the other hand, is influenced by the driver's knowledge and skills, and is also influenced by other human factors such as personality, motivation and fatigue. In a similar fashion to Lazarus & Folkman's (1984) transactional model, reactions are determined by the discrepancies between task and capability. When task demand exceeds individual capability, the driver loses the ability to control the car and is at increased risk of accident involvement. Whilst the model emphasises that task difficulty is one of the main determinants of behaviour, it does acknowledge that difficulty and risk are correlated.

Video-based and simulation methods have since supported and expanded on the suggestions made in the initial TCI model. One study presented participants with video sequences of driving at various speeds, and asked them to rate how difficult and risky they would feel as the driver of the car (Fuller, McHugh, & Pender, 2008). Additionally, participants provided ratings of how often they believed they would lose control of the car or be involved in an accident. They found that participants perceived no risk of loss of control until shown a speed faster than which they would feel comfortable with, at which point these ratings increased. This suggests that perceptions of the task difficulty were higher than the individual's perceived capability at this point, supporting the TCI model. Simulator research has also expanded on the model's suggestions. These have tested the model by asking participants to drive at fixed speeds (Lewis-Evans & Rothengatter, 2009) or drive with fixed time headways in relation to the car in front (Lewis-Evans, De Waard, & Brookhuis, 2010). Findings from these studies have provided mixed conclusions. Both found correlations between ratings of task difficulty, feelings of risk and ratings of effort. However, whilst the time headway study

found that ratings were low until a certain threshold had been reached, the study measuring driver speed did not find the same relationship.

In the current study, participants were initially asked to rate their own driving skill, before being asked to watch the same driving clips as those discussed in Chapter 3. Safe, hazardous and crash clips were presented in blocks, and after each block participants were asked to provide ratings of task difficulty, risk and effort as well as ratings of perceived control and risk. There were two main aims. The first aim was to expand the literature on driver capability by investigating the relationship between trait anxiety and perceptions of driver capability. Using McCormick's (1986) scale, participants were asked to rate themselves, the average driver and a very good driver on a range of seven semantic dimensions.

The second main aim of the study was to investigate how levels of anxiety affect levels of task difficulty, risk and workload. This was achieved with subjective and autonomic measures. Subjective responses came from ratings of task difficulty administered after the presentation of each block of driving clips. The autonomic measures taken in this study included pupil diameter and HRV. As discussed in Chapter 1, changes in HRV can be reflective of changes in demand and mental load (Mullen et al., 2012; Stuiver et al., 2014), without any significant differences in subjective responses (Dijksterhuis et al., 2011). Pupil diameter has also been associated with changes in workload, and this effect is found across visual (Chen & Epps, 2014), auditory (Kramer et al., 2013) and physical (Zenon, Sidibe, & Olivier, 2014) domains. Increases in stress have also been associated with increases in pupil diameter and HRV (Yamanaka & Kawakami, 2009). Within the field of driving, pupil diameter has also increased as a result of both increased anxiety (Pedrotti et al., 2014) and increased perception of risk (Charlton et al., 2014).

Based on the literature, it was predicted that participants would rate themselves as better than the average driver, but worse than a very good driver. It was also suggested that this relationship may be affected by levels of trait anxiety. With regards to task difficulty and workload, it was predicted that ratings of task difficulty would increase with increasing levels of danger in the presented driving clips, with some possible effects of trait anxiety. Pupil diameter was also hypothesised to increase with increasing levels of danger, and levels of LF and HF-HRV would change. Based on the fact that the previous literature has found effects of anxiety on these autonomic measures, it was also hypothesised that levels of trait anxiety would result in changes in pupil diameter and HRV.

## 4.2 Methods

### 4.2.1 Participants

Thirty-nine participants took part in this study; however, due to an inability to collect the majority of dependent variables, data from three participants had to be discarded, leaving a total of 36 participants in the final analysis. These 36 participants had an overall age range of between 18-23 years (*m*=19.38, *sd*=1.57). Twenty-seven were female and nine were male. The participants were all undergraduate students from the University of Nottingham; they were recruited online and were provided with course credit. All of them had a full driver's licence, and had been in possession of it for an average of 2.03 years (*sd*=1.44 years). Annually, they drove an average of 1257.4 miles (*sd*=1494.98 miles). Seven had been in a minor road accident, two had been in a major accident, and two had previously been convicted for driving offences. Ethical approval was obtained from the University of Nottingham, and participant consent was obtained prior to experimentation.

### 4.2.2 Design

This study used a mixed design, with one continuous variable and one within-subjects variable. Using the same method as in Study One, the continuous variable in this study was the level of trait anxiety expressed by participants, according to scores on the Y2 part of the STAI.

The within-subjects factor was the level of accident risk in the video clips shown to participants, all of which were filmed from the driver's point of view. These were the same 18 clips as those used in Chapter 3, therefore clips were either uneventful, contained a hazard, or contained a crash.

As cardiovascular activity can occur slowly in comparison to other physiological processes, it was decided that video clips would be shown in blocks. As a means of counterbalancing, these blocks were shown with either increasing or decreasing levels of arousal. In other words, half of the participants were shown safe clips, followed by hazardous and crash clips, or crash clips followed by hazardous and safe clips. Not including the time taken to complete questions asked in-between clips and blocks (See Section 4.2.3), safe blocks lasted for 242 seconds, hazardous blocks lasted for 312 seconds, and crash blocks lasted for 172 seconds.

Dependent variables included ratings on perceptions of driver capability, which was completed prior to viewing the videos. Whilst the participants watched the videos, measures of pupil diameter (in mm), LF-HRV, HF-HRV (both in n.u), and the LF/HF ratio were observed. In between blocks, ratings of task difficulty, effort, risk, likelihood of losing vehicle control and preferred driving speed were also measured.

### 4.2.3 Materials & Stimuli

As with Study One, both parts of the STAI were used (See Chapter 1 for a description of the inventory). Trait anxiety scores averaged at 38.14 (*sd*=9.12) and the average state anxiety score was 31.61 (*sd*=6.86) Cronbach's α indicated good reliability for both state and trait aspects of the inventory (Cronbach's $\alpha$=.891 and .912 respectively).

The 18 clips created for Chapter 3 were used in the current study. Two seconds prior to viewing each block, a message would appear on screen saying 'Block X', and two seconds prior to each clip, participants would see message saying 'Clip 'Y' written in white Arial font on a black background, with 'X' and 'Y' representing the appropriate block and clip numbers respectively.

A basic driving demographic questionnaire (See Appendix 'G'), the perception of driver ability questionnaire (McCormick et al., 1986) (See Appendix 'H'), a brief questionnaire on the perceived frequency of road events occurring (See Appendix 'I'), and a questionnaire based on assumptions made by the TCI model (Fuller et al., 2008; Lewis-Evans & Rothengatter, 2009) were administered (See Appendix 'J'). For the McCormick (1986) questionnaire, participants use a series of seven-point scales to rate 'an average driver, 'me as a driver' and 'a very good driver' on the following bipolar dimensions: foolishness ('foolish-wise'), predictability ('unpredictable-predictable'), reliability ('unreliable-reliable'), consideration ('inconsiderate-considerate'), safety ('dangerous-safe'), state ('tense-relaxed'), and responsibility ('irresponsible-responsible'). Answering '1' on these scales indicated the driver in question was worse on the given dimension, and an answer of '7' indicated the driver was very good on the given dimension. Cronbach's α indicated good reliability on all

items for average ($\alpha$= .738) and very good drivers ($\alpha$=.827). However, there was less internal consistency when participants rated themselves as drivers ($\alpha$=.622).

To ensure that participants were engaging with the video task, they were asked two brief questions in-between each clip, regarding the perceived frequency of each event occurring on everyday roads. Each question was asked on a seven point scale, and asked a) how often the participant believes the incident within the clip occurs each month on the roads, and b) how often they are involved in the event each month. After each block of six clips, the TCI questions were administered. Five questions were asked on a seven point scale. The first three asked how difficult and risky participants would find the driving environments, and how much effort they believed they would have to use to maintain vehicle control. Answering '1' on the scale would indicate minimal risk, difficulty or effort, and '7' indicated maximum levels. The remaining two questions asked how likely it would be that the participant would lose control of their vehicle, and how likely it would be that they would maintain the recommended speed limits. Answering '1' would indicate unlikeliness to lose control of the vehicle or driving well below the recommended speed limit, and answering '7' indicated a high probability of losing vehicle control or driving well above the recommended speed limit. Figure 4-1 outlines how these questions were asked.

How difficult would you find it to drive in these environments at the speeds shown?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very easy | | | | | | Very difficult |

How risky would you find it to drive in these environments at the speeds shown?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Not at all risky | | | | | | Very risky |

How much effort do you think you would have to use to keep control of your vehicle?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Not a lot of effort | | | | | | A lot of effort |

If you were driving in these environments every day for a month, how likely is it that you would lose control of your vehicle?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very unlikely | | | | | | Very likely |

If you were driving in these environments every day for a month, what sort of speed would you prefer to be driving at?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Well below the recommended speed limit | | | | | | Well above the recommended speed limit |

*Figure 4-1: Questions given to participants after viewing each of the blocks. These questions are based on those asked in previous studies testing the assumptions of the TCI model (Fuller et al., 2008; Lewis-Evans & Rothengatter, 2009)*

The latter two questionnaires were administered within the programmed experiment. This, along with the eye tracking, was done using an SMI RED 250 system, which comes with a 22 inch Dell monitor and allows for unrestrained eye tracking. The experimental program was created using Experiment Center™3, and iViewX™3 was used to create a 9 point calibration. Instructions within the program were created using 24-point black Arial font presented at the top of the screen on a grey background. To measure HRV, an ear clip was attached to PPG100C and BioPac MP150 amplifiers and recorded using Acqknowledge version 4.1, which sampled data at a rate of 1000Hz.

### 4.2.4 Procedure

Participants initially completed the STAI and the driver demographic questionnaire. The ear clip was then attached to the bottom of the left earlobe and they were given brief verbal instructions on what the experiment would involve. Eye tracking calibration then took place and the study commenced. The perception of driver capability questionnaire was completed, before the participants were shown the video clips and blocks according to the condition assigned to them. In between each clip, questions about general and personal frequency were completed, and in between each block the task capability questionnaire was completed. After watching all three blocks participants were debriefed as to the nature of the study. Overall the entire procedure lasted 45 minutes.

## 4.3 Results

HRV data were pasted into an Acqknowledge journal, before being transferred to and uncounterbalanced in Microsoft Excel. Questionnaire data were automatically stored into a

.tsv file, which was also uncounterbalanced using Excel. Pupillometry data were extracted and converted into a .txt file using BeGaze™3, before a MATLAB R2012a script parsed and uncounterbalanced the data. All data were put into a series of ANCOVAs, with clip type included as a within-subjects factor and trait anxiety as a continuous variable. As with the study conducted in Chapter 3, all trait anxiety scores were centred from the mean before being included as a covariate in the analysis.

Again, partial eta squared is reported as a measure of effect size, and where there have been violations of sphericity, Greenhouse-Geisser corrected values have been reported. Where there are significant interactions, planned contrasts, unless otherwise stated, compare safe and dangerous clips, followed by hazardous and crash clips. On all figures, error bars represent standard error of the mean.

### 4.3.1 Personal driver capability

As we were interested in observing how participants think of themselves in relation to other drivers, a simple contrast was used to analyse any significant effects. This contrast compared average driver ratings to self-driver ratings, and very good driver ratings to self-driver ratings.

Whilst there were no main effects of trait anxiety on responses, significant main effects of driver type were found for all questionnaire dimensions (all $p$s<.001, all $\eta_p^2$>.4). Contrasts suggested that participants rated themselves as better than the average driver for all items of the scale (all $p$s<.001), with the exception of driver state ($p$=.485, $\eta_p^2$=.014). However, for all items, participants rated themselves as worse than a very good driver (all $p$s<.001) (See Table 4.1)

**Table 4.1: Mean scores for each factor on the driver ability questionnaire according to the type of driver (values in brackets represent standard deviation).**

| | Average Driver | Very Good Driver | Self as a Driver |
|---|---|---|---|
| Foolishness | 4.19 (0.86) | 6.22 (0.87) | 5.17 (0.85) |
| Predictability | 4.14 (1.13) | 5.94 (0.98) | 5.03 (0.91) |
| Reliability | 4.33 (0.96) | 6.36 (0.72) | 5.19 (0.79) |
| Consideration | 3.83 (0.91) | 6.44 (0.99) | 5.56 (1.11) |
| Safety | 4.72 (0.61) | 6.58 (0.87) | 5.58 (1.05) |
| State | 4.81 (0.82) | 5.92 (0.97) | 4.64 (1.25) |
| Responsibility | 4.56 (0.84) | 6.39 (0.96) | 5.36 (0.83) |

A significant interaction was also found between the type of driver concerned, and centred trait anxiety scores with regards to driver state ($F(2,68)=3.64, p=.031, \eta_p^2=.097$), with contrasts suggesting that this interaction was due to differences between participants rating themselves in comparison to very good drivers. Regression analyses suggested that centred trait scores could positively predict differences between ratings of state between very good drivers and selves as drivers ($F(1,34)=9.21, p=.005$), with an $R^2$ of .213 and a $\beta$ of .062 (See Figure 4-2).

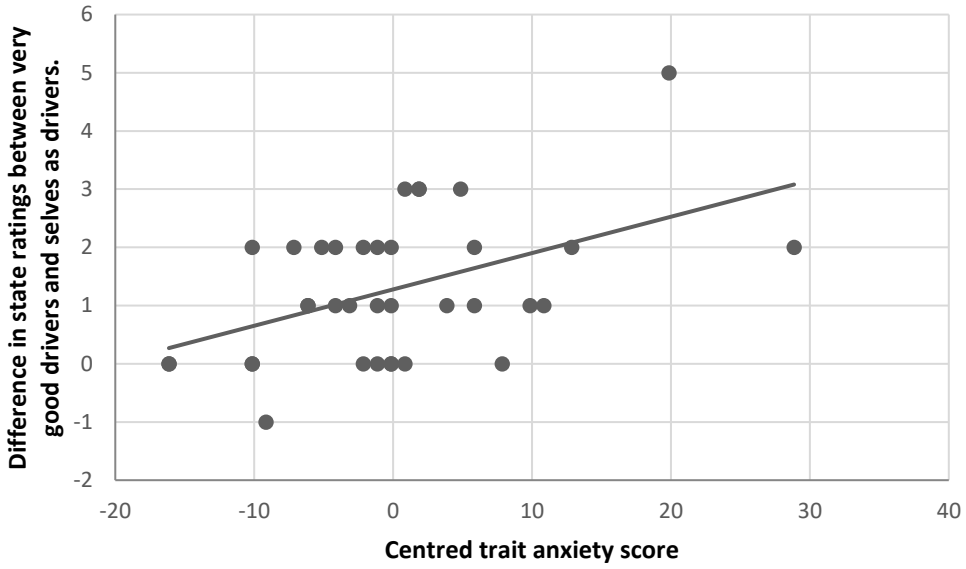



*Figure 4-2: The relationship between centred trait anxiety scores and differences in driver state ratings. This suggests that as trait anxiety levels increased from the average score (m=38.14), there were greater differences between ratings of very good drivers and selves as drivers in terms of their state.*

### 4.3.2 Task Capability responses

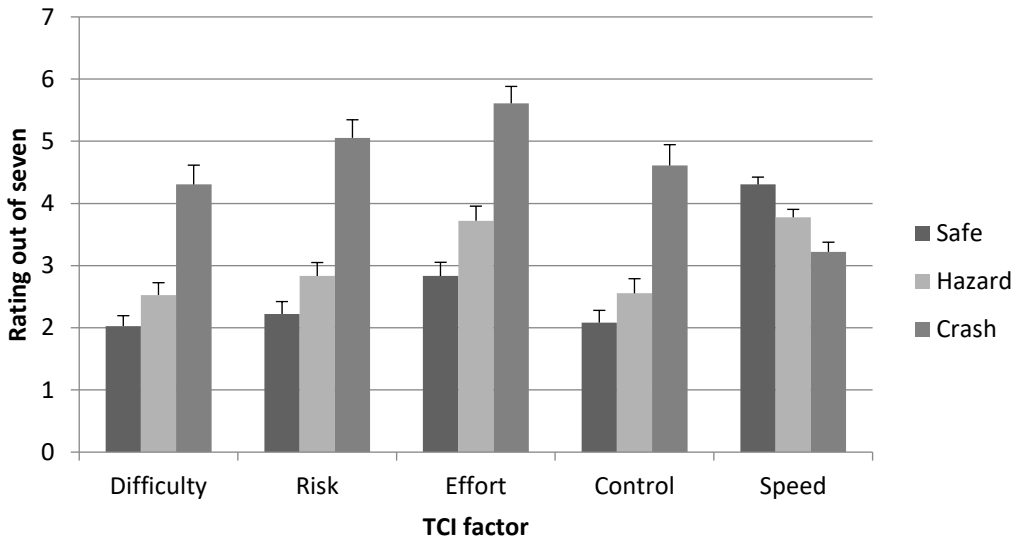



*Figure 4-3: TCI responses according to clip type*

Scores for responses on the task capability interface and general frequency questions were taken and averaged across the clips. These scores were analysed using a mixed ANCOVA comparing clip type and trait anxiety.

Trait anxiety did not significantly predict any scores on the TCI questions, nor did it significantly interact with the type of driving clip shown (all *p*s>.05). However, a significant main effect of clip type was found for all subscales (all *p*s<.001). Helmert contrasts revealed that participants rated uneventful clips as less difficult, risky and effortful. Participants also believed these events occurred more frequently, that they would have more control in such environments and that they would drive at faster speeds (all *p*s<.001). The same pattern was found when comparing hazardous to crash clips (See Figure 4-3).

As previous research has consistently found relationships between ratings of task difficulty, effort and risk, correlations between responses were also analysed for each type of video clip shown (See Table 4.2). In the majority of cases, there are significant positive correlations

between ratings of difficulty, risk, effort and control. With the exception of safe clips (all ps>.05), there are also significant negative correlations between these factors and preferred speed. The only exception to this is a nonsignificant correlation between ratings of risk and effort for hazardous clips ($p$=.09) and between ratings of effort and preferred speed for hazardous clips ($p$=.2).

**Table 4.2: Correlations between ratings of difficulty, risk, effort, likelihood of maintaining control and preferred speed for each clip type.**

| | | Difficulty | Risk | Effort | Control | Preferred Speed |
|---|---|---|---|---|---|---|
| **Safe Clips** | | | | | | |
| | Difficulty | | .758** | .567** | .337* | -0.173 |
| | Risk | | | .584** | .391* | -0.183 |
| | Effort | | | | .468** | -0.097 |
| | Control | | | | | -0.065 |
| | Preferred Speed | | | | | |
| **Hazardous Clips** | Difficulty | | .691** | .469** | .490** | -.565** |
| | Risk | | | 0.287 | .554** | -.560** |
| | Effort | | | | .558** | -0.22 |
| | Control | | | | | -.524** |
| | Preferred Speed | | | | | |
| **Crash Clips** | Difficulty | | .761** | .568** | .744** | -.568** |
| | Risk | | | .745** | .744** | -.414* |
| | Effort | | | | .759** | -.414* |
| | Control | | | | | -.581** |
| | Preferred Speed | | | | | |

* $p$<.05

** $p$<.01

### 4.3.3 Pupil diameter

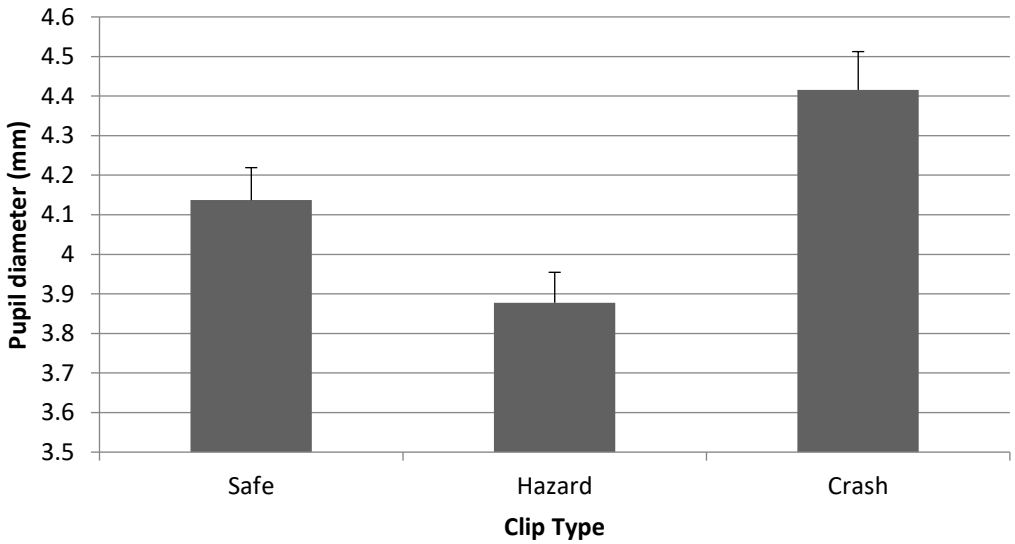



*Figure 4-4*: *Pupil diameter according to clip type.*

A mixed ANCOVA comparing clip type with trait anxiety was conducted on pupil diameter data. A main effect of clip type was found ($F(1.44,49.07)=79.44$, $p<.001$, $\eta_p^2=.7$) without any influence of anxiety ($F(1,34)=3.5$, $p=.07$, $\eta_p^2=.093$) or interaction ($F(1.44,49.07)=2.19$, $p=.136$, $\eta_p^2=.061$). Contrasts found that pupil diameter was significantly smaller during hazardous clips ($m= 3.87$mm) than accident clips ($m= 4.42$mm; $p<.001$, $\eta_p^2=.869$) (See Figure 4-4).

### 4.3.4 Heart Rate Variability

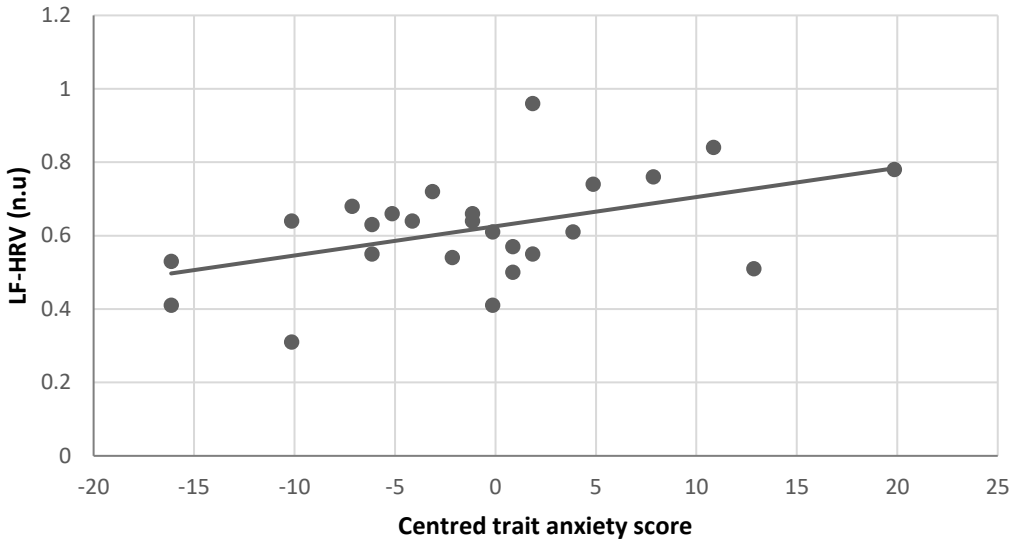
HRV was analysed over the entirety of each block. The raw signal was pre-processed using a FIR low-pass filter with a cut-off frequency of 40Hz. This was done in accordance to previous studies that have used these parameters when processing PPG signals for HRV analysis (Lu, Yang, Taylor, & Stein, 2009; Selvaraj et al., 2008). An automated program in

Acqknowledge version 4.1 was used to calculate LF-HRV (0.04-0.15Hz), HF-HRV (0.15-0.4Hz) and the LF/HF ratio in, in normalised units (n.u). Due to excessive motion artefact, data was discarded for five participants. Due to abnormally high readings, LF/HF ratios were only analysed for 22 participants, and due to an inability to detect HRV values, data from 25 participants were analysed with regards to LF and HF n.u.

Significant main effects of clip type were found for both LF-HRV ($F(1.56,35.9)=4.13$, $p=.033$, $\eta_p^2=.152$) and HF-HRV ($F(1.53,35.28)=4.11$, $p=0.34$, $\eta_p^2=.152$). Contrasts revealed that LF-HRV was significantly higher for hazardous ($m=0.68$) than crash clips ($m=0.55$, $p=.011$, $\eta_p^2=.251$), and HF-HRV was lower for hazardous ($m=0.32$) than for crash clips ($m=0.45$, $p=.011$, $\eta_p^2=.251$).

There was also a significant main effect of trait anxiety scores on LF and HF-HRV. Regression analyses suggested that trait anxiety positively predicted LF-HRV ($\beta=.008$, $R^2=.223$), whilst at the same time negatively predicting HF-HRV ($\beta= -.008$, $R^2=.228$) (See Figure 4-5).

a)




b)

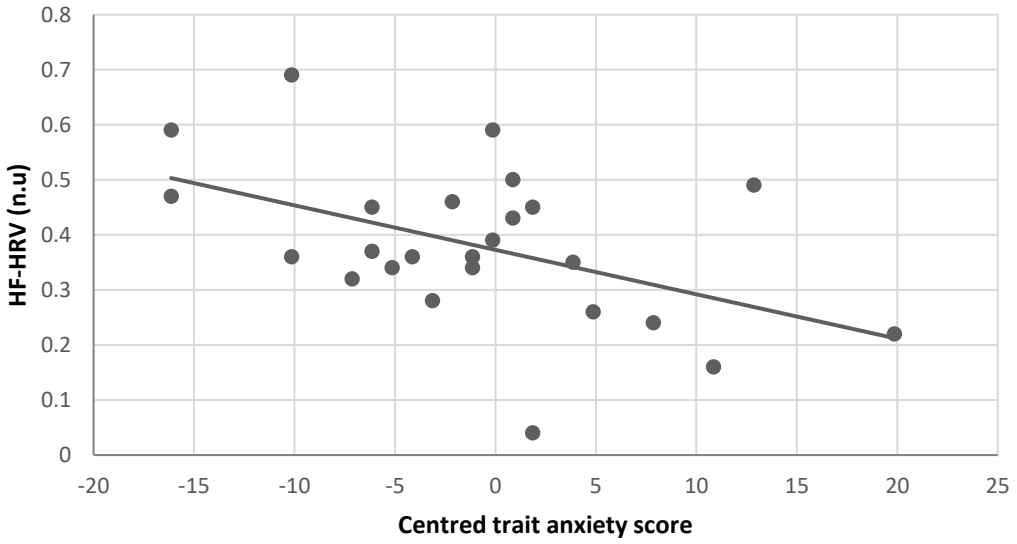



*Figure 4-5 The relationship between centred trait anxiety scores and a) LF-HRV (n.u), and b) HF-HRV (n.u).*

## 4.4 Discussion

The aim of this study was to investigate the effects of trait anxiety on autonomic responses and perceptions of task difficulty and perceived control whilst watching driving clips with varying degrees of danger. Additionally, the effects of trait anxiety on overall perceptions of driver capability were investigated. Overall, there were differences in perceived capability, with participants rating themselves as better than average but worse than a very good driver.

Perceptions of task difficulty also increased according to the type of driving clips shown, but these effects were independent of trait anxiety. Autonomic measures also suggested differences between different driving clips, in the absence of any anxiety effects. There was, however, an overall effect of trait anxiety on levels of LF and HF-HRV.

### 4.4.1 Findings

#### 4.4.1.1 Perceptions of driver capability

Results from the driver capability data suggest that all participants, regardless of trait anxiety levels, rated themselves as better than the average driver, but worse than a very good driver, on the majority of semantic dimensions. This supports the previous findings, and our predictions, that drivers enhance their perceptions of their own capability. The fact that drivers still rated themselves as worse than a very good driver also supports previous suggestions that these scales may help make the term 'average' less ambiguous (Sundstrom, 2008). Additionally, with the exception of the 'consideration' dimension, drivers did not rate the 'average' driver any lower than 4 out of 7 on each of the semantic dimensions. This would provide support for a self-enhancement bias (McKenna et al., 1991) as opposed to a downward comparison between selves and the average driver.

The only semantic dimension that did not find any significant differences between ratings of selves and the average driver was 'state'. Participants rated themselves as just as calm or tense as the average driver. As noted in Section 4.2.1, participants had been in possession of a drivers licence for just over two years, and had an average annual mileage of just over 1200 miles, which would indicate that the sample were less experienced drivers. It is possible that participants were aware that they had less knowledge, in comparison to a more experienced

driver, of how they would cope within various driving situations. Previous research has also demonstrated that less experienced drivers may perceive themselves to be more at risk of accidents on the road (Tronsmoen, 2008). This would explain why there is no self-enhancement bias when participants compared themselves to the average driver; both state scores are averaged within the middle of the scale because less experienced drivers cannot say for sure that they will be calmer than the average driver. Further research could expand this by comparing groups with different levels of driving experience on the McCormick (1986) scale.

This study also extended previous research by associating ratings on the McCormick (1986) scale to trait anxiety. Results suggested that higher levels of trait anxiety predicted greater differences between ratings of very good drivers and selves as drivers on the 'state' scale. In other words, greater levels of trait anxiety meant that a participant was more likely to rate a very good driver as 'relaxed' and themselves as 'tense' on the roads. It is possible that participants with higher levels of trait anxiety may negatively affect their state anxiety whilst they are driving, and as a result see themselves as a lot more tense than someone they would perceive to be a very good driver. It is, however, debatable as to whether this negative perception would be beneficial or detrimental to driving behaviour. It is argued in the general anxiety research that it may be more beneficial in more dangerous situations, whereas in other activities such perceptions can be detrimental (Graydon et al., 2012). Future research could be conducted in simulators, to assess whether a negative perception of driver state is indicative of more safe or dangerous behaviours within different driving contexts.

The use of simulator, or on-road, research may also be beneficial to future research as it is difficult to conclude from the current study whether perceptions of capability are accurate predictions of driver behaviour. Research assessing driver capability has recently shifted its

focus from primarily using questionnaires, to comparing subjective perceptions of capability to objective measures of driving skill. Results so far have been mixed. For example, in older drivers a greater perception of capability did not accurately assess measured driving behaviours (Freund et al., 2005), whereas in another study assessing personality characteristics, increased perceptions of capability were shared by a specialist instructor who assessed driving performance (McPeek et al., 2011). Future research should continue to compare subjective perceptions to objective measures of driver behaviour to obtain a better understanding of judgement accuracy.

#### 4.4.1.2 Perceptions of task difficulty

All findings from ratings of task difficulty were independent of trait anxiety. With increasing levels of danger within driving clips, all participants suggested they would find driving in that environment more difficult, effortful and risky, believed they would be more likely to lose control of their vehicle, and indicated that they would prefer to drive at a lower speed limit. This indicates that environments with increasing amount of danger result in a lower perceived capability to be able to cope with the task, indicating increased difficulty. Additionally, ratings of task difficulty, risk and effort correlated across all types of driving clip. This supports previous research which has found similar correlations (Lewis-Evans et al., 2010; Lewis-Evans & Rothengatter, 2009). As described in the TCI model (Fuller, 2005) task difficulty is estimated as the difference between task demands and perceived capability, and as effort could be a function of the amount of capability required to complete a task, it is reasonable to predict it would be correlated with difficulty. Risk may also be a function of the individual's perceived capability, hence it is also correlated with both risk and effort.

This study also extends previous findings on task capability by finding negative correlations between difficulty, effort, risk, control and levels of preferred speed for dangerous clips. The TCI model has previously suggested that drivers need to alter their behaviour when a task becomes more difficult, in order to maintain control of the vehicle. These findings support this by suggesting that as a driver perceives the task as more difficult or believe they may be likely to lose control of the vehicle, they would attempt to make the task easier by reducing their levels of preferred speed.

However, it is also worth noting that there were no correlations between any of the TCI dimensions and levels of preferred driving speed with regard to safe clips. In these clips, the car was simply driving along and nothing happened which would put the driver at risk of an accident. The TCI model does also suggest that motivational factors can cause a driver to adopt their own levels of task difficulty, and this can be achieved by changing speed levels. This study suggests that this effect occurs in safe environments, and the fact that trait anxiety did not interact with this would suggest that speed choices are made due to a motivational factor other than anxiety. However, as the question of speed choice was only asked with regards to whether someone would drive well above or well below the recommended speed limit, it may not be clear how these ratings may relate to specific speed choices. A more suitable approach for future research may be to ask drivers to state their preferred maximum speed limit, and compare subsequent speed choices to this (Lewis-Evans & Rothengatter, 2009).

#### 4.4.1.3 Pupil diameter

Findings regarding pupil diameter are less clear. Despite reporting increasing levels of task difficulty according to increasing levels of danger in clips, pupil diameter was significantly smaller in hazardous clips compared to crash clips. If we accept that pupil diameter is a measure of cognitive workload, then it would be argued that environments with hazards are less cognitively challenging than environments where crashes occur. As crashes are less likely to occur than hazards, then it is possible that drivers have more experience with dealing with hazardous situations, which may make them less cognitively demanding. However, it would not explain why pupil diameter is larger when viewing safe clips, which should be less cognitively demanding than hazardous clips. It should be noted at this point that effects of perceptual demand may also have an effect. Research has suggested that the pupil can dilate as a result of low-level image features such as colour and motion, as well as semantic content (Naber & Nakayama, 2013). Additionally, some research has suggested that pupil diameter can be more sensitive to perceptual than cognitive demands (Causse, Senard, Demonet, & Pastor, 2010; Chen & Epps, 2014). As clips were provided by the DVSA and various internet sources, it was not possible to control for image quality or the amount of visual information available. Therefore, it is also acknowledged that differences in pupil diameter could be due to differences in perceptual demand.

#### 4.4.1.4 Heart rate variability

The HRV findings suggest changes in LF and HF power as a result of different clip types, as well as according to different levels of trait anxiety. LF power was greater for hazardous clips

than for crash clips, and HF power was lower for hazardous than for crash clips. This behaviour may indicate reciprocal coupling of sympathetic activation; in other words, as sympathetic activity increases, parasympathetic activity decreases (Backs et al., 2003). If it is argued that reduced HF-HRV is indicative of mental workload and lower levels of cognitive and autonomic flexibility, then it would be argued that environments with hazards are more mentally demanding than environments with crashes, and that there is less flexibility to cope with the environmental demands associated with crashes. Therefore, in the context of hazardous environments, the 'fight-or-flight' behaviour associated with LF-power is more influential than the ability to deal with such a demanding situation.

HRV results also suggested that trait anxiety positively predicted levels of LF-HRV and negatively predicted levels of HF-HRV. This finding is line with general theories on the relationship between anxiety and HRV (Friedman, 2007). This finding not only extends research on the relationship between trait anxiety and HRV, it also applies these findings to the field of driving. As the Polyvagal Theory suggests that an increase in HF power indicates an increased ability to regulate emotions (Porges, 2007), it could be argued in this context that drivers with increased levels of anxiety would be less able to regulate their emotions on the road. This suggestion complements the findings on driver capability, which suggested that increased levels of anxiety were associated with increased differences between selves and very good drivers on state scores. Again, simulator research could provide further support for this theory; it has been previously suggested that higher levels of HF power are associated with better task performance (Thayer et al., 2009), yet this claim cannot be made from the current study as no driving performance measures were taken.

### 4.4.2 General Limitations

One general limitation, that has also been discussed in Section 3.4.2, is that the nature of watching a video of driving, rather than engaging in the behaviour itself, can be seen as a rather passive task. Other than asking participants to imagine that they were the driver of the car, no other apparatus was provided to give the illusion of driving or having any control over anything that was happening within the clips. This may be more important within the context of perceived capability. In Charlton et al's study (Charlton et al., 2014) measures of subjective driving risk were compared across photos, viewing videos and driving in a simulator. They found that ratings of risk were higher for photos than for videos, and ratings were higher for videos than in the simulator. This effect was attributed to the levels of controllability associated with each medium. Thus findings may need to be extended to simulator or on-road research to increased perceived controllability of the driving environment and potentially increase accuracy of task difficulty ratings.

### 4.4.3 Conclusions

In summary, participants mainly perceived their driving behaviour as better than the average driver, but worse than a very good driver. Trait anxiety was also predictive of differences between very good driver and self-driver ratings of state. Increasing levels of danger in driving clips resulted in increases in perceived difficulty overall. However, autonomic data provided mixed conclusions as to whether this actually reflected increased levels of cognitive or mental workload. What it does emphasise, however, is the need to collect subjective and objective measures simultaneously.

A suggestion for further research that has been consistent throughout this chapter is the need to extend findings to more interactive environments, such as simulators. The remaining studies conducted within this thesis are therefore conducted within driving simulators. The next chapter gives an overview of the use of simulators within driving research, and the subsequent three chapters discuss simulator research that focuses on both state and trait anxiety.

# Chapter 5. Driving Simulators as a tool for measuring driving performance.

## 5.1 Introduction

What has been made clear from the previous two chapters is that in order to obtain a more accurate measure of driving behaviours with regards to anxiety, it may be important to use driving simulators. The main objective of a driving simulator is to give the illusion that a driving task is being performed within a virtual environment. This means that the simulated environment must be designed in such a way that the driver is provided with visual and motion feedback that allows them to believe they are driving a car. Within this environment, a wide variety of measures of driving performance and behaviour can be taken. These include longitudinal control measures such as speed, lateral control measures such as the car's position within the driving lane, distance and time headways, reaction times to hazardous events and frequency of dangerous events and behaviours. Additionally, subjective measures, as well as eye movements and physiological measurements can be taken simultaneously. This means that measuring data within simulators can provide a rich dataset outlining a driver's behaviour, awareness, arousal levels and levels of workload whilst they are driving within a safe environment.

The aim of this chapter is to outline the types of simulators that are available, their importance to the field of driving, and some of the practical and ethical issues that need to be considered. Finally, the Nottingham Integrated Transport and Environment Simulation (NITES) facility is discussed, as these simulators are used for the remainder of the studies conducted in this thesis.

## 5.2 The physical characteristics of driving simulators

In driving research, the simulators used will all vary in what is known as physical fidelity (Blaauw, 1982). This refers to the degree to which the physical characteristics of the simulator correspond to what the driver expects to see and experience in real driving situations. Depending on the physical attributes of a simulator, it can be argued that it is of either a low, medium or high fidelity. The purpose of a simulator is to allow the driver to perceive they are driving in as realistic an environment as possible, and this can be achieved by providing a series of visual, auditory, haptic and motion cues.

The majority of simulators consist of the basic car components such as a steering wheel, pedals and a gear box. These provide the driver with basic cues towards haptic and motion feedback. Visual cues are provided by projecting a series of images onto a curved or flat screen. The extent of the image is often referred to as the driver's field of view. It is recommended that a minimum acceptable field of view should be at least $60^{o}$x$30^{o}$ (Padmos & Milders, 1992), however the majority of simulators typically project images with a $180^{o}$ field of view (Arioui & Nehaoua, 2013). The size of field of view must be taken into consideration when designing a simulator. If it is too low, then the driver may not receive enough visual feedback, but if the field of view is too great then this can increase the risk of simulator sickness, especially in fixed-base simulators (Greenberg & Blommer, 2011). Transport and refresh delays must also be taken into consideration when conducting simulator research. The former of these refers to the time between the driver's actions and the visual feedback on screen, and the latter refers to the frequency at which the screen is updated in order to correctly simulate motion. Any delays in either of these can potentially induce levels of sickness; some researchers recommend that this delay be no longer than 50 msecs (Franck, Casalli, & Wierville, 1988). Finally, audio feedback provides sounds of the environment and

the vehicle's movement. The number of speakers, as well as the location of speakers, will vary between simulators, but the aim of these is to reproduce 3D sound that captures a good sense of source direction for the driver (Arioui & Nehaoua, 2013).

The degree of fidelity within the simulator will also depend on its mechanical properties. Simulators are often classified as either fixed-base or motion-base. A fixed base simulator will provide no motion feedback to the driver, and will just consist of the basic car components either attached to a desk or a steel rig. As a result any motion cues will be provided entirely by visual and audio feedback. Simulators with a motion-base, on the other hand, will provide motion feedback to the driver. Different types of motion platforms are available; the most common of these is the 6 degrees of freedom Gough-Stewart platform (Arioui & Nehaoua, 2013). Again, it is important that the motion feedback provided by the simulator closely resembles the behavioural inputs provided by the driver, such as braking and accelerating, as any delays in this may reduce the simulator's physical fidelity and increase any sensory conflicts experienced by the driver (see Section 5.4.3).

It could be argued that higher fidelity simulators should be used when conducting research, as they provide the driver with a more immersive experience and may therefore result in more externally valid findings (Kaptein, Theeuwes, & van der Horst, 1996). However, selecting a simulator for research will often depend on a compromise between financial costs, practicality and the purposes of the research question. For example, whilst physiology can be measured in simulator environments, it has been argued that the interpretation of results can be difficult due to the increased risk of movement artefacts, particularly in methods that require electrodes to be placed on the fingertips (Brookhuis & de Waard, 2011). To reduce any effects of motion artefacts, one may choose to conduct physiology research in a fixed-

base simulator. Additionally, some have argued that whilst motion-base simulators do provide a greater degree of immersion, they also increase rather than decrease simulator sickness rates (Dziuda, Biernacki, Baran, & Truszczynski, 2014); therefore researchers may again want to consider using a fixed-base simulator if they wish to reduce levels of sickness.

In summary, simulators are required to provide the driver with appropriate visual, audio and motion feedback necessary to feel a sense of immersion within the given driving environment. Several factors, such as the degree of visual field of view, the rate of feedback delays and the provision of additional motion cues can increase or decrease the fidelity of the simulator. Simulators with high levels of fidelity would include motion feedback and a wide visual field of view, whilst low fidelity simulators would include a minimal amount of cues and contain very few car components, such as a simulated computer game. However, researchers must also be careful when selecting a simulator, as the degree of physical fidelity selected for the given simulator may influence the reliability of results collected as well as degrees of simulator sickness.

## 5.3 The use of simulators within driving research

There are many advantages to using driving simulators to measure driving behaviour, both from an ethical and practical perspective. Simulators are a safe environment in which drivers will not actually injure themselves or damage a car if they crash their vehicle. Because of this many different tasks can be manipulated or measured whilst completing simulated driving, without risking any significant harm to the driver or others. This is particularly relevant when investigating driving situations which, for ethical purposes, would be deemed too dangerous to complete on real roads. Such situations include mobile phone use and drink driving, both

of which are illegal on UK roads. Simulator research can investigate which behaviours are most affected by dangerous acts such as these. For example, research into mobile phone use whilst driving has found that using a phone whilst driving increases reaction times to safety critical events, and increases perceptions of mental workload (Alm & Nilsson, 1995). Research into alcohol consumption has suggested that it can lead to increased crossing between lanes, a reduction of mean time headways, and reduced perceptions of both frustration and awareness of impairment (Fairclough & Graham, 1999).

From a practical perspective, one of the main advantages of driving simulators is that scenarios can easily be manipulated depending on the needs of the researcher. Simulator software can easily create and manipulate driving scenarios that could not easily be controlled using on-road research. For example, studies investigating the effects of the environment on driving can easily manipulate scenarios to represent day or night-time driving (Konstantopoulos et al., 2010), or manipulate visibility levels by creating scenarios that include foggy conditions (Brooks et al., 2011). Because scenarios can create such conditions that are controlled across participants, it is easier to suggest that differences in measurement are a result of experimental manipulations. It is also easy to collect dependent measures other than driving behaviour, such as eye movements (Cooper, Medeiros-Ward, & Strayer, 2013) and physiology (Dijksterhuis et al., 2011), as well as subjective measures such as feelings of workload or affect.

One area where the ethical and practical advantages of simulator use is evident is within the field of training. Training drivers who are less experienced or who are perhaps deemed to be less safe may be beneficial within a simulated environment. For example, when comparing the consistency of driving performance in younger and older drivers, simulator research has

suggested that older drivers are far less consistent in measures of headway, lane positioning and reaction time variability (Bunce, Young, Blane, & Khugputh, 2012). The authors of this paper conclude that this could be due to cognitive decline, and suggest that simulator-based training programs could help with such issues. Subsequent research has provided older drivers with either cognitive battery training or a series of training sessions within a simulator; results suggested that whilst both groups improved in future cognitive tests, only the group who received simulator training improved in their driving performance on real roads (Casutt, Theill, Martin, Keller, & Jaencke, 2014). The use of simulators as training tools is also relevant for more novice drivers. In the Netherlands, there are over 100 sites where learner drivers can complete their initial hours of training in a simulator; this can provide a rich dataset investigating novice drivers, which has been used in previous research to evaluate the rates of errors and lapses committed by novices (De Winter, Wieringa, Kuipers, Mulder, & Mulder, 2007), and evaluate how well initial driver training performance can predict future on-road test results (de Winter et al., 2009).

Driving simulator research can also evaluate the effectiveness of new driver technology or the effectiveness of safety interventions, and use this information to provide recommendations. For example, research has investigated the effects of congestion assistance technology on workload, and found that not only does it reduce levels of mental workload, but drivers also generally report that they are satisfied using such technology (Brookhuis et al., 2009). Research into safety interventions such as advanced yield markings and signs has found that these interventions increase the likelihood of glancing towards potentially hazardous locations and increase the likelihood of yielding to any pedestrians who unexpectedly cross the road (Fisher & Garay-Vega, 2012). In this example, these findings led

to authors to recommend their use on real roads, as they are small and relatively inexpensive to implement.

The majority of the principles discussed also apply to the use of driving simulators within anxiety research. This is particularly true with regards to ethical purposes; essentially, if it is predicted by the researcher that a more anxious personality or feeling may result in more dangerous behaviours, or changes that could place a driver at risk of an accident, then it is advisable on safety grounds to compete such tasks in a simulator. One recent study, for example, predicted that trait anxiety may have negative effects on driving confidence and performance, and that this relationship would be mediated by alcohol consumption (Aston, Shannon, & Liguori, 2014). Whilst trait anxiety was only associated with driving confidence levels, the possibility of it affecting performance makes the simulator a safe environment to complete the driving task in. Another study looking at the effects of an emotionally involving conversation found that those who were discussing something they had a phobia of, showed a reduction of horizontal and vertical fixations in a simulated driving task, as well as increases in heart rate (Briggs, Hole, & Land, 2011). Again, if it is argued that these behavioural changes are dangerous for driving, then it would not be safe to complete these tasks on real roads. Recent simulator research has also been useful in investigating the effects of Lorazepam, a drug commonly used to treat anxiety, on simulated driving performance (Daurat et al., 2013). The authors found that a 2mg dose resulted in significant reductions in lateral control; these findings were similar in comparison to increased levels of blood alcohol concentration. Thus, like research into safety interventions, such findings could result in recommendations not to drive whilst taking anxiolytics.

In summary, driving simulators are particularly useful within the field of driving for ethical and practical purposes. They allow research into topics that would be too dangerous to test on real roads, plus the easy manipulation of simulator scenarios allow for quick and efficient testing of different independent variables. The findings from simulator studies can result in a variety of wider applications and recommendations, such as the use of simulator training and safety interventions. These points can also be applied to anxiety research conducted within simulators. Taken together, driving simulators can provide a safe environment within which many different research topics can be investigated, and several dependent variables can be collected within a short period of time.

## 5.4 Issues with the use of driving simulation

Whilst driving simulators are a useful tool for collecting data regarding driver behaviour, there are several issues that need to be considered. Some of these question the overall validity of the results collected, and whether these findings can be generalised to real world settings. Others are of a more ethical consideration, and the researcher in question can take practical measures to ensure these are dealt with effectively. Such ethical considerations include the risk of negative transfer of simulator behaviours, and the potential risk of simulator sickness. Each of these three topics are discussed in the following sections.

### 5.4.1 Validity

One question often asked when collecting data is whether the findings from the driving simulator in question can be generalised to real-world findings. In other words, there is a question of to what degree simulator results are externally valid. This question is often investigated in validation studies that compare behaviours observed in the simulator to on-

road behaviours. These behaviours are then compared using ANOVAs and correlations to establish levels of behavioural validity. If data from the simulator and on-road tests are the same, then absolute validity is established (Blaauw, 1982). If data are not exactly the same in both conditions, but the findings are of the same magnitude and in the same direction, then relative validity is established (Tornros, 1998).

The question of whether driving behaviours reflect absolute or relative validity compared to on-road research is dependent on several factors. It has been argued that validity of a measure can be highly dependent on the study itself. In particular, the chosen sample, methodology, simulator characteristics, the method of on-road testing and the method of data collection can all have an impact on the resulting validity of the measured behaviour (Mullen, Charlton, Devlin, & Bédard, 2011).

The external validity of measuring driving behaviour in the simulator has several practical implications, particularly for the field of novice driver training. For example, in the Netherlands, fixed-base simulators are used for initial driver training (de Winter et al., 2009). Additionally, the literature consistently states that simulators are a valid tool for training fundamental skills such as hazard perception (Underwood, Crundall, & Chapman, 2011). Therefore it is important that the behaviours learned in such environments are at least similar to those produced in on-road driving. Overall, studies comparing simulated and on-road tests establish relative validity or find significant correlations between methods, regardless of the measurement chosen. In de Winter's (2009) study, fewer steering errors during initial simulator training significantly predicted the chances of passing the on-road test 6 months later. Two additional studies comparing fixed-base simulators to on-road performance have established relative validity regarding error measurement. Whilst one of these studies found

significant correlations between simulator and real-road driving for specific errors (Mayhew et al., 2011), the other only found non-significant differences between conditions on a subset of driving errors (Meuleners & Fraser, 2015), hence only relative validity was established. Finally, a recent simulator study comparing the glance durations of distractions inside and outside the vehicle for novice drivers argued that relative validity could be established on the basis that obtained glance durations were similar to on-road findings from a previous study (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010).

As already discussed, establishing validity of a chosen variable is highly dependent on a variety of methodological and practical factors. Depending on the measure in question, most studies tend to find at least relative validity. When investigating driver speed, for example, simulator speeds have been found to be similar, but still lower than those measured on the road (Bella, 2008). Additional research has also found, when comparing simulated and on-road driving around a university campus, that speeds are only similar at just over half of the locations analysed (Klee, Radwan, & Al-Deek, 1999). Both of these studies suggest speed variables measured in the simulator are relatively valid. Measures of time headway, regardless of whether they are distance or time-based headways, did not differ between simulators and on-road car following tasks, meaning that absolute validity was established in this study (Risto & Martens, 2014). However, studies into lateral positioning have failed to find either relative or absolute validity for simulator data (Blana & Golias, 2002; Hallvig et al., 2013).

The latter of these two studies compared the effects of driver fatigue on real and simulated roads (Hallvig et al., 2013). Whilst they concluded that there was low validity for their chosen behavioural measures, they did conclude that good relative validity was found for

several physiological measures. Recent research has focused on the validity of measuring physiology in driving simulators, and there is a general consensus that at least relative validity can be established, and occasionally absolute validity (Li, Zhao, Xu, Ma, & Rong, 2013). For example, one study comparing a range of cardiovascular variables between simulators and real roads concluded overall that good levels of both relative and absolute validity had been established (Johnson et al., 2011). Additionally, another study comparing secondary task effects on skin conductance levels in simulator and real environments found that both environments elicited similar changes in conductance from baseline to the first level of secondary task difficulty (Reimer & Mehler, 2011). However, some studies have suggested higher levels of physiological activity on the road than in the simulator. Whilst some attribute this effect to increased effort on the roads (Engstrom et al., 2005), others claim that this effect is due to increased levels of perceived stress (Milleville-Pennel & Charron, 2015). It is worth noting that Engstrom's (2005) study was based on a comparison of data on three separate studies, and as no statistical comparison was made between different types of driving method, it is difficult to say for sure whether these claims are supported by the evidence presented.

Nonetheless, it suggests that with regards to behavioural and physiological measurements, data overall supports the idea that driving simulators are a valid tool for measuring driver behaviour and awareness. Despite the wide variety of methodological and individual characteristics that may potentially influence results, the majority of studies seem to establish at least relative validity for both behavioural and physiological variables. Whilst no direct comparisons to on-road behaviour have been made in this thesis, it is believed that the use of a driving simulator to collect data should provide valid results that can provide a general understanding of on-road behaviours and reactions.

### 5.4.2 Risk of behavioural transfer

One ethical consideration, that is not discussed as frequently in the literature, is the risk of negative behavioural transfers from the simulator to real roads (Caird & Horrey, 2011). It has already been emphasised that simulators are able to measure and observe driving behaviours within a safe environment. Regardless of simulator type, the participant does not go through the same consequences of dangerous driving as they would in the real world. For example, if a participant were to have a car accident in the simulator, the car would not be damaged and the participant would not be hurt. Because of this, it has been suggested that participants may temporarily feel a false sense of invulnerability. As a result of this, if someone were to go driving immediately after completing an experiment, it is possible they may drive less safely on real roads, therefore it may increase their chances of accident involvement.

Despite the fact there is no real empirical evidence to support this theory, it has been advised that researchers are cautious and take this into consideration when conducting simulator research (Caird & Horrey, 2011). Therefore, for each of the remaining studies conducted, participants were advised on the risk of driving in the real world immediately after completing a simulator study. They then signed consent forms declaring that they understood these risks, agreed not to drive for at least 30 minutes after completing the study, and would inform the researcher if they felt the study affected any of their future driving behaviour.

### 5.4.3 Simulator sickness

Another important issue regarding the use of simulators in research is the risk of developing simulator sickness. Simulator sickness is the feeling of illness or physical discomfort when performing a task in a simulator. This feeling can be caused by a wide variety of factors, such

as individual characteristics, simulator properties and scenario design. Moreover, it is a consistent phenomenon across both fixed-base and motion platform simulators (Aykent, Merienne, Guillet, Paillot, & Kemeny, 2014; Dziuda et al., 2014).

Simulator sickness can be a problem both for the participant and the researcher. For the participant, it can increase feelings of visual disturbance, disorientation and nausea. For the researcher, there are two main issues. Firstly, simulator sickness can increase dropout rates from studies. Whilst the literature is inconsistent regarding these dropout rates, they can range from anything between 17.6% (Kawano et al., 2012) to as high as 59% (Matas, Nettelbeck, & Burns, 2015). Secondly, severity of sickness symptoms has been associated to changes in driving behaviour, such as average speed and steering wheel reversal frequency (Helland et al., 2016), as well as headway time variability (Kluever, Herrigel, Heinrich, Schoener, & Hecht, 2016). Therefore, it is important to understand why simulator sickness may occur, what can be done to measure it, and what can be done to screen for it and minimise any adverse effects.

The three main theories that are associated with simulator sickness are sensory conflict theory (Reason & Brand, 1975), postural instability theory (Riccio & Stoffgregen, 1991) and poison theory (Treisman, 1977). Sensory conflict occurs when there is a mismatch between the visual and vestibular cues expected by a participant. For example, a driver expects to experience synchronous visual and movement changes whist driving a car. Within fixed-base simulators, visual cues are often experienced without motion cues, which can in turn influence higher sickness rates in comparison to those experienced in motion-based simulators (Aykent et al., 2014). However, whilst both visual and motion cues are provided in motion-based simulators, a latency between the two cues can also induce sickness. Recent

research has demonstrated that increasing visual latency can lead to increased ratings of simulator sickness (Blissing, Bruzelius, & Eriksson, 2016), and research into motion cues has suggested that the greater the discrepancy between expected and perceived cues, the higher the rate of simulator sickness (Groen & Bos, 2008). Sensory conflict may also explain why those with more experience of performing a task in the real world may be at greater risk of sickness (Pausch, Crea, & Conway, 1992). Because there is a greater expectation of how visual and motion cues should be synchronised, there would be a greater perceived mismatch in the simulator.

However, sensory conflict theory does not explain the physiological development of simulator sickness, nor does it explain phenomena such as adaptation to simulators (Domeyer, Cassavaugh, & Backs, 2013). In contrast, poison theory (Treisman, 1977) suggests that some of the symptoms produced as a result of simulator exposure are similar to those experienced after ingesting poison, and as the body's reaction to ingesting poison is to be sick, simulator sickness symptoms develop. It has also been argued, from an evolutionary perspective, that this sensation could also due to the fact that the body is not used to modern modes of transport (Brooks et al., 2010). Postural instability theory (Riccio & Stoffgregen, 1991), on the other hand, suggests that sickness arises due to inadequate experience in maintaining postural stability in an environment. In comparison to sensory conflict theory, postural instability theory may be able to explain why adaptation effects occur (Pinto, Cavallo, & Ohlmann, 2008). Because the individual is able to learn how to maintain stability within this new environment, they are able to adapt to the environment and sickness symptoms are reduced. However, unlike poison theory, and similarly to sensory conflict theory, it cannot explain the physiological causes of simulator sickness.

Recent research has attempted to investigate the effects of simulator sickness on neurological and physiological variables. A recent EEG study inducing sickness in a 6 degrees of freedom motion-base simulator found that increases in sickness were associated with increases in alpha power in the parietal lobe, increased theta power in the left and right motor areas, and increased power overall in the occipital lobe (Chen et al., 2010). The authors argue some of this increased power, particularly in the occipital lobe, may reflect an increase in task difficulty or increased conflict, and whilst this causes the brain to work harder, it is associated with an increase in sickness. Other research into physiological influences suggests that increased sickness is associated with reductions in skin temperature and heart rate intervals, as well as increases in skin response amplitude that approach statistical significance (Min, Chung, Min, & Sakamoto, 2004). Additionally such changes, as well as being associated with increased sickness rates, have also been associated with increases in state anxiety as measured by the STAI (Bertin et al., 2004). This implies that care needs to be taken particularly when studying the relationship between anxiety and driving, as it may suggest any physiological and behavioural changes attributed to anxiety changes may in fact be due to increased sickness.

There are many things a researcher can do in order to minimise any potential effects of simulator sickness, both within the simulator itself and within scenario designs. For example, within the simulator itself it is important to ensure that any visual displays are aligned correctly, otherwise this may result in an increase in intrasensory cue conflict, which can result in symptoms such as fatigue and headaches (Stoner, Fisher, & Mollenhauer Jr, 2011). With regard to scenario design, it is important to take the design and duration of the drive into consideration. It is recommended that the amount of 90 degree turns should be minimised as

these increase simulator sickness, and sessions within the simulator should be shorter if the drive is more intense (Stoner et al., 2011).

If possible, the researcher should also attempt to reduce the amount of visual information within scenarios, in order to reduce the amount of optic information available. Optic flow refers to the movement of objects within the environment as a person moves in relation to their environment. Within driving, objects often move away from the centre of the focus of expansion as the car travels forward. The rate and direction in which these objects travel can give us information on the car's behaviour, for example its direction of travel and speed. Whilst this information provides information about the environment, it is also argued that this information can increase levels of sensory conflict, which in turn can increase levels of sickness. Recent research has investigated the effects of reducing optic flow on sickness levels (Jaeger, Gruber, Mueri, Mosimann, & Nef, 2014). They reduced levels of optic flow by decreasing the brightness of the screen and reducing the amount of roadside objects such as buildings and trees. They found that by reducing the amount of visual information, levels of sickness were lower in comparison to a control scenario.

However, it is also important to note that depending on the driving task in question, recommendations regarding scenario design may not always be possible to follow. For example, the research presented in Chapters 7 and 8 of the thesis are comparing environments with different levels of demand. To increase levels of demand within scenarios, the amount of turns to complete and the presence of buildings and additional cars was necessary, despite the increased risk of sickness involved. This example highlights how simulation research needs to take into account the needs of the researcher versus the well-being of the participant.

One screening measure that can be used to assess levels of simulator sickness is the Simulator Sickness Questionnaire (SSQ- Kennedy, Lane, Berbaum, & Lilenthal, 1993) (See Appendix 'K'). The SSQ is a 16-item questionnaire that was developed to replace the original Pensacola Motion Sickness Questionnaire (MSQ- Kellogg, Kennedy, & Graybiel, 1965). The SSQ was created on the basis that some of the items from the original MSQ, such as fatigue, may not necessarily be related to simulator sickness. It comprises of 16 symptoms that reliably increase in severity ratings after exposure to a driving simulator. A factor analysis revealed that these items formed three subscales of symptom; these subscales are related to nausea, oculomotor disturbances and disorientation (Kennedy et al., 1993). Items are rated between 'None' and 'Severe' and participants are asked to rate to what degree they feel each of the symptoms at that point in time, with higher ratings indicating higher levels of sickness. The questionnaire can be administered at any point in time by the researcher, either before or after simulator exposure. However, it has also been noted that by asking participants about their current levels of sickness before exposing them to a simulator, this may in turn influence sickness levels (Stoner et al., 2011).

In summary, simulator sickness is a widespread issue in driving research that should be considered for ethical and practical purposes. Theories for the causes of simulator sickness include increasing levels of sensory conflict and an inability to maintain postural stability within a simulated environment. As well as this, there are many other factors that can influence sickness levels, such as age, gender, visual complexity and scenario duration (Classen, Bewernitz, & Shechtman, 2011). For the purposes of the studies conducted in this thesis, several measures were taken to reduce simulator sickness. For ethical reasons all participants were informed of the risk of sickness prior to participation. In all studies, projector alignments were checked prior to testing to ensure that there was no visual

disorientation. All participants were also given an opportunity to practice driving in the simulator before commencing with the experiment, after which they would be given an SSQ to complete. The researcher would then check these questionnaires and remind the participant of the risks of sickness, before offering them water. Participants would also be reminded at this point that they were free to drop out from the study at any point if they felt too unwell to continue. All scenarios were no longer than five minutes in duration, and participants were allowed breaks in between each of these scenarios. For the study described in Chapter 6 and the undemanding scenarios described in Chapters 7 and 8, optic flow was reduced by reducing the amount of traffic on the roads.

## 5.5 Nottingham Integrated Transport and Environment Simulation (NITES) facility

To conduct the remaining studies discussed in this thesis, the Nottingham Integrated Transport and Environment Simulation facility (NITES) was used. NITES is a £1.3 million facility that was funded by the HEFCE Capital Infrastructure fund, and is situated at the University of Nottingham. It consists of three simulators: a motion-base simulator (NITES 1), a fixed-base simulator (NITES 2) and a fully instrumented Ford Focus (NITES 3). The remaining studies conducted in this thesis used NITES 1 and NITES 2, so these two simulators will now be discussed.

NITES 1 is a high fidelity simulator with a 6 degrees of freedom Bosch Rexroth motion platform. On top of the motion platform is a 5 metre fibreglass dome containing a standard BMW mini. This mini has its engine removed but contains the remaining components expected within a car. In place of the wing mirrors are two 7” TFT-LCD screens, which display scenario images at a 800 x 480 WVGA resolution. Other images for the scenario are

projected onto the inside of the dome's wall using six projectors mounted onto one gantry system. These provide a 270$^{o}$ single image for the driver's main window, and a single image projected onto the back of the dome, which can be seem from the car's rear view mirror. An external sound amplifier is also attached to the sound system, allowing audio from the scenario to be routed to the mini's speakers. Four eye tracking cameras are placed to the left and right of the car's dashboard, which can calibrate and record eye movements. A video camera inside the car acts as a feed for a monitor in the simulator's control room, so that the researcher can track the driver's facial expressions. The car also contains an intercom system on the right hand side of the steering wheel, which is connected to a microphone and speaker in the NITES 1 control room. The outside and inside of the dome can be seen in Figure 5-1.

a) b)

*<u>Figure 5-1:</u> The outside of the NITES 1 dome (a), and a participant completing a driving task inside the dome (b). The participant is wearing a headband to record functional near infra-red spectroscopy (fNIRS), which will be discussed in further detail in Chapter 8.*

NITES 2 is a medium fidelity fixed-base simulator with a steel frame rig. This rig contains the basic car components, such as a pedal set, gearbox, instrument cluster, adjustable car seat and a rear view mirror. This is situated in front of a cylindrical projection screen with a diameter of 5 metres. Images are projected onto this screen using three projectors mounted onto a gantry, producing 180$^{o}$ of field of view. The rear view mirror image is displayed on a

37” HD TV placed behind the rig. Audio is played out during the drive using two speakers placed either side of the front of the rig. Eye tracking cameras are also available in NITES 2; these are placed at the front of the rig (See Figure 5-2).

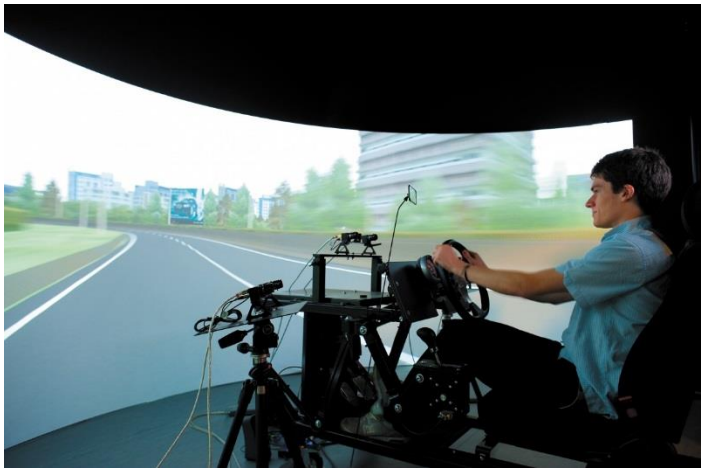


*Figure 5-2: A driver completing a task in NITES 2.*

For both simulators single-chip DLP projectors are used, which project images at a resolution of 1600x1200 pixels. A series of PC-IGs that run Windows XP with Tempest installed are used to project scenario images onto each of the simulator’s projection screens. For NITES 1, there are seven IGs, one for each projector and one controlling the image output for the side view mirrors. For NITES 2 there are four IGs, one for each of the three projectors and one for the rear view mirror image. Both simulators can be controlled by the researcher using two HOST computers, both of which use run Windows XP with XPI simulation software installed. HOST 1 runs the scenario editor and execution programs, which can be used to create and run scenarios. HOST 2 can be used to extract data from completed drives; measures of longitudinal control are extracted at a rate of 100Hz, whilst measures of lateral control are extracted at a rate of 50 Hz.

Both simulators are also able to record eye movements and physiological data. Eye movements from the camera are recorded using FaceLab version 5.0, and the data from this is system is connected to HOST 2 using FaceLink 2.0. As with the previous studies, physiological data can be recorded using a series of BioPac amplifiers connected to a computer, which outputs the signal in Acqknowledge 4.1. In both NITES simulators, this is achieved using a Dell Precision M4500 laptop running Windows 7. This is then connected to one of the PCs in the control using an Ethernet cable in NITES 1, and a KVM switch cable in NITES 2. An example of how each control room is set up is provided in Figure 5-3.

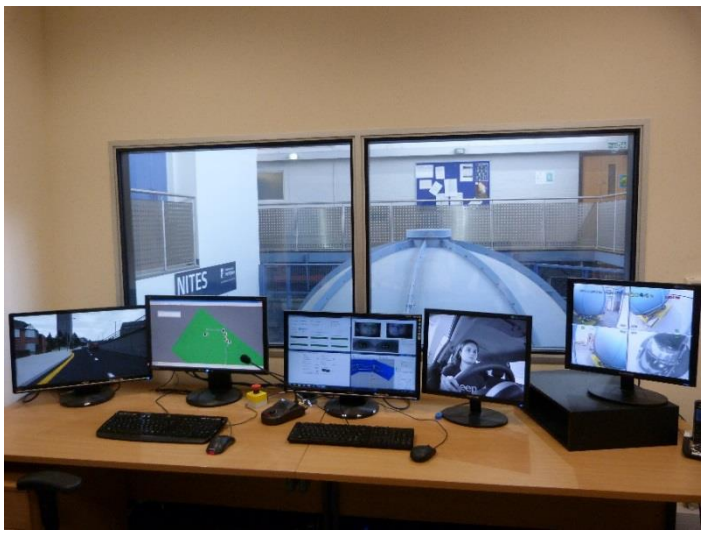



*Figure 5-3: The NITES 1 control room. Each of the monitors has a separate purpose. Monitors in this room are used for (from L-R): viewing the scenario as it plays out for the participant, the editing and execution of scenarios, recording eye movement data, viewing the driver as they complete the task, and viewing the outside of the dome. In NITES 2 three monitors are provided. One of these runs the simulator, one monitors the driver, and the other records eye movement and physiological data. The latter of these uses a KVM switch to switch between recording computers.*

## 5.6 Conclusions

Simulators have become an essential tool for the field of driving research. Regardless of whether a simulator is fixed-base or motion-base, they provide visual, audio and motion

feedback that makes the driver believe they are taking part in a task that is similar to real world driving. Their use has been important within many areas of driving research, including emotion and anxiety research.

The NITES facility can provide a safe environment in which drivers can complete tasks, hence its use in the remaining studies discussed in this thesis. However, it is acknowledged there are several issues that should be considered when conducting research, such as the validity of findings, risk of behavioural transfer and risk of simulator sickness. Whilst no direct comparisons to other studies or on-road research have been made in the thesis, based on the literature, the findings discussed are believed to be at least representative of relative validity. Risks of behavioural transfer and simulator sickness, however, have been directly addressed in the remaining studies, and the measures taken have been discussed in Sections 5.4.2 and 5.4.3. It is believed that by conducting this research within the NITES facility and taking all necessary measures, the drivers involved are completing tasks within a safe and immersive environment that is representative of real-world driving.

# Chapter 6. State anxiety, autonomic activity and driving performance during simulated motorway driving: an exploratory study.

## 6.1 Introduction

As discussed in Chapter 4, it is important to extend research into anxiety and driving into a more interactive environment, and Chapter 5 emphasises how this can be achieved using the NITES facility. The next three chapters discuss studies that were conducted within NITES, focusing on the effects of both state and trait anxiety. Whilst the previous studies have focused on the effects of trait anxiety, and some previous simulator research has found relationships between trait anxiety and driving behaviours (Stephens & Groeger, 2009), the majority of simulator and on-road research has focused on the effects of changing state anxiety levels. Thus the first study discussed explores the effects of changing state anxiety levels during simulated driving.

Research into cognitive performance has argued that experiencing an emotional state may result in behavioural changes that are independent of trait; for example, one study looking to performance on a progressive matrices task found a curvilinear relationship between levels of state neuroticism and task performance that was independent of trait neuroticism (Beckmann, Beckmann, Minbashian, & Birney, 2013). This effect is also apparent in the context of anxiety. One study looking at motor task performance found a strong U-shaped relationship between levels of state anxiety and the amount of errors made, without any effects of trait anxiety (Halvari & Gjesme, 1995). When people are driving, it is highly likely that the unpredictability of events such as hazards and the behaviour of other road users would result in a driver feeling higher levels of state anxiety. The previous two studies suggest that emotional states, rather than traits, may be better predictors of performance; on this basis it is

possible to suggest that state anxiety may be more predictive of driver behaviour than trait anxiety.

Research conducted on real roads has suggested changes to both physiological and behavioural measures as a result of increased state anxiety. One study asked participants to drive on real roads and give a rating of emotional states every three minutes, as well as spontaneously stating any emotions if they wished to. Findings suggested that anxiety was frequently reported, and was associated with increase in heart rate that was not present when reporting feelings of anger or happiness (Mesken et al., 2007). Another study compared performance on mock and real versions of the British Driving Test, and found that whilst state anxiety was higher at test for all candidates, those who failed had higher levels of heart rate and committed a greater number of major errors during the test (Fairclough et al., 2006). If increases in heart rate do reflect preparation for dealing with stressful stimuli, then this suggests that the experience of anxiety whilst driving may result in autonomic changes that require the individual to use internal resources to cope with this increased stress. This may not, however, be useful, as driving requires the individual to also process information from the environment. This is apparent in Fairclough et al's (2006) study, where those who showed increases in heart rate also eventually failed their test, meaning that an external examiner deemed them too unsafe to drive independently.

On-road research is important as it is conducted in an environment most closely resembling real-life driving, and on this basis may provide the most externally valid findings (Kaptein et al., 1996). However, it is worth noting that a researcher is often present in the car when a driver is completing an experiment, and for safety reasons an additional driving instructor is also in the car; this in itself may increase levels of state anxiety. The advantage of completing

similar studies within a simulated environment is that the driver can still complete tasks in an interactive and safe environment without the presence of an additional person. Simulator research, like on-road research, has found that increases in anxiety, or placing someone in an anxiety-inducing condition whilst driving, can result in changes to behaviour and attention. Such changes can include less efficient search patterns, demonstrated by reductions in horizontal scanning (Briggs et al., 2011), increased reaction times to respond to changing traffic lights (Salvia et al., 2012) and higher levels of speed and speeding violations (Roidl et al., 2014).

The above findings consistently suggest that increases in anxiety can lead to behavioural changes that could be dangerous on the roads. However, there are some issues with the methods of recording and reporting levels of state anxiety. For example, in Roidl's (2014) study, ratings were given retrospectively rather than during driving. Furthermore, in Briggs et al's (2011) study, it is claimed that STAI state scores were taken before and after driving tasks to see whether manipulations did lead to changes in anxiety. However, these scores are not subsequently reported, which makes it more difficult to conclude whether any subsequent changes in attention were due to successful changes in anxiety. A method that is now becoming more commonly used to manipulate levels of anxiety is to provide participants with a set of instructions or a brief task prior to completing the assigned driving tasks. These are often designed to make the participants anxious, and anxiety questionnaires are administered before and after these instructions or tasks. Scores are then compared to a control group, and the two groups are then compared with each other on a series of measures. As an example, one study asked participants in a high anxiety induction group to spend a brief amount of time describing their least favourite body part, whilst participants in another group were played relaxing music for five minutes (Morton & White, 2013).

In the previous example, participants then completed a drive around a simulated environment; findings suggested that whilst the manipulation was successful in increasing levels of anxiety, there were no changes in behaviour, except for an increased time to brake at pedestrian crossings. Other studies using similar methods to induce emotional states have also found the manipulation to be successful but no effects on subsequent behaviours, leading researchers to conclude that the induction itself may not be enough to transfer to actual situations (Jeon et al., 2014). It is also possible, however, that instructional sets were not relevant enough to the subsequent driving task. Studies that have found subsequent changes in driving behaviours as well as increases in state anxiety have often used instructional sets designed to promote competitiveness. In such studies, participants are told prior to completing a task that their results will be placed in a league table in comparison to others in the study, and are sometimes told there may be a chance to win a prize based on task performance. Studies that have used such instructions suggest that drivers are less proficient at processing information (Murray & Janelle, 2003), have significant increases in heart rate (Mullen et al., 2012) and increases in pupil diameter and self-reported measures suggest that the task becomes more effortful for the driver (Wilson et al., 2006).

The overall aim of the current study was to explore the effects of increased state anxiety on simulated motorway driving. Whilst previous research using competitive instructional sets has found changes in behaviour associated with increased state anxiety, these studies were conducted in medium fidelity environments; the current study was conducted in NITES 1, a high fidelity driving simulator. Whilst driving, a wide variety of behavioural, attentional and physiological measures were taken. In order to obtain additional measures that may be relevant to road safety, such as time headways, participants completed two types of driving task, one in which they drove at their own pace, and one in which they were required to

follow a police car. Each of these two drives was completed before participants received an additional set of instructions; participants in the experimental group were informed about procedures that would need to be followed in the event of an emergency, and that any subsequent results would be placed into a league table. Based on the previous literature, it was predicted that participants in this group would experience an increase in state anxiety in comparison to controls. Once these instructions had been administered, participants then had to complete the same driving tasks again. In this case, it was predicted that participants in the anxiety induction group would show changes in driving behaviour that may indicate dangerous driving, such as increased speeds and decreased time headways, as well as reductions in spread of search and physiological changes such as increases in heart rate.

## 6.2 Methods

### 6.2.1 Participants

Forty-one participants expressed interest in the study, all of whom were university students. Three subsequently dropped out due to simulator sickness, meaning that 38 participants completed the entire procedure. A power calculation was completed on the required sample size for a within-between subjects interaction using G*Power version 3.1.9.2. Assuming an power level of at least 0.8, a medium effect size ($f$=0.25), this suggested a minimum sample size of 34 when assuming two between subjects groups (control and experimental instruction groups) and two within-subjects levels (baseline and test drives). This suggested that the sample was adequate in the current study. They were aged between 18-26 years old ($m$=19.7, $sd$=1.66), and 25 were female. They had held a full licence for an average of 2.25 years ($sd$=1.78) and reported driving an average of 3178 miles per year ($sd$=4662.5). Six reported that they had previously been involved in a minor accident, four reported being involved in a major accident, and one had previously received a driving conviction. Ethical approval was

obtained from the University of Nottingham, and participant consent was obtained prior to experimentation. Course credit was provided as incentive to participate.

### 6.2.2 Design

This study used a mixed design, with one between and one within-subjects factor. The between-subjects factor was the type of instruction set given to participants. In the experimental condition, participants were told that they would be left alone within the simulator and that the stairs leading up to it would be removed, in order for the simulator's motion base to be activated. They were then told what would happen in the event of an emergency, and then instructed on how to use the emergency escape ladder should they need to. The researcher would then tell the participant that their performance was being monitored and ranked amongst other study participants. The researcher then would leave the participant in the simulator dome and close the door whilst the mobile stairs were manoeuvred out of the way, and then turn on the simulator's motion base, which would raise the dome several feet. Those in the control group were not told this information, nor were the stairs moved away, and the dome's entrance was kept open. They were simply told that they would be completing the same two drives again. It is important to note that whilst participants in the experimental group were made to believe that motion was being used, the motion base was not activated for either group during any of the drives. To test the manipulation's reliability, the state part of the STAI was administered after instructions had been given. This score was then compared to the state score initially given. Allocation to either condition was randomised before entering the simulator.

The within-subjects factor was the time at which participants completed their drives, and this was on two levels. Participants completed two 'baseline' drives, and were then provided with

either control or experimental instructions. These were followed by the same two drives that were this time completed under ‘test’ conditions.

To obtain a variety of dependent variables that may be indicative of dangerous driving behaviours, two separate drives were completed during both ‘baseline’ and ‘test’ conditions. A car-following task (described in Section 6.2.4) was administered to obtain headway variables, measured in both time headways (in seconds) and in the percentage of time spent too close to the following vehicle. As well as this, a ‘free driving’ task was also administered (also presented in Section 6.2.4). This was done to collect information on additional driving variables. Speed variables, in mph, included the average and standard deviation speeds as well as the percentage of time spent over 70mph and the percentage of time spent under 60mph. As the maximum speed limit on UK motorways is 70mph, driving at over 70mph or under 60mph could reflect dangerous driving by over or under-speeding respectively. The standard deviation of lane position (SDLP) was also calculated. Physiological data included mean skin conductance levels (in μS) and mean heart rate (in BPM), and attentional variables included the mean spread of horizontal and vertical search (in $^{o}$).

This resulted in four drives that were to be completed: one baseline following task, one baseline free driving task, one test following task, and one test free driving task. All of these took place on the same stretch of dual carriage motorway. Baseline drives were always completed before experimental drives. However, the order in which the following and free driving tasks were completed within these conditions was counterbalanced.

### 6.2.3 Materials/Stimuli

Participants were initially given the STAI to complete both the state and trait aspects of the questionnaire. The state part of the questionnaire was administered a second time to check that manipulation's effectiveness. Mean trait anxiety scores overall were 38.78 (*sd*=8.81), and before the between-subjects manipulation, overall mean state scores were 34.26 (*sd*=8.72). The same driver demographic questionnaire as the one used in Chapters 3 and 4 was also used, and two simulator sickness questionnaires (SSQ- Kennedy et al., 1993) were administered, one after the initial practice drive and one after the experimental drives had been completed.

The driving simulator used in this study was the NITES 1 facility described in Chapter 5. However, only the front 180$^{o}$ of vision was projected in the dome during this study, and the motion base was only used to initially raise the dome for those in the experimental group, prior to completing their test drives.

Eye movements were tracked using FaceLab 5.0 and the camera setup described in Chapter 5. However, due to technical issues only the cameras directly in front of the participant were used to record eye movements. Eye movements were calibrated using a series of points projected to the central and periphery areas of the driver's field of view.

Driving scenarios were created using XPI Simulation editor software. The initial practice drive and the four main drives were completed on a section of a motorway, with traffic passing in both directions. In all scenarios participants began on the hard shoulder and had to drive into the lane on their right to merge into traffic. The motorway speed was 70mph, and the drive lasted approximately five minutes, meaning that participants drove approximately

six miles (the time taken depended on individual speeds). During the practice drive, the scenario lasted around three and a half minutes, meaning that participants drove approximately four miles. If the participant felt like they needed more practise, then they were given the chance to drive this scenario again. Scenarios were projected onto the simulator screens using XPI ISO.

Physiological data were recorded using a remote wrist strap that allowed transmission of PPG100C and GSR100C information. A heart rate recorder was plugged into the device and strapped to the participant's third finger on their right hand. Two finger straps to measure skin conductance were also plugged into the device; these were filled with an isotonic gel (GEL101, Biopac Systems Inc., Goleta CA., USA) and attached to the participant's second and fourth fingers on their right hand. These interacted with respective PPG100C and GSR100C amplifiers, which were attached to a laptop that recorded physiological data using Acqknowledge version 4.1, at an acquisition rate of 1000Hz.

### 6.2.4 Procedure

Participants completed both the parts of the STAI, along with the driver demographic questionnaire. They were then taken to the simulator, took part in a practice drive and completed the first SSQ. The researcher then gave the participant instructions on how to complete the drives, communicating through a microphone that projected sound into the NITES 1 dome. If the participant was completing a following task, they were told to imagine that they were driving on the M1, on the way to the experiment. They were unsure of the correct route, so they would need to follow a police car. This car would move into the middle lane and the participant would need to follow them, remain there when it was safe to do so and keep a safe distance from the car. If the participant was completing a free driving task,

they were to imagine that they were driving to the experiment along the M1, they were going to arrive at their destination on time, and they should drive as they normally would. After the baseline drives, depending on which instruction group they had been assigned to, they were then either told they would be completing the two drives again, or they were given the anxiety induction instructions described in Section 6.2.2. After the state part of the STAI had been completed a second time, the researcher left the dome, closed the door, and moved the stairs if the participant was in the anxiety induction condition. The test drives were then completed.

If participants had a simulated crash before reaching halfway through the scenario, the scenario was restarted. If they had a simulated crash more than halfway through, the scenario ended and this data was used for subsequent analysis. After the drives, the researcher then collected the participant from the projection dome, administered a second SSQ and debriefed the participant.

## 6.3 Results

Driving behaviour and eye movement data were extracted from XPI ISO using the IOS Data Extraction Tool.. Using MATLAB R2012a, the first and last 100 metres of each drive was removed to account for starting the car and stopping the simulation. These data were parsed and the chosen dependent variables were averaged and placed into separate arrays according to their respective driving conditions. The exception to this was time headway between the participant and the police car during the following tasks. To obtain this, vector distances between the participant's car and the car to be followed were calculated, before using this information, along with information on the participant's speed and distance travelled, to calculate time headways. SDLP data were averaged over the entire dataset for each participant; due to individual

differences in time completion, average time to complete the baseline following and free driving tasks were 339.75 and 309.22 seconds respectively, and the average time to complete the test following and free driving tasks were 337.87 and 312.65 seconds respectively.

Skin conductance and heart rate data were pasted into an Acqknowledge journal. A script created in MATLAB R2012a was then used to remove any motion artefacts and average out heart rate and skin conductance values for each of the four drives. Due to excessive motion artefacts across all four drives, data from three participants were excluded from physiological analysis. Due to problems with raw physiological recordings, data from one participant's free driving tasks were excluded from analysis, and data from one participant's following tasks were excluded from analysis.

All data were analysed using IBM SPSS version 21. Unless otherwise stated, a series of 2x2 ANOVAs were conducted, with instruction group and type of drive (either a 'baseline' drive or 'test' drive) for both following and free driving tasks. All effects sizes are reported as parital eta squared and all errors bars represent standard error of the mean. Due to problems with recording, eye tracking data from 25 participants is reported for both the free driving and following tasks.

### 6.3.1 State Anxiety Manipulation

A 2x2 mixed ANOVA was conducted, with instruction group and time of STAI administration as between and within-subjects factors respectively. Groups did not significantly differ overall in levels of state anxiety ($F(1,36)=.032$, $p=.859$, $\eta_p^2=.001$), nor did time of administration affect overall state anxiety ($F(1,36)=.084$, $p=.774$, $\eta_p^2=.002$). However, there was a significant interaction between the two ($F(1,36)=7.47$, $p=.01$, $\eta_p^2=.172$). Follow-up tests reveal that whilst there were no differences between state anxiety

scores in the control group ($t$ (18)=1.61, $p$=.125), for the experimental group state scores were significantly higher after the manipulation had been given ($m$=35.26) than before ($m$=32.26) ($t$ (18)=3.02, $p$=.007) (See Figure 6-1).

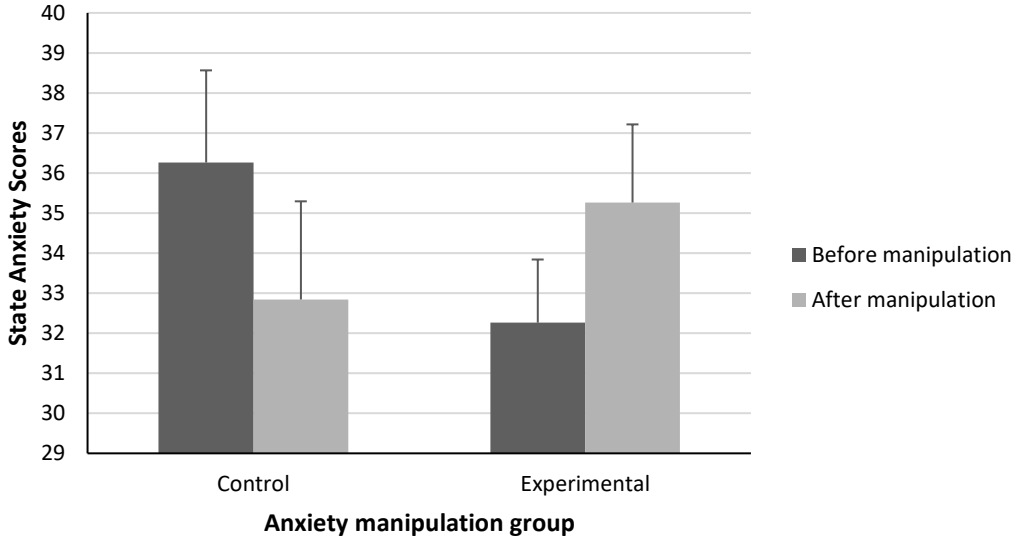



*Figure 6-1*: *State anxiety scores according to manipulation group, before and after the time of manipulation.*

### 6.3.2 Free Driving Task

Due to errors with one of the files, behavioural data from one of the participants in the control condition were removed from this analysis. For all speed and lateral position information, a mixed design ANOVA found no main effects of time of drive or instruction group, nor a significant interaction (all $p$s>.05).

An analysis of the eye movement data found no significant main effects of time of drive or instruction group, nor a significant interaction (all $p$s>.05). There was, however, a marginal effect of time of drive for the spread of vertical search [$F$(1,23)=3.38, $p$=.079, $\eta_p^2$=.128]. This

suggested that spread of vertical search was marginally higher during test drives ($m$=11.03$^{o}$) than during baseline drives ($m$=10.66$^{o}$).

No main effects or interactions were found for heart rate data, and no interactions or main effects of instruction group were found for skin conductance levels (all $p$s>.05). A marginal interaction between instruction group and time was found [$F(1,32)=2.96$, $p$=.095, $\eta_p^2$=.085]. This seemed to suggest that conductance levels increased from baseline to test for those in the control group, but did not increase for those in the high anxiety induction group (See Figure 6-2).

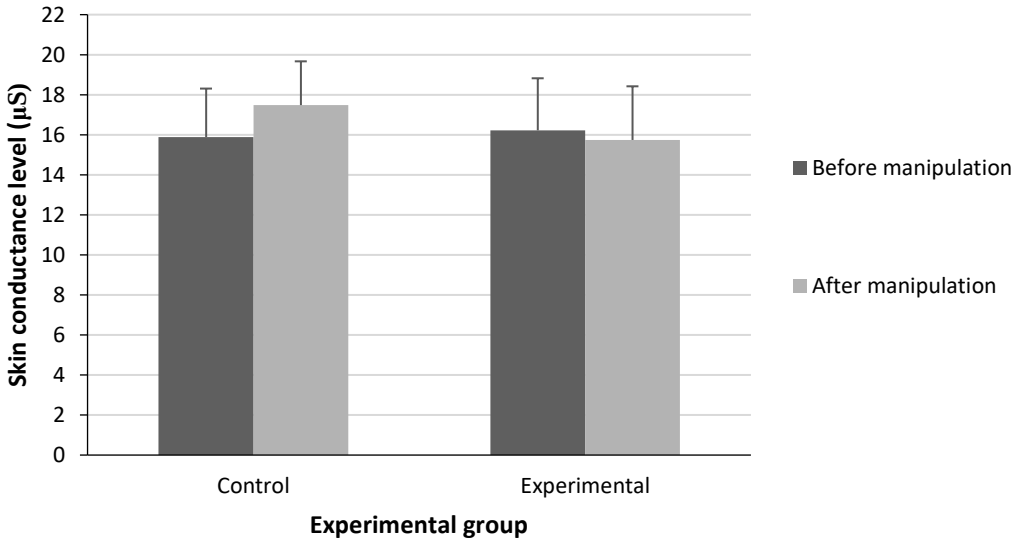



*Figure 6-2: Skin conductance levels during the free driving task, according to instruction group and time of drive.*

### 6.3.3 Following Task

Time headway information was removed for one participant due to problems with data. Any time headway values greater than six seconds were also removed, in order to ensure that

participants were genuinely following the police car. This meant that time headway data for another two participants were excluded (See Figure 6-3 for distributions of time headways). However for the remaining behavioural variables data from all participants were analysed. No main effects of drive time or instruction group were found, nor any significant interactions (all *p*s>.05). There was, however, a marginal effect of drive time on SDLP [$F(1,36)=3.31$, $p=.077$, $\eta_p^2=.084$]. This suggested that SDLP was marginally higher during test drives ($m=1.28$) than during baseline drives ($m=1.23$).

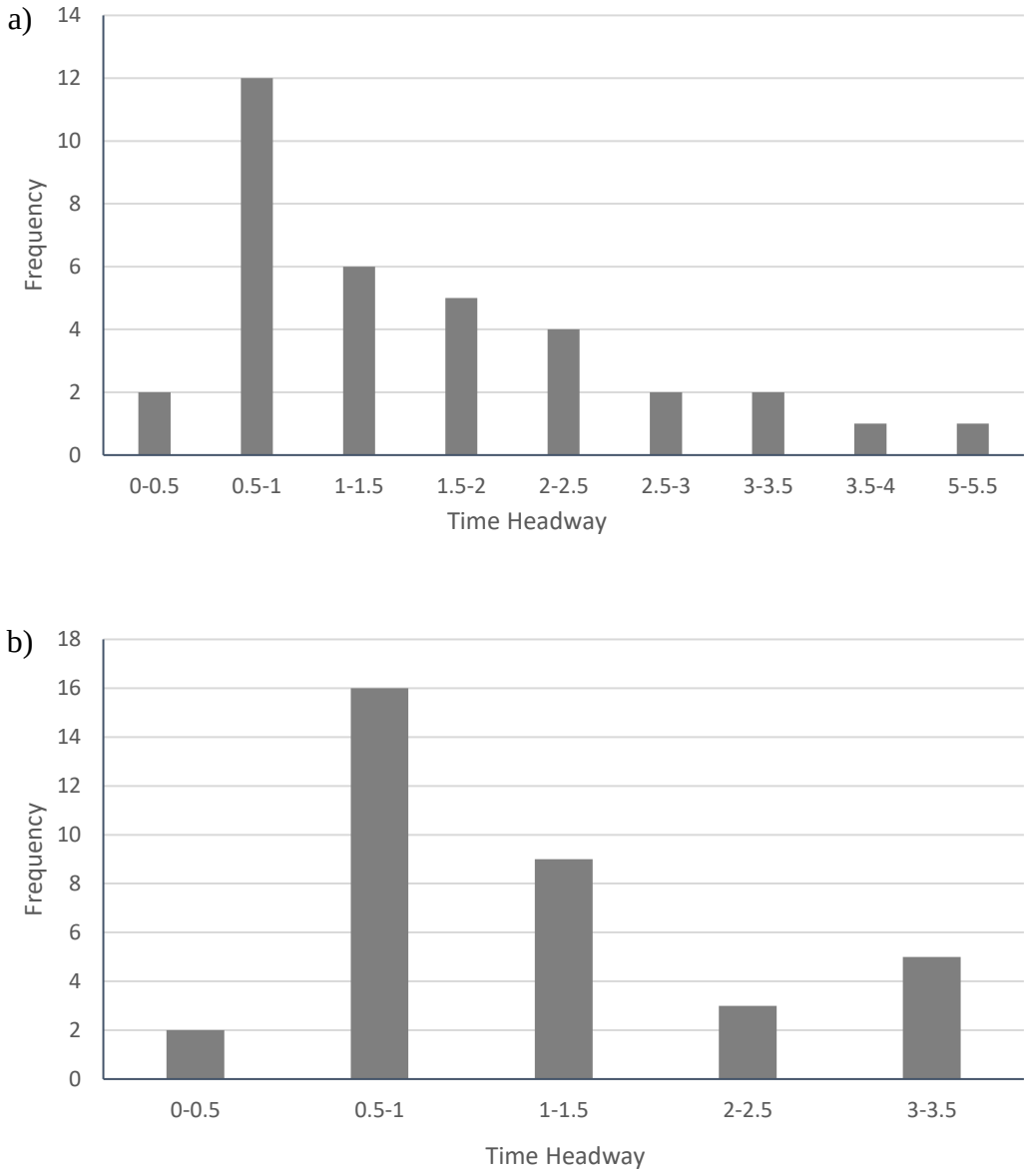



*Figure 6-3: Distributions of time headways between a) the baseline following task, and b) the test following task. Distributions of time headways are binned by 0.5 second intervals.*

Analysis of the eye movement data found no significant interaction between variables; however, a marginal main effect of instruction group was found [$F(1,23)=4.06$, $p=.056$, $\eta_p^2=.15$]. This suggested that horizontal spread of search was marginally higher for those in the control group ($m=14.27^o$) than those in the experimental group ($m=11.44^o$). A significant main effect of drive type was also found for horizontal spread of search ($F(1,23)=23.83$,

$p$<.001, $\eta_p^2$=.505). Horizontal search was significantly higher during test drives ($m$=13.93°) than during baseline drives ($m$=11.43°) (See Figure 6-4).

There were no main effects or interactions found for skin conductance levels, and no significant interaction or main effect of instruction group on heart rate (all $p$s>.05). There was, however, a marginal effect of time on heart rate [$F$(1,32)=4.07, $p$=.052, $\eta_p^2$=.113]. This suggested that for all participants, heart rate was marginally lower during test drives ($m$=74.71 BPM) than during baseline dries ($m$=78.09 BPM).

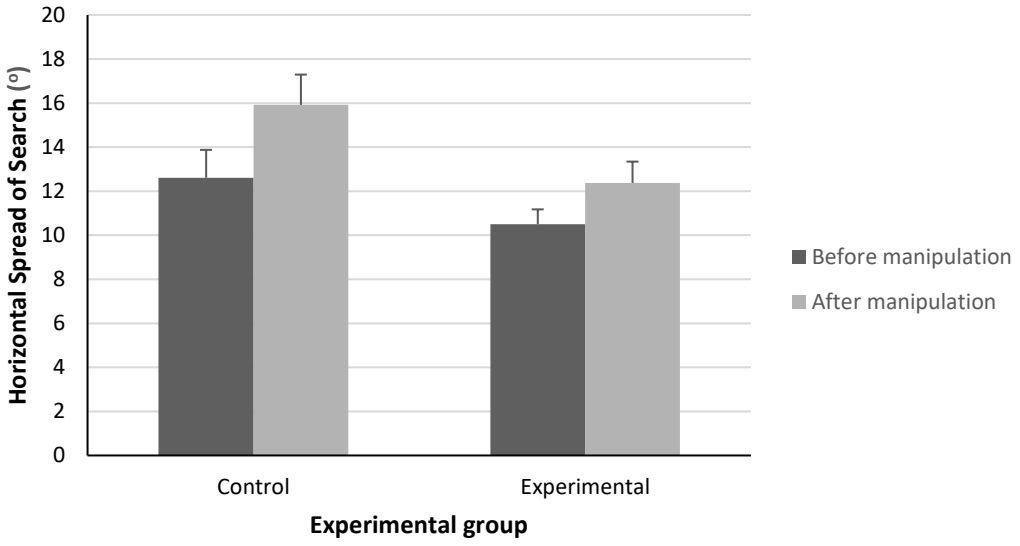



*Figure 6-4: Horizontal spread of search during the following task, according to instruction group and time of drive.*

## 6.4 Discussion

The aim of this study was to attempt to manipulate state anxiety by providing important safety-related instructions and informing participants that any measures collected would be ranked in comparison to other participants. Participants were then compared to a control

group on a series of driving behaviours taken over two types of driving task, a free driving task and a car following task. Results suggested that whilst the safety-related instructions successfully increased state anxiety in comparison to control instructions, this did not result in significant changes in driving behaviour compared to controls or compared to a baseline drive.

### 6.4.1 Findings

The first aim of the study was to use instructional sets, prior to completing to driving tasks, was that we were able to successfully manipulate levels of state anxiety. Whilst participants in the control group showed no significant changes in anxiety, those who were given an alternative instructional set showed significant increases in state anxiety compared to initial levels. Firstly, this finding supports the growing body of research that encourages the use of instructional sets to increase levels of anxiety. Another interesting point to note is that the majority of previous research that uses instructional sets to increase anxiety attempts to make said instructions purely ego-threatening. This means that the instructions given may make the participant believe their performance on the following task may have some consequence on them as an individual. Whilst some of the instructions given in the current study could be described as ego-threatening, for example by stating that results would be placed in a league table, the majority of the instructions given to the high anxiety group focused on the safety procedures that needed to be followed in an emergency. This may imply that safety-related concerns could also elevate state anxiety levels, at least within a simulated environment. Whilst participants may have some awareness they are not in a real driving environment, the threat of an emergency related to simulator use may still have real consequences for the individual, hence this may cause concerns and elevate state anxiety. However, as the instructions used in this study also contained ego-threatening instructions, future research

may want to investigate this suggestion by comparing the use of either safety-related or ego-threatening instructions.

However, it is also worth noting that mean state anxiety scores across time and condition ranged between 32-36. Despite finding a significant interaction that suggests the manipulation was successful, these scores are still below Spielberger's (1983) expected state anxiety norms for college students, which are 36.47 and 38.76 for males and females respectively. This issue has also been found in previous research, and it has been argued that this could be due to the strength of the anxiety manipulation itself (Mullen et al., 2012). However, it could also be possible that participants are still aware that they are taking part in a study being conducted in a relatively safe environment. Therefore whilst there may be some increases in state anxiety due to being given safety-related and ego-threatening instructions, the knowledge that they are in a safe environment and can drop out of the study at any time may mean that state anxiety will not reach relatively high levels.

Additionally, it is noted that there were differences between the control and experimental groups with regards to their baseline anxiety levels; those in the control group had an average baseline score of 36.26, whilst those in the experimental group had a baseline anxiety score of 32.26. Whilst there was interest in the interaction between groups, in that scores for the experimental group significantly changed whilst those in the control group did not, future research may wish to consider controlling for baseline levels of anxiety prior to administering threatening instructions.

The overall mean levels of state anxiety may also explain why no significant different differences in behaviour were found, despite increases in state anxiety in the experimental

group. Nonetheless, considering that the majority of research has found changes in driving behaviour as a result of state anxiety increases, the lack of significant results in the current study are somewhat surprising. Additional ANCOVAs were conducted to consider the potential effects of trait anxiety on driving behaviour; however, these were also non-significant, indicating that neither state nor trait anxiety levels had any effects on driving behaviour.

Previous research has also suggested that thoughts that occur during driving can be independent of the task itself, and often consist of the planning of present and future actions (Berthie et al., 2015). Therefore it would be expected that participants in the experimental group would still be thinking of what they would need to do in an emergency whilst they are driving, and if these instructions did successfully increase anxiety, then thinking about them whilst driving would maintain that anxiety, and this would potentially have an effect on behaviour. However, this was not the case. It is possible, as with previous driving research, that the state anxiety induction itself was not strong enough to transfer to the actual driving task itself (Jeon et al., 2014). Even if participants in the experimental group were thinking about any procedures they would need to follow, they may have been aware that the chances of something happening were small, which may have made them less anxious whilst driving. Therefore, whilst the initial instructions may have increased anxiety, this may not have been enough to transfer to the task itself, despite the inclusion of ego-threatening instructions.

Some of the eye movement data suggested changes in search patterns according to the time at which driving tasks were completed. When a participant had to follow a police car along the motorway, horizontal spread of search was greater at test than at baseline, regardless of instructional group. As there were no main effects of instructional group, and the task itself

did not change from baseline to test, these effects cannot be due to changes in anxiety or demand. These changes could be attributed to practise effects; however, this would not explain why the same effects were not found during the free driving task, where vertical spread of search was marginally greater at test compared to baseline. It is possible that the differences in spread of search could reflect different attentional priorities whilst completing different types of task. For example, when following a car, more attention may be needed on the horizontal axis to search for cars that may try to merge into the lane between the participant and the car being followed. When a participant is driving on a motorway at their own pace, however, extra information may be needed along the vertical axis in order to search for cars that may be merging into the participant's lane from further along the road. However, as previous research has consistently demonstrated that the most useful information on potential dangers lies within the horizontal axis, greater levels of scanning along the vertical scanning without greater levels of horizontal scanning may not reflect an optimal search strategy.

Findings from the physiological data were also minimal. For the free driving task, there was a marginal interaction between time of test and experiment group which suggested that skin conductance levels increased from baseline to test for the control group, but there was little change for the experimental group. This does not provide support for the anxiety literature, which often finds increases in skin conductance levels according to increased anxiety (Kissel & Littig, 1962), and because there were no differences in the task demands between baseline and test drives, it is hard to attribute the findings to an increase in arousal or increased workload. It is possible that those in the control group were orienting more towards the tasks after the baseline drives had been completed, in comparison to those in the experimental group. Perhaps those in the experimental group were thinking about the instructions given to

them prior to the test drives, and were therefore less able to orient towards the test drives in the same way as controls. If a driver's thoughts can be independent of the task itself and consist of the planning of present and future actions (Berthie et al., 2015), then this explanation is possible. However, it is also worth noting that like heart rate, skin conductance levels in particular can be influenced by a wide variety of factors, such as age, gender, sweat gland density and BMI (Doberenz, Roth, Wollburg, Maslowski, & Kim, 2011), and this should be kept in mind when considering this interpretation.

The heart rate data from the following task suggested that heart rate was marginally lower during test drives than during baseline drives. This in itself suggests participants oriented more towards the driving task after baseline drives. After baseline drives, participants may be more able to take in necessary information from the environment whilst driving, in support of the cardiac intake-rejection hypothesis (Lacey et al., 1963). This may also explain why the spread of horizontal search was significantly higher during test drives. If participants were better at taking in environmental information during the test drives, it is expected they would also be better at scanning the environment for information. However, whilst this increased intake in environmental information may lead to more efficient scanning patterns, the fact that SDLP was also marginally higher during the test drive suggests that this may not necessarily lead to safer driving behaviours.

### 6.4.2 Limitations

As well as some of the limitations listed above, there are some general limitations to this study. Firstly, some of the findings presented from the self-paced and following tasks indicate that different demands may be required to complete each task successfully. However, as no subjective measures of demand were recorded during this study, it is difficult to say for sure

whether this explanation is correct. Whilst previous research has indicated that behavioural and physiological measures can be found independently of each other (Dijksterhuis et al., 2011), the addition of a subjective measure may provide a clearer interpretation of the current results. For example, measures such as the NASA-TLX (Hart & Staveland, 1988) are recorded on scales measuring different types of demand, as well as overall demand levels; in the context of this study, this could inform us of what specific demands are required in each type of task completed.

Secondly, whilst the tasks themselves may be described as representative of everyday driving, in comparison to previous research these motorway tasks may be seen as relatively undemanding. Guidelines provided by the Driver and Vehicle Standards Agency note that whilst dangerous events do occur on the motorway, motorways can be particularly monotonous roads to drive on and are statistically safer than other roads (Driver and Vehicle Standards Agency, 2014). If the tasks themselves were not demanding enough then this may explain the lack of significant results in the study. As well as providing a subjective measure of workload, future research should consider the effects of increasing demands on such roads. For example, an increase in visual demands could be achieved by increasing traffic density, and previous research has suggested that increases in traffic density can lead to behavioural changes such as shorter time headways (Zhang & Kaber, 2013).

There is also a possible limitation of using a police car in the following tasks. A police car was initially chosen on the basis that it had distinguishing features which a participant would be readily able to identify and follow. However, it is also noted that a police car could be seen as an authority figure, and as a result it may adapt the behaviours of those following it. Whilst this issue remains unexplored, this could potentially explain why there is a slight positive

skew on time headways (shown in Figure 6-3); whilst the Highway Code recommends a following distance of at least two seconds between a driver and the car in front of it, the majority of participants drove less than two seconds behind the police car. Future studies using following tasks may wish to compare police cars to different vehicles with perhaps less authority, in order to assess whether this is the case.

### 6.4.3 Conclusions

To summarise, the aim of the current study was to explore the effects of increasing state anxiety on subsequent driving behaviours and physiological patterns. Results suggested that the type of anxiety induction used was successful in increasing state anxiety in the experimental group. However, in later drives, this increase in state anxiety did not result in any changes in behaviour. Several explanations for this have been discussed, such as the strength of the anxiety manipulation and overall levels of anxiety across the study. Some marginal results were found across the two types of drive completed, but these differed across the two drives, indicating that different demands were required to complete each task. However, no subjective measure of workload was recorded, meaning that this interpretation is less clear. Suggestions made for future research also included changing the levels of demand within the driving environment itself, to assess how this affects workload and subsequently assess how this is affected by increases in anxiety. The study discussed in the next chapter addresses these issues by initially providing half of the participants with a similar set of anxiety-inducing instructions, and then asking them to drive in simulated environments with different levels of perceptual and behavioural demand.

# Chapter 7. The effects of state anxiety manipulations on driving in demanding and undemanding environments.

## 7.1 Introduction

The findings from Chapter 6 suggested that whilst the instructions given to participants were successful in increasing levels of state anxiety, this did not result in any changes in driving behaviours. Possible reasons for this included the nature or strength of the instruction manipulation, and the levels of demand presented within the driving task itself. The study discussed in the current chapter addresses these two issues.

Firstly, whilst the instructions given in the previous chapter did increase state anxiety levels, anxiety scores were still below Spielberger's (1983) norms. It is possible that the use of safety-related instructions can manipulate state anxiety, but not to a strong enough degree that it translates to driving behaviours. Previous research that has used instructions to promote competitiveness has also described such instructional sets as 'ego-threatening'. Ego-threatening instructions, as well as promoting competition between participants, suggest that the results of the study will have some real-world consequence such as revealing scores to other participants (Chamberlain & Hale, 2007), or revealing some measure of real-world behaviour. In transportation research, previous instructions have suggested that driving performance in the simulated environment will reflect real-world behaviours (Murray & Janelle, 2003), or that performance on the given driving task will reflect measures of the participant's intelligence (Schmidt-Daffy, 2013). Giving such instructions results in successful increases in state anxiety, as well as changes in subjective measures of workload (Wilson et al., 2006) and less efficient search strategies such as more random scanning patterns (Allsop & Gray, 2014).

Secondly, it was argued in Chapter 6 that the task of driving on the motorway may not be demanding enough to elicit any changes in behaviour. Increases in demand should reflect an increase in subjective workload, which in itself is a reflection of the driver's current ability to meet the demands of the task. Workload has been described as something that can increase in an individual when they feel they can complete a task, but at a cost (Paxion et al., 2014). Such costs can include increases in perceived effort required and frustration experienced (Hart & Staveland, 1988). A driver may also change their behaviour to compensate for increased workload by making changes such as speed reductions and changes in performance on a secondary task (Platten, Schwalm, Hulsmann, & Krems, 2014).

There are several ways in which demand within the driving environment can be manipulated and subsequently increase workload levels; common methods include the addition of a secondary task such as answering a cell phone or completing a cognitive task. One method of manipulating demand, which has received increased attention in the literature, is to manipulate levels of visual complexity. Increasing levels of visual complexity means that the driver needs to attend to more environmental information, which may make the driving task more difficult. For example, one study measured the effects of increasing levels of visual complexity whilst driving on a motorway, using an in-vehicle information system (IVIS) arrows task (Engstrom et al., 2005). Results suggested that as visual demands from the IVIS task increased, drivers' speeds reduced, reflecting a compensatory strategy to deal with both tasks. Mean skin conductance levels also increased, suggesting an increase in arousal, and inter-beat-intervals reduced, reflecting autonomic increases in workload. This implies that drivers can alter their behaviour to cope with increases in visual complexity by using compensatory strategies. However, some of the literature has also implied that increases in

visual demand may not necessarily make drivers safer, or that compensatory changes in behaviour may not be enough to reduce the likelihood of accident involvement. For example, one study manipulated visual complexity by increasing levels of fog on the road, and found that this reduced visibility made drivers reduce their speed in order to maintain their lane position (Brooks et al., 2011). However, the authors argued that these reductions in speed would not have been sufficient to allow the driver to stop for any on-road obstacles or hazards. An additional study comparing situational awareness in city and rural environments found that being exposed to a hazard in a city environment reduced a driver's comprehension levels; in other words, in a more visually complex environment, after hazard exposure they were less able to accurately describe the behaviour of surrounding traffic (Kaber, Zhang, Jin, Mosaly, & Garner, 2012).

City environments can be seen as more visually complex than rural environments due to an increase in objects such as buildings and pedestrians. Previous research has increased the amount of buildings and billboards in the driving environment in order to increase visual complexity, and found that this increase in visual clutter led to decreases in speed (Horberry, Anderson, Regan, Triggs, & Brown, 2006). From a workload perspective this may reflect a compensatory mechanism; however, these changes were not accompanied with increases in subjective workload, as measured by the NASA-TLX. Therefore such findings may also reflect the driver choosing to adopt a safer speed in order to reduce task difficulty (Fuller, 2005).

Another common method of increasing visual complexity is to increase the density of traffic on the roads. For example, one study investigated the effects of increased traffic flow on a two lane motorway (Teh, Jamson, Carsten, & Jamson, 2014), with results suggesting that an

increase in traffic density reduces mean speeds and increases subjective workload. These changes in visual complexity may result in changing levels of workload and behaviour as the driver needs to try to monitor and predict the behaviour of a greater number of road users, which can increase demand. This effect may be particularly relevant in urban and city environments, where the driver must also monitor the behaviour of pedestrians, who may be obscured by visual clutter such as parked cars. This suggestion was investigated in a study by Edquist et al. (Edquist, Rudin-Brown, & Lenne, 2012). Levels of mental workload increased with increasing levels of visual complexity, mean and maximum speeds reduced and reaction times to a secondary task increased. This suggests that drivers found visually complex environments more demanding, but were able to change behaviours to compensate for that. However, when an unexpected pedestrian appeared from the side of the road, reaction times to brake increased with increased visual complexity, again implying that compensatory changes in behaviour may not necessarily lead to reduced likelihood of accident involvement in these circumstances.

Recent research has also attempted to manipulate levels of vehicle handling as well as visual complexity to make driving tasks more demanding. It is argued in the literature that vehicle manoeuvres such as turning at intersections and changing lanes places additional attentional demands on the driver. This is because when driving is completed on a straight stretch of road, most attention can be allocated to information in the central area of the scene; however, when completing a manoeuvre, a driver must allocate their attention to others who are driving in multiple lanes and directions, making the task more complex for the driver completing the manoeuvre (Chang, Lin, Fung, Hwang, & Doong, 2008). One on-road study conducted in Germany compared the performance of drivers in environments with low or high levels of visual complexity and vehicle handling, and found that higher levels of demand increased

levels of mental workload and reduced accuracy on a secondary task (Jahn et al., 2005). Furthermore, when data from intersections was separated into left and right turns, results found lower levels of secondary task accuracy and longer reaction times at left turn intersections (which are equivalent to right turn intersections on UK roads), which the authors suggest is due to a greater need to observe the environment in order to safely give way to other traffic. Additional research into environmental complexity and vehicle handling has found that both can increase levels of workload overall, but they can individually increase workload in certain circumstances. For example, in a following task changes in vehicle handling demands increase subjective workload without any influence of visual complexity (Stinchcombe & Gagnon, 2010).

There is limited research into the effects of emotion and driving with respect to different levels of environmental complexity, however there is a suggestion that these factors interact. One on-road study asked drivers to rate their levels of emotion whilst driving in two sections of road varying in levels of traffic density, and results found that levels of stress and aggression were higher when levels of traffic density were higher (Hennessy & Wiesenthal, 1999). A recent simulator study extended the research of Edquist et al. (2012) by comparing those with high and low levels of sensation-seeking in driving situations with low and high levels of visual complexity (Rudin-Brown et al., 2014). Compared to those with high levels of sensation-seeking, those with lower levels were argued to be better at adapting to changes in environmental complexity, as they were more likely to shift to a more central lane position when environmental complexity increased. Whilst these studies do not specifically investigate anxiety, they do suggest that the driving environment itself can influence levels of emotion, and that drivers with traits that have previously been associated with anxiety in the

driving literature (Ulleberg, 2001) may be able to adapt their behaviour as a result of increased complexity.

Taking these points into consideration, the aim of the current study was to use a set of ego-threatening instructions to increase levels of state anxiety in participants and measure how this increase in anxiety would affect driving performance in driving situations with varying levels of demand. After being given instructions, participants drove in four scenarios with varying levels of visual complexity and vehicle handling, before driving in a final scenario which aimed to measure drivers' reactions to an unexpected hazard. Measures of driving behaviour, subjective workload and autonomic measures were taken. In line with previous research, it was predicted that increases in demand from the environment would result in increases in subjective workload, and that changes in driving behaviour and autonomic response may reflect these subjective changes. Additionally, it was predicted that those provided with ego-threatening instructions would show significant increases in state anxiety compared to controls, and that this increase in state anxiety would result in changes in behaviour that would interact with levels of demand.

## 7.2 Methods

### 7.2.1 Participants

Forty-eight participants were initially recruited for the study; however, four participants did not complete the study due to simulator sickness, thus only data from the remaining 44 participants were analysed. The same power calculations that were specified in Chapter 6 were also used for the current study, this time specifying two between-subjects groups (control and experimental instruction groups) and four repeated measures levels (two levels of visual and two levels of behavioural complexity). This suggested a minimal sample size of

at least 24, again suggesting that the sample size was adequate for the current design. The remaining participants were aged between 18-24 years, with an average age of 20.82 (*sd*= 1.67). Twenty-eight were female and 16 were male. They were all undergraduate and postgraduate students from the University of Nottingham. All of them had a full driver's licence, and had been in possession of it for an average of 3.26 years (*sd*=1.63). Eight had previously been in a minor road accident, three had been in a major accident, and six had previously received driving convictions. Ethical approval was obtained from the University of Nottingham, and participant consent was obtained prior to experimentation. Some were recruited online using the same procedures as those from Chapters 4 and 6, and were provided with course credit, whilst some were provided with an inconvenience allowance at the end of the study.

### 7.2.2 Design

A mixed factorial design was used in this study, with one between-subjects factor and two within-subjects factors. As with Chapter 6, the between-subjects factor was the induction of high state anxiety in an experimental group, compared to controls. All participants were told that they were to complete a series of five drives, and that they would have to complete a questionnaire after each drive that assessed how easy or difficult they found the task. However, those in the experimental condition were also informed that their performance was being monitored. This was highlighted by showing participants the eye tracking, simulation and video camera monitors available to the researcher just outside the simulator. They were then informed that their performance in the simulated drives would be indicative of real-world driving performance, thus poor performance on the drives would indicate that the participant was a poor driver in real life. These instructions were based on those given in previous research (Murray & Janelle, 2003). Finally, as in Chapter 6, they were told that their

performance would be ranked amongst other participants in the study. The state part of the STAI was then re-administered to assess the manipulation's efficacy. Those in the control condition were not told any of this ego-threatening information, and instead simply completed the state part of the STAI straight after their practice drive.

The two within-subjects factors manipulated were the levels of visual and behavioural-based complexity, and these aimed to change levels of workload. In both cases, demands were either low or high. Visual complexity was manipulated by changing levels of traffic and pedestrian density. When levels were low, there were very few cars and pedestrians within the scenario, and when levels were high, a large number of cars and pedestrians were within the scenario. In conditions with low levels of vehicle handling, participants were simply required to drive along a straight road. When vehicle handling levels were high, participants were required to make three left and three right turns, at various junctions and intersections.

This resulted in four possible drives that were to be completed: one with low visual complexity and vehicle handling levels, one with low visual complexity and high vehicle handling levels, one with high visual complexity and low vehicle handling levels, and one with high visual complexity and high vehicle handling levels. Examples of the least and most demanding drives are provided in Figure 7-1. The order of completing scenarios was counterbalanced for each participant, in that all 24 possible orders of driving scenario were completed once for each condition. However, it is worth noting that whilst there were attempts to control for the environmental characteristics of the scenario, due to the nature of the environments available, drives with low levels of visual complexity were completed on rural roads with a speed limit of 60mph, whilst drives with high levels of vehicle handling had to be completed in residential environments, with a speed limit of 30mph. Drives were an

average of 2 miles each and took approximately 3 minutes to complete, depending on driver speed and the speed restrictions on the roads.

a) b)

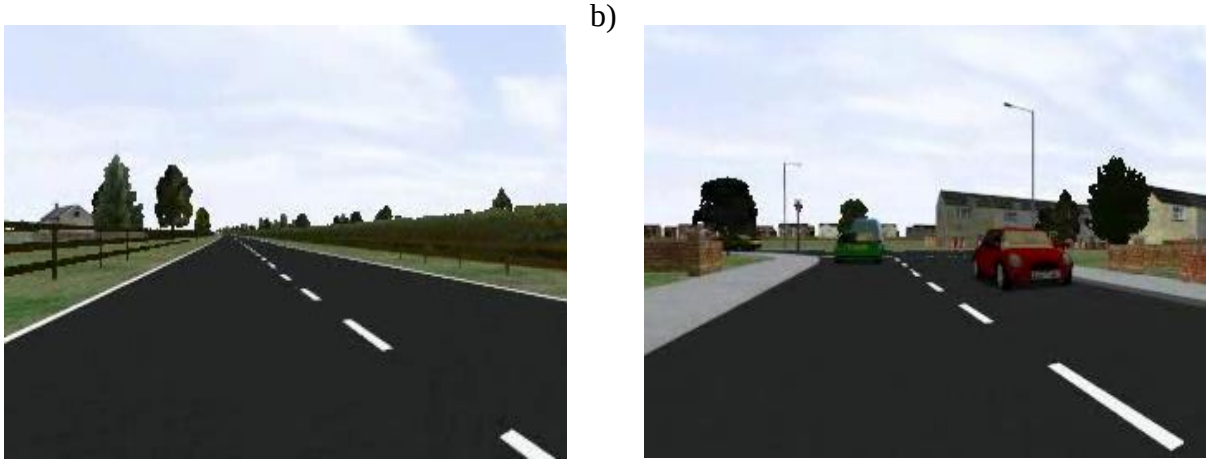


*Figure 7-1: Examples of drives with a) low levels of visual complexity and low levels of vehicle handling, and b) high levels of visual complexity and high levels of vehicle handling.*

After all four drives had been completed, all participants then completed a fifth and final drive. This was in a scenario with high visual complexity and high vehicle handling levels, and included an unexpected hazard just before the end of the drive. The hazard in question was a bicycle emerging from a house at the side of the road, and pulling into the road directly in the path of the participant's vehicle; participants were required to brake very sharply in order to avoid collision with the cyclist.

Autonomic measures that were taken included mean skin conductance levels (in μS) and the number of EDRs per minute for each drive, as well as heart rate (in BPM). However, due to excessive movement artefacts, EDRs were counted after data collection using close visual inspection, and heart rate was estimated based on reliable signals within the data. After manually counting the total amount of EDRs for each drive, this was then converted into a

measure of EDRs per minute in order to account for the fact that participants would not complete each drive in the same amount of time. As with the data discussed in Chapter 3, using a measure of total EDRs may be confounded by such time differences. EDRs were measured per minute as it took a series of minutes, rather than seconds, to complete each drive. Spread of horizontal search was also calculated (in degrees). With regards to driving behaviour variables, measures of lane position (calculated as SDLP) and speed were observed. However, only speed variability (measured as standard deviation of speed) was taken; this was due to the difference in speed restrictions in rural and residential environments. From the hazardous drive, measures of reaction time to first press the brake in response to the hazard (in seconds) and distance from the hazard when the brake was first applied (in metres) were also taken.

### 7.2.3 Materials/Stimuli

#### 7.2.3.1 Questionnaires

As with Chapter 6, participants were initially given the STAI to complete both state and trait parts of the questionnaire. The state part of the questionnaire was then re-administered after the state anxiety manipulation to assess its effectiveness. Mean trait anxiety scores were 37.39 (*sd*=11.51) and prior to the instructional manipulation, state anxiety scores across groups was 30.27 (*sd*=7.56). The driver demographic questionnaire used in Chapters 4 and 6 was once again used in this study, and the SSQ was again administered twice (once after the practice drive and once after the experimental drives).

After each completed drive, the NASA-TLX (Hart & Staveland, 1988) was also administered (See Appendix 'L'). The NASA-TLX is a 21-point Likert scale with six items, that assess the degree to which workload is affected in given tasks. It asks to what degree participants felt the task was mentally, physically and temporally demanding, as well as how much effort the participant felt they put into the task, how well they think they performed the task and how frustrated the participant felt. Whilst it was felt that levels of vehicle handling would be reflected by some of the items on the NASA-TLX, such as physical demand and effort, an additional item was included to reflect levels of visual demand. In accordance with previous research, raw scores were multiplied by 5 to provide individual subscale scores out of 100, and the average of these subscales provided the overall workload score. Higher scores on each subscale, as well as the total, reflect higher levels of workload; this includes the performance subscale, where a higher score indicates a participant believes they have failed the current task.

#### 7.2.3.2 Simulator

Participants completed the experiment in the NITES 2 simulator, as described in Chapter 5. All scenarios were created and shown using XPI ISO Simulation Software. In all scenarios with low vehicle handling, participants started on a single-lane rural roads which were restricted to the UK national speed limit, which is 60mph. In scenarios with high vehicle handling, participants were required to make a series of turns within a residential area with a maximum speed limit of 30mph. Pre-recorded audio instructions were programmed into the scenarios to inform the participant which direction they should be turning in. Scenarios with higher levels of visual complexity were programmed to include an increased number of cars and pedestrians.

#### 7.2.3.3 Eye tracking and physiology

Two remote cameras were placed on the front of the NITES 2 rig. Eye tracking data were obtained using FaceLab 5.0, and linked to the simulator data using FaceLink 2.0. Calibration was completed using eleven calibration points, one on each side screen of the simulator and nine central points.

Physiology data were obtained using heart rate and skin conductance devices linked to a Biopac MP150 amplifier. Heart rate was recorded using a finger strap attached to the participant's middle finger on their right hand, and linked to a Biopac PPG100C amplifier. Skin conductance was recorded using two finger straps filled with isotonic gel (GEL101, BioPac Systems Inc, Goleta CA, USA) and attached to the index and ring fingers of the participant's right hand. These were linked to a BioPac GSR100C amplifier. These amplifiers were linked to a remote laptop that recorded physiological data using Acqknowledge version 4.1, sampling at a rate of 1000Hz.

### 7.2.4 Procedure

Participants completed the STAI for the first time, and were taken into the simulator and given the opportunity to complete a practice drive which required the participant to complete a series of four turns. At this point the participant was allowed as much practise as they needed until they felt happy to continue with the study. Afterwards, they completed the first SSQ before being taken out of the simulator and being given the instructional manipulation. Those in the experimental condition were given the instructions described in Section 7.2.2,

whilst those in the control group were simply told that they would be completing five drives. After this, the state part of the STAI was completed a second time. Then, all participants were taken back into the simulator, where skin conductance and heart rate recorders were attached to the participant's right hand and eye tracking calibration took place. After this each experimental drive was completed, according to the counterbalancing order assigned before commencing the study. After completion of each drive, the NASA-TLX was completed. After all five drives, physiological equipment was removed from the participant before they were fully debriefed and given a mood repair task. On the basis that previous research into the topic of mood repairing has suggested using jokes or cartoons can be effective (Goeritz, 2007), a series of funny exam answers were shown to participants.

## 7.3 Results

Driving behaviour and eye movement data were extracted from XPI ISO using the IOS Data Extraction Tool. MATLAB R2012a was then used to parse the data, and the chosen dependent variables were averaged and placed into separate arrays according to their respective driving conditions. To account for the fact that participants initially had to start the car moving, data were analysed from the first point at which the participant reached a speed of 20mph. As with the study discussed in the previous chapter, SDLP data were averaged across the entire drive for each participant. For behaviourally low demanding tasks, those with low and high visual complexity were these windows were an average of 201.89 and 183.57 seconds respectively, whilst for tasks that were high in behavioural, those with low and high visual complexity were an average of 206.57 and 266.07 seconds respectively.

Vector distances between the participant's car and the bike in the hazardous drives were calculated in MATLAB to obtain the distance from the bike at which the participant began

braking. The first point at which the car began braking compared to when the bike began moving was used to calculate the reaction time (in seconds) to respond.

Skin conductance and heart rate data were recorded in an Excel file by the researcher. Due to excessive motion artefacts and a lack of electrodermal responses, EDR data is reported for 36 participants, whilst heart rate data were analysed for 20 participants. Due to issues with recording, eye movement data were analysed for 29 participants.

### 7.3.1 State anxiety manipulation

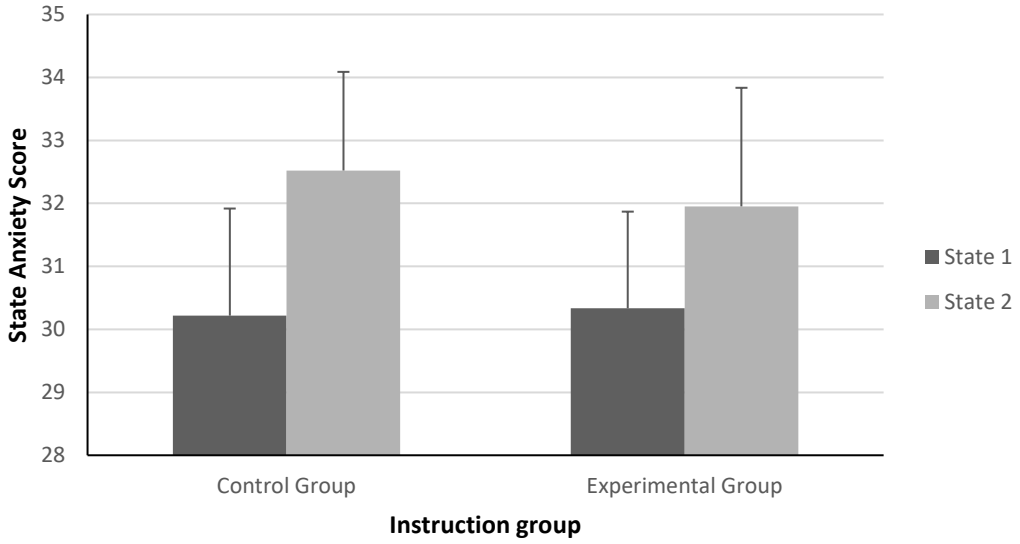



*Figure 7-2: State anxiety scores before and after instructions, according to experimental group.*

In order to assess the effectiveness of the state anxiety manipulation used, a 2x2 ANOVA (instruction group x time of questionnaire administration) was conducted. This found no between subjects effect of condition ($F(1,42)=.011$, $p=.917$, $\eta_p^2<.001$), and no interaction between condition and time ($F(1,42)=.121$, $p=.73$, $\eta_p^2=.003$). There was a marginal main

effect of time [$F(1,42)=3.97$, $p=.053$, $\eta_p^2=.086$] which suggested that state scores were marginally higher at time two ($m=32.25$) than at time one ($m=30.27$) (See Figure 7-2).

Overall, this suggested that the ego-threatening instructions used were not successful in increasing levels of anxiety. However, as one aim of the study was to assess the effects of increased state anxiety on driving, the scores from the second state questionnaire were then subtracted from the first questionnaire score to obtain of measure of anxiety change levels from time one to time two. This is a method that has been used in previous driving research to assess effects of anxiety changes on heart rate (Briggs et al., 2011). This anxiety change score was then used as a covariate in 2x2 ANCOVAs for the remaining analyses, with levels of visual and behavioural demand as within-subjects factors.

### 7.3.2 Measures of workload

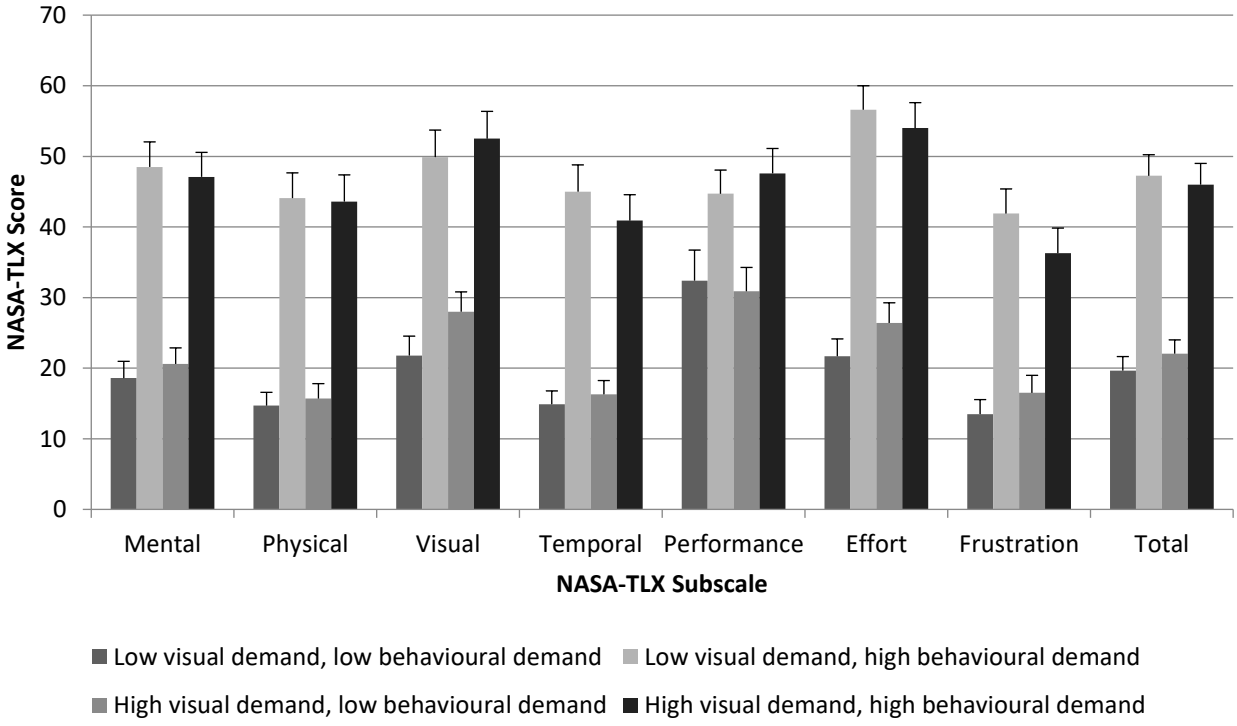
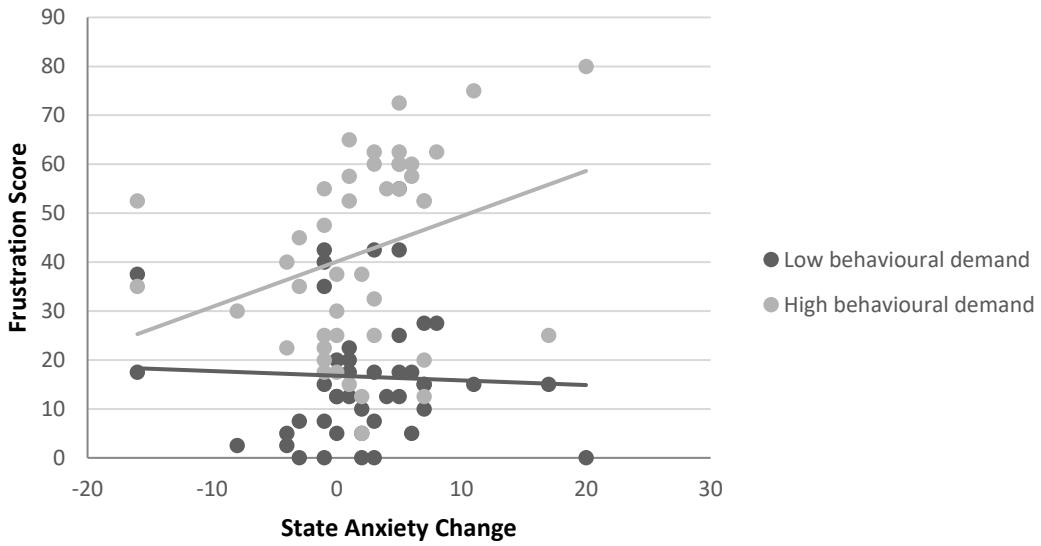



*Figure 7-3: Scores for each NASA-TLX subscale, according to driving condition.*

Significant main effects of visual complexity were only found for the visual demand subscale ($F(1,42)=8.15$, $p=.007$, $\eta_p^2=.086$). This suggested that visual demand scores were significantly higher when the visual complexity of the scenario was high ($m=47.61$) than when the visual complexity of the scenario was low ($m=42.5$). A main effect of vehicle handling was found for all subscales as well as the overall workload, all of which suggested that scores were significantly higher when the participant was required to make turns (all $p$s$<.01$, all $\eta_p^2>.15$).

A significant interaction was also found between visual complexity and vehicle handling for the effort ($F(1,42)=5.71$, $p=.021$, $\eta_p^2=.12$) and frustration ($F(1,42)=6.93$, $p=.012$, $\eta_p^2=.142$). subscales. In both cases, this seems to suggest that when levels of vehicle handling are low, levels of effort and frustration increase with increases in visual demand. However, when vehicle handling levels increase, self-reported levels of effort do not increase, but levels of frustration decrease.

No main effects of anxiety change scores were found, nor was there a significant interaction between anxiety changes and levels of visual complexity. There was, however, a significant interaction between anxiety changes and levels of vehicle handling for the frustration subscale ($F(1,42)=5.18$, $p=.028$, $\eta_p^2=.11$). This suggested that whilst changes in state anxiety did not predict levels of frustration in drives with low vehicle handling levels, when a participant was required to make turns, increases in state anxiety positively predicted frustration levels ($\beta=.884$, $R^2=.09$) (See Figure 7-4).




*<u>Figure 7-4:</u> Frustration scores on the NASA-TLX according to levels of behavioural demand and changes in state anxiety.*

A significant three-way interaction was also found between visual complexity, vehicle handling and state anxiety changes ($F(1,42)=4.17$, $p=.047$, $\eta_p^2=.09$). This suggested that there was no relationship between state anxiety change and mental workload when visual and vehicle handling complexities were low. However, when demand increased, there was a positive relationship between state anxiety changes and levels of mental workload, particularly when vehicle handling levels were high (See Figure 7-5).

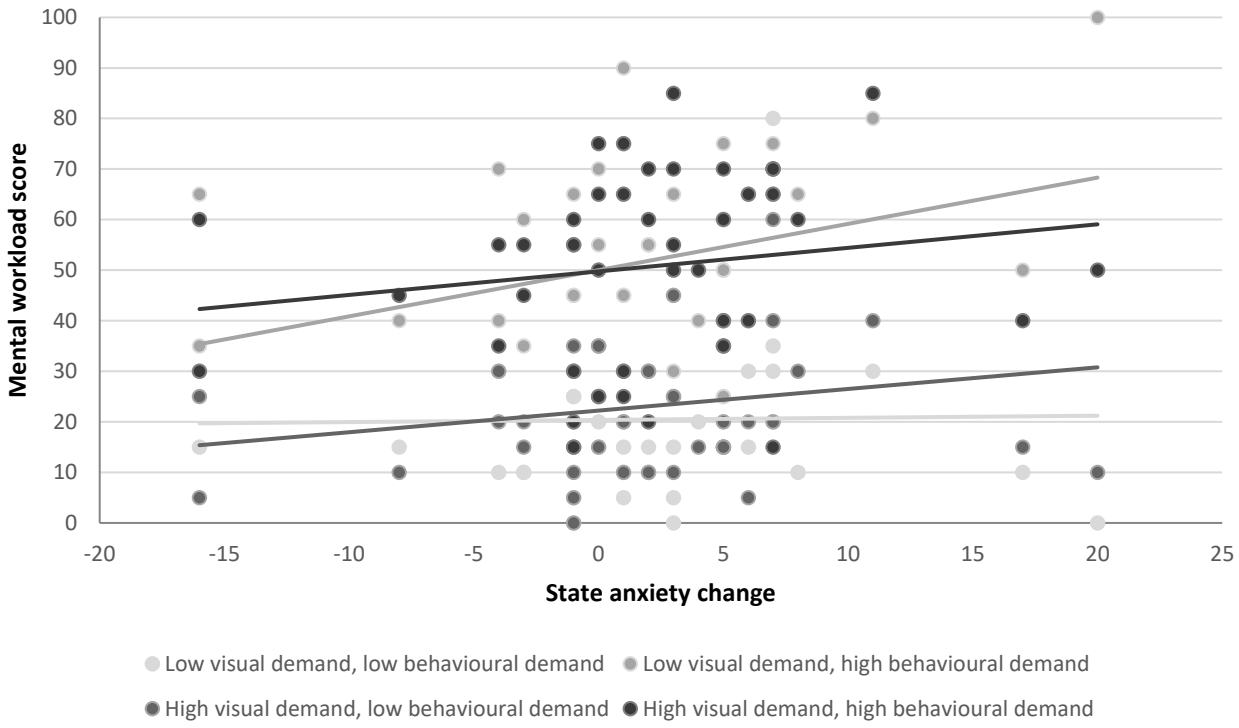
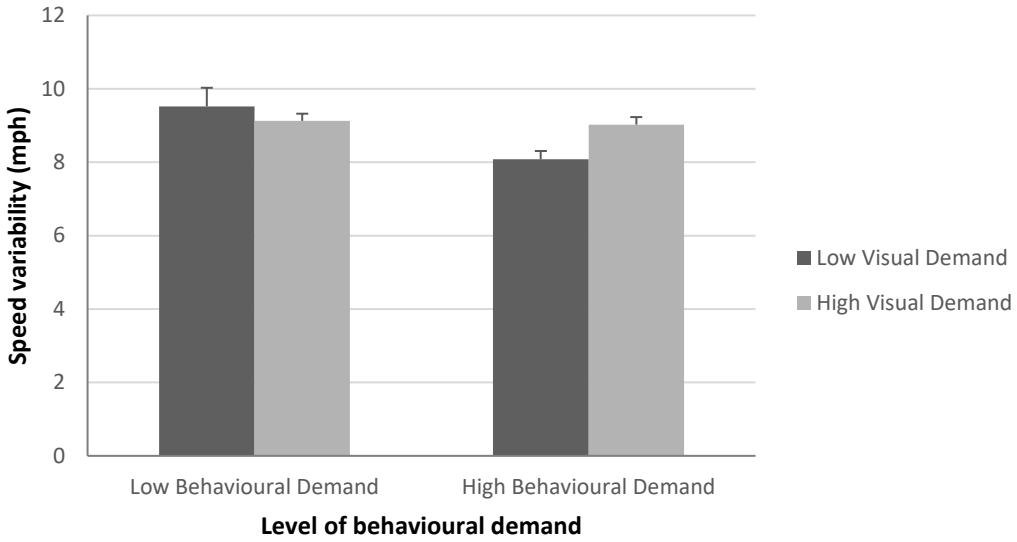



*Figure 7-5: Levels of perceived mental workload according to levels of visual complexity, vehicle handling and state anxiety change.*

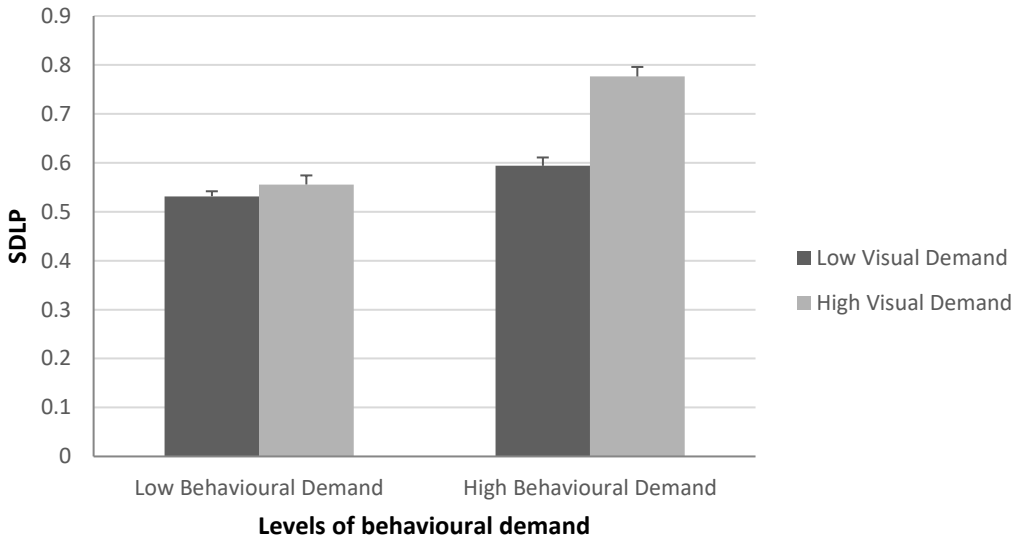
### 7.3.3 Driving behaviour

For speed variability, no main effects of visual complexity, vehicle handling or state anxiety change were found. However, there was a significant interaction between visual complexity and vehicle handling ($F(1,42)=4.39$, $p=.042$, $\eta_p^2=.095$) . This suggested that when drivers were not required to make any turns, speed variability would decrease with increasing visual demand. When participants were required to make turns however, speed variability increased with increasing levels of demand (See Figure 7-6a).

a)




b)

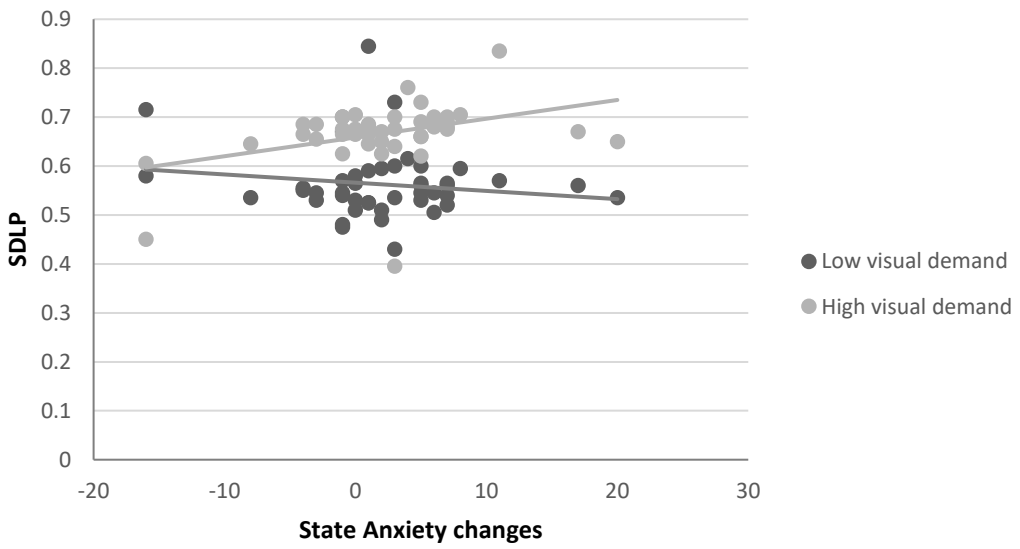



*<u>Figure 7-6</u>: The effects of visual and behavioural demand on a) speed variability, and b) SDLP*

For SDLP, significant main effects of visual complexity ($F(1,42)=47.24$, $p<.001$, $\eta_p^2=.53$) and vehicle handling were found ($F(1,42)=50.13$, $p<.001$, $\eta_p^2=.54$). SDLP was significantly higher when visual complexity was high ($m=0.67$) than when visual complexity was low ($m=.056$), and SDLP was higher when vehicle handling levels were high ($m=0.69$) than when vehicle handling levels were low ($m=0.54$). There was also a significant interaction between

levels of visual and behavioural demand ($F(1,42)=7.49$, $p=<.001$, $\eta_p^2=.29$). This suggested that SDLP did not change with increasing levels of visual complexity when levels of vehicle handling were low. However, when a participant was required to make turns, increases in visual demand were associated with increases in SDLP (See Figure 7-6b).

Whilst there were no main effects of state anxiety changes on SDLP, there was a significant interaction between state anxiety changes and levels of visual complexity ($F(1,42)=7.49$, $p=.009$, $\eta_p^2=.15$). This suggested that with low levels of visual complexity, an increase in state anxiety was associated with decreases in SDLP. However, when visual complexity was higher, increases in state anxiety were associated with increases in SDLP (See Figure 7-7).




*<u>Figure 7-7:</u> The relationship between state anxiety changes and SDLP, according to differences in visual demand.*

Due to simulator sickness only 40 of the 44 participants completed the hazardous drive. Regression analyses on reactions to the unexpected hazard found no significant influence of state anxiety change on hazard reaction times or the distance from the bike when the brake

was first applied. As 16 of the participants collided with the bike, a logistic regression was also conducted to assess whether changes in state anxiety could predict the likelihood of colliding with the bike; however this analysis was also not significant (all *p*s>.05).

To assess whether the chosen hazard was effective, a series of correlational analyses were conducted on reaction times, distance from the bike when braking, heart rate and skin conductance. Additionally, measures of speed and speed variability were included. There was a negative correlation between average speed and distance from the bike ($r$=-.772, $n$=31, $p$<.001), suggesting that those travelling at a greater speed were closer to the bike before they started braking. Distance also positively correlated with speed variability ($r$=.613, $r$=31, $p$<.001) and horizontal gaze ($r$=.448, $n$=23, $p$=.032), suggesting that that a greater flexibility in speed adjustments and a wider spread of horizontal search were associated with a larger braking distance.

### 7.3.4 Eye Movements

Analysis of the eye movement data found no significant main effects of visual complexity, vehicle handling, or state anxiety changes. However, there was a significant interaction between levels of visual complexity and vehicle handling for spread of search ($F$(1,27)=8.9, $p$=.006, $\eta_p^2$=.25). The interaction suggested that when participants were not required to make any turns, spread decreased with increasing levels of visual complexity. However, when participants were required to make turns, spread of search increased with increasing levels of visual complexity (See Figure 7-8).

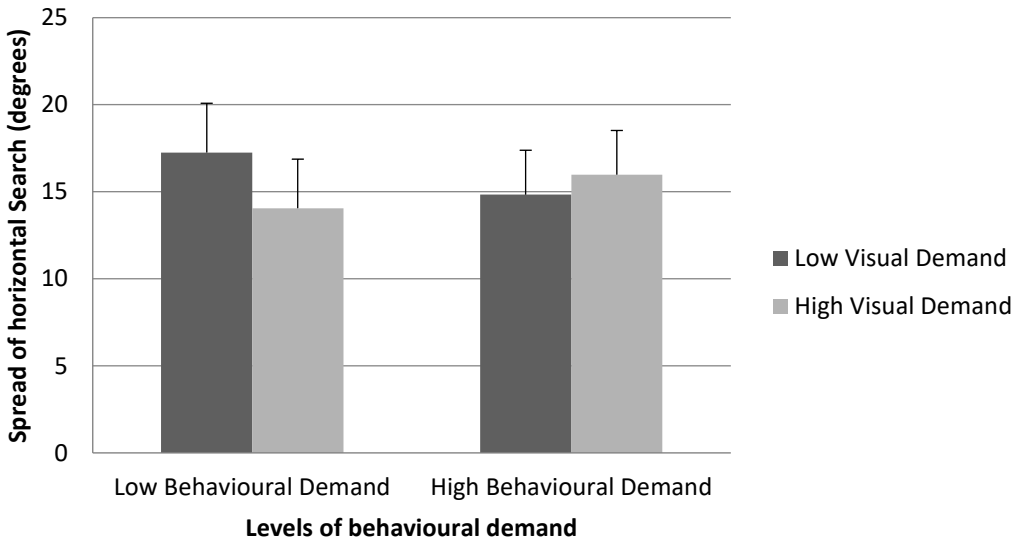



*Figure 7-8: Changes in spread of search according to levels of visual complexity and vehicle handling.*

### 7.3.5 Skin Conductance

Analysis of the skin conductance data found no significant main effects of visual complexity or state anxiety changes (all *p*s>.05). However, there was a significant main effect of vehicle handling on both skin conductance levels ($F(1,42)=21.32$, $p<.001$, $\eta_p^2=.34$) and the number of EDRs per minute ($F(1,32)=19.71$, $p=<.001$, $\eta_p^2=.381$). Skin conductance levels and the number of EDRs per minute were significantly higher when vehicle handling levels were high (*m skin conductance*=8.5μS, *m number of EDRs per minute*=14.01) than when vehicle handling levels were low (*m skin conductance*=7.29μS, *m number of EDRs per minute*=8.39).

A significant three-way interaction was also found between visual complexity, vehicle handling, and state anxiety changes, with regards to skin conductance levels ($F(1,42)=15.04$, $p<.001$, $\eta_p^2=.26$). This interaction suggested that when both visual and vehicle handling demands were low, there was not a relationship between state anxiety changes and skin conductance. When either visual or vehicle handling demand was high, an increase in state

anxiety was associated with an increase in skin conductance levels. However, when both visual and vehicle handling demands were high, an increase in state anxiety was associated with decreases in skin conductance (See Figure 7.9).

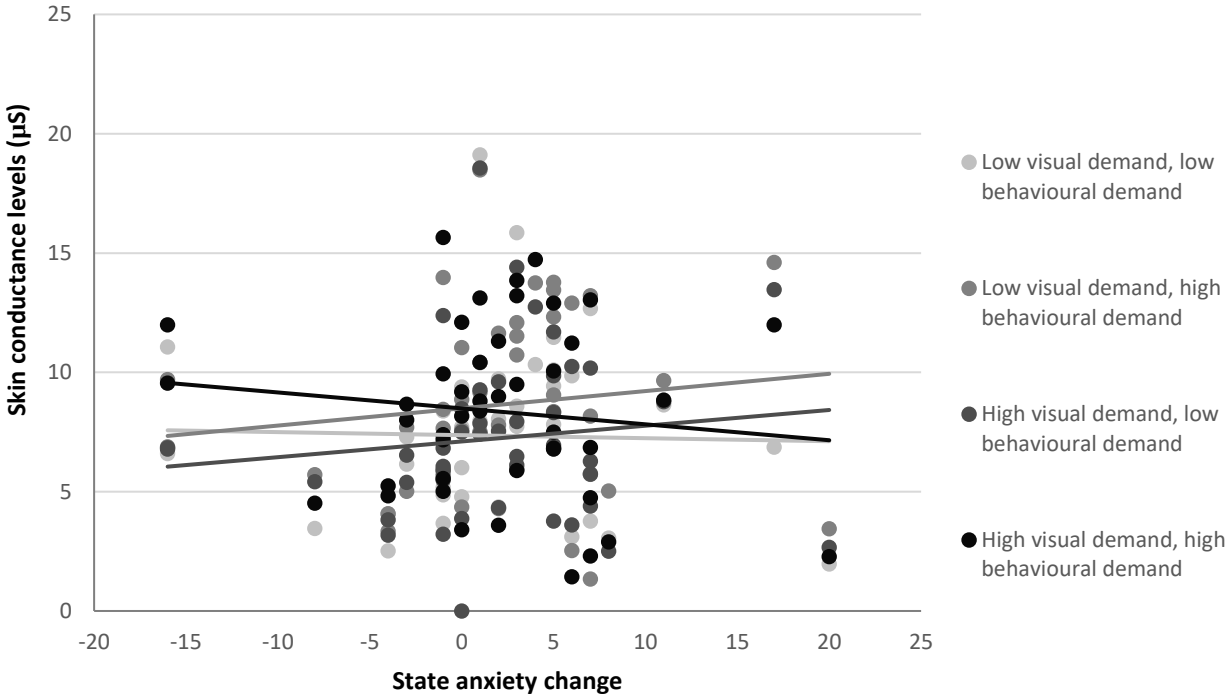



*Figure 7-9: The relationship between state anxiety changes and skin conductance levels, according to differences in visual and behavioural demand.*

### 7.3.6 Heart Rate

ANCOVAs on the heart rate data found significant main effects of visual complexity ($F(1,18)=5.5$, $p=.031$, $\eta_p^2=.234$) and vehicle handling ($F(1,18)=33.6$, $p<.001$, $\eta_p^2=.651$). Heart rate was significantly higher in drives with high visual complexity ($m$=79.1BPM) than in drives with low visual complexity ($m$=77.68BPM). Heart rate was also significantly higher during drives with high levels of vehicle handling ($m$=80.81BPM) than with low levels of vehicle handling ($m$=76.86BPM).

## 7.4 Discussion

The aim of the current study was to use an ego-threatening manipulation to increase levels of state anxiety within an experimental group compared to controls. Thesegroups were then to be compared with each other on a series of driving tasks varying in levels of both visual and vehicular demand. However, results suggested that the ego-threatening instructions used were not successful in increasing levels of state anxiety. Instead, the effects of state anxiety changes were analysed across the drives in question. This suggested that increases in state anxiety were associated with increases in levels of frustration and mental demand, changes in SDLP according to levels of visual demand, and changes in physiological reactivity that were dependent on the type and level of demand in the driving situation.

### 7.4.1 Findings

#### 7.4.1.1 Visual complexity and vehicle handling

Firstly, analyses of the NASA-TLX scores indicated that the manipulations of visual demand and vehicle handling were successful at increasing levels of perceived workload. Higher levels of vehicle handling were associated with increases on all subscales, as well as the overall workload score, whereas increases in visual complexity only increased scores on the visual demand subscale. This latter finding may be surprising, given that previous research has associated increases in visual complexity with increases in mental demand (Edquist et al., 2012; Rudin-Brown et al., 2014); nonetheless the significant increases for the visual demand subscale indicate that the visual complexity manipulation used was successful.

The interaction between visual complexity and vehicle handling for ratings of effort and frustration also suggested that scores on each increased with increased visual complexity, but only when levels of vehicle handling were low. Additional interactions with ratings of speed variability, SDLP and horizontal spread of search may reflect the different attentional properties of each type of driving situation, and the different compensatory behaviours drivers may use to accommodate for increases in demand within each context. For example, drives with low levels of vehicle handling were completed on single-lane carriageways with no intersections, and in this context increases in visual complexity resulted in decreases in speed variability and spread of horizontal search. Previous driving literature would suggest that a more optimal search strategy would involve an increase in horizontal scanning (Mourant & Rockwell, 1972); however, recent literature into the effects of perceptual load have suggested that scanning behaviour may also be determined by the value of a scanning region (Marciano & Yeshurun, 2015). Thus in the drives with low levels of vehicle handling, increases in traffic density may have required participants to reduce horizontal scanning and focus on the car ahead in order to predict its speed or behaviour, allowing the participant to maintain a more constant speed and maintain a safe distance from other cars. The lack of increase in SDLP with increasing visual complexity indicates that this compensatory behaviour did not necessarily make the participant more dangerous.

Drives with high levels of vehicle handling, on the other hand, required participants to make a series of six turns whilst completing the drives, and results in this case suggested that increases in visual complexity led to increases in speed variability, SDLP and spread of horizontal search. As previously discussed by Edquist et al. (2012), in complex environments drivers must monitor the movements of both vehicles and pedestrians, and attempt to estimate if they will move in a way that results in a hazard. In this context, salient visual information

would be presented in both the central and peripheral areas of the visual scene; increases in visual complexity would require an increased need to scan both areas, thus explaining the increase in horizontal spread of search in the current study. Speed variability also increased, which supports previous research (Edquist et al., 2012); however, it is less clear whether this change is indicative of compensatory changes in response to increased visual complexity. Along with increases in SDLP, this effect may in fact indicate that the changes in driving behaviour are not necessarily safer, despite an increase in horizontal scanning.

It is also important to note that main effects of vehicle handling were found for levels of skin conductance, the number of EDRs per minute and heart rate. Skin conductance changes may indicate an increase in orienting towards tasks which required the participant to make turns. Heart rate increases may indicate increases in workload, which complements the findings from the NASA-TLX scores and suggests that drivers were aware of the increased demands associated with vehicle handling and using internal resources to cope with such demands. These physiological findings expand on previous research investigating the effects of vehicle handling (Jahn et al., 2005; Stinchcombe & Gagnon, 2010), and supports the idea that the simple act of manoeuvring a car can increase driver demands. Future research should consider the use of vehicle handling as a means of manipulating demand.

#### 7.4.1.2 State anxiety changes

One of the first predictions regarding state anxiety effects was that the use of ego-threatening instructions would successfully increase levels of state anxiety in an experimental group compared to controls. However, results indicated no significant effects of the manipulation on anxiety levels; this is surprising, considering that the majority of previous research using such

instructions have found a clear effect. There are several reasons this may have occurred in the current study. Firstly, mean state anxiety scores across time of administration and experimental group ranged from 30-32. As with the state anxiety scores in Chapter 6, these are considerably lower than Spielberger's norms (1983). The mean state anxiety scores reported in Chapter 6 were higher than those reported here (mean scores across conditions in Chapter 6 ranged from 32-36); therefore it could be argued that a decrease in simulator fidelity resulted in a further decease in state anxiety scores due to the participant's increased awareness they were not driving in the real world. However, it is also worth noting that previous research which has found successful state anxiety increases has also used simulators with similar or lower fidelities than NITES 2 (Murray & Janelle, 2003; Wilson et al., 2006). Additionally, the average state anxiety scores from the laboratory studies conducted in Chapters 3 and 4 were 31.33 and 31.61 respectively. This could overall indicate that the instructions used simply failed to make the participants in the current study anxious. One issue to consider is that some of the previous studies using ego-threatening instructions have also included a motivational factor, such as a cash prize for having the best performance across participants. As such an instruction wasn't used in this study, future research may want to compare instructions with or without an instructional set to assess whether this affects levels of anxiety. Additionally, future research may want to compare the effects of ego-threatening instructions across simulators with different fidelities.

Although state anxiety was not affected by instructions, there was still a considerable variety of state anxiety changes between STAI-Y1 administrations, both positively and negatively. Additionally, as there was still an interest in investigating the relationship between increased state anxiety and driving, the difference in state anxiety scores was taken across all participants and analysed for each driving situation. These results suggested that increases in

state anxiety could lead to changes in subjective perceptions of demand, driving behaviours and physiological reactivity.

Firstly, analysis of the NASA-TLX revealed an interaction between state anxiety and levels of vehicle handling on frustration scores; when vehicle handling levels were higher, an increase in state anxiety was associated with an increase in frustration scores. This is considered with previous research that has associated angry reactions with an anxious driving style (Lucidi et al., 2010; Ulleberg, 2001), or research that has suggested that state levels of anger predict stress whilst driving (Hennessy & Wiesenthal, 1999). This suggests that increased demands as a result of increased vehicle handling can lead to higher levels of frustration if a driver is anxious. The fact that the same interaction was not found between state anxiety changes and visual complexity suggests that it may be the driving event itself that induces anger rather than levels of visual clutter; for example, a driving scene may have a higher traffic density, but it is the subsequent consequences, such as a traffic jam (Fairclough & Spiridon, 2012), that would induce anger levels.

A significant three-way interaction was also found between state anxiety changes, visual complexity and vehicle handling. When both types of demand were low, there was no association between increased state anxiety and mental workload. When demand increased, whether that be visual or vehicle handling demands alone, or both simultaneously, increases in state anxiety were associated with increases in mental workload. This seems to be particularly true when vehicle handling levels were higher; it is possible that because increases in both types of demand mean that an increase in attention is required to successfully complete the driving task, those who show increases in anxiety find the task more difficult. This is particularly true in cases where vehicle handling increases, and the

driver is required to use additional attentional resources when assessing whether it is safe to pull out of a junction. However, a lack of interactions between state anxiety and spread of search indicate that, in support of previous emotion research, changes in emotion do not necessarily affect the driver's skills (Abdu et al., 2012), thus in the current study, those with greater increases in anxiety may be more likely to underestimate their capabilities in completing the driving situation in question.

A lack of interaction between state anxiety changes and driving behaviours would also suggest that anxious participants were underestimating their capabilities in more demanding situations. However, the exception to this was a significant interaction between state anxiety changes and visual complexity that was found for SDLP. When driving scenarios became more visually complex, regardless of levels of vehicle handling, those who were more anxious were less able to maintain their lane position. This indicates that an increase in perceptual demands made those who were anxious less able to maintain control of the car, meaning that anxiety in this context may increase the likelihood of dangerous behaviours.

A significant three-way interaction was also found in relation to skin conductance levels. When both visual complexity and vehicle handling levels were low, there was no association between state anxiety and skin conductance. When only visual complexity or vehicle handling was high, there was a positive association between state anxiety increases and skin conductance. However, when both types of demand were high, there was a negative association between state anxiety increase and skin conductance. If skin conductance is a measure of mental effort in response to increased task demands (Helander, 1978), then it is possible that those who show increases in anxiety are able to invest more mental effort into driving when demands increase, but when demands are too high, they are less able to invest

the same levels of mental effort. This may potentially reflect a curvilinear relationship between driving demand and physiological reactivity in those who show increases in levels of anxiety, and this possibility may need to be explored in future research.

Whilst state anxiety increases resulted in significant changes to both SDLP and skin conductance levels, it is worth noting that it did not significantly affect responses to an unexpected hazard. There are two potential explanations for this effect: either the hazard itself was not effective, or state anxiety did not affect responses to the hazard. However, there is reason to believe that the hazard was effective across all participants. A hazard requires the driver to taken sudden and evasive action to avoid a crash. Hazards such as unexpected pedestrians and sudden braking of vehicles in front of the driver have been successful in eliciting evasive actions from the driver, and have been affected as a result of manipulations in traffic density and the emotional valence of images (Edquist et al., 2012; Trick et al., 2012). In particular, the hazard used in the current study was a bike appearing from a house at the side of the road, and cycling directly into the path of the participant's vehicle. Similar hazards have previously been rated as realistic as well as dangerous across a range of drivers and motorcyclists (Shahar, Poulter, Clarke, & Crundall, 2010). Additionally, data from the correlational analyses conducted suggested that more dangerous behaviours, such as a higher average speed, were associated with a shorter distance between the participant and the hazard. On the other hand, those who were more effective in scanning the visual scene and were more flexible in their speed adjustments could brake at a further distance.

Therefore, based on the previous literature and the behaviour across all participants in the study, it is believed that the hazard in question was effective. On this basis, it can be suggested that state anxiety increases did not result in more dangerous responses to the

hazard. Additional research could include multiple types of hazards, such as vehicles, to see whether this finding is applicable across all hazard types. Alternatively, the timing windows of hazards could be researched. For example, hazards with clearer precursor windows (the time between the first appearance of the source of the hazard, to the time that the driver begins to brake) could be used to measure attentional control. If drivers with increases in state anxiety are poorer at maintaining attentional control, then evidence of this may be found in the time leading up to a hazard.

### 7.4.2 Limitations

As well as some of the limitations discussed above, there are some general limitations to the study. Firstly, it is important to note that some of the physiological measures were difficult to interpret due to excessive motion artefacts; this was particularly true for measures of heart rate. Because of this, general estimates of heart rate were used based on visual inspection of reliable heart rate signal; due to this, interpretations of this data may need to be taken with caution. It would be recommended for future researchers to avoid using finger-strap based PPG measures when measuring autonomic behaviours whilst driving. As a result of this, PPG measures in the study conducted in Chapter 8 were taken using an ear clip, which was much less susceptible to motion artefacts.

Secondly, due to the nature of the scenarios provided in the scenario software, there were differences in speed limits between driving scenarios with low and high levels of vehicle handling, hence it was not possible to analyse average speeds in the current study. Previous research has attempted to overcome this issue by using speed ratios as a measure of performance (Kaber et al., 2012), however future research should consider stricter controls of speed limits in order to assess whether changes in vehicle handling result in compensatory

changes in speed. Additionally, due to the nature of the scenarios provided, the driving scenario with low visual complexity and high vehicle handling had to be completed in a residential rather than rural area; whilst there was little traffic on the roads, the addition of buildings could have arguably increased visual complexity. Therefore stricter controls on levels of visual complexity should be considered in future research.

An additional caveat of the current study was the nature in which SDLP measures were taken. Standard deviation of lane position is ideally measured over driving scenarios where roads are straight, making it an ideal measure for the study completed in the previous chapter; however it is worth noting that previous research has previously measured SDLP on curved roads (e.g. Dijksterhuis, 2011; Stolywik, 2005). In the current study, due to the unpredictable nature of the traffic in the simulator software, drivers may have also been required to navigate around parked cars or unexpected hazards during sceanrios with high behavioural demand, which may have placed additional limitations on the SDLP measures taken.

Additionally, due to increases in traffic density and the need to make turns in certain scenarios, this resulted in differences between scenarios in terms of their time windows. A similar issue is also evident in the previous study, although on a ore minimal scale. SDLP mesures have been shown to increase as a function of both time and distance (Karwowski, 2006). Even results that have not shown statistical significance have still shown a increasing trend of SDLP over time ( Riemersma, Sanders, Wiedervenck & Gaillard, 1977). This is because mean lane position has less of an opportunity to to show large changes over a shorter time fram (Vester& Roth, 2011). In combination with the aforementioned limitations, this hghlights how SDLP meausres must be interpreted with caution and care. It also highlights how stringent researchers must be with lateral measures of driving performance, and how

care must be taken with issues of time and distance. Future research may be able to account for time and distance measure limitations, for example, by calculating SDLP per metre or per minute.

Another potential methodological issue with regards to this study was the use of different incentives to take part. Initially, only course credit was offered as an incentive; however it was decided to also include a financial incentive to increase participant numbers. Whilst both can be perceived as positive rewards, recent research has suggested that incentives of different values can result in different levels of effort or engagement in driving simulation tasks. Landsdown and Saunders (2012) asked participants to complete a series of easy and difficult driving tasks that involved following a lead vehicle, and provided them with no reward, a chocolate or fruit-based reward, or a financial reward of five pounds. They found that as incentive value increased, so did the levels of lateral vehicular control (as measured by mean steering wheel angle) and longitudinal vehicular control (measured as the coherence of speed between the participant and the followed vehicle, and the modulus of the speed signal between the participant and followed vehicle).Whilst there is no specific financial value assigned to the course credit provided in the current study, it is possible that individuals may perceive their value as financially different, thus it may have resulted in performance differences between those who did and did not receive money. Additionally, despite the fact that Lansdown and Saunders (2012) found no differences in effort according to payment group, it is argued that driving research typically provides financial incentives greater than the five pounds provided by Lansdown and Saunders (2012). The monetary incentive was chosen in accordance to previous studies into the payment and effort relationship (Heyman & Ariely, 2004). Because the current study provided a £10 financial incentive, it is still possible that this reward could have resulted in increased levels of effort as well as increased levels of

performance in the task. Whilst the remainder of research in the thesis only uses one type of incentive, this is an issue that researchers should consider when conducting simulator studies.

### 7.4.3 Conclusions

In conclusion, the aim of the current study was to assess the effects of ego-threatening instructions on levels of state anxiety, and then assess how changes in state anxiety affect driving behaviour across drives with different levels of visual complexity and vehicle handling. Unlike previous research, the use of ego-threatening instructions did not successfully increase state anxiety, indicating that the use of motivational instructions or the fidelity of the simulator in question may also be important. When changes in state anxiety were considered across all participants, findings indicated an increase in mental effort with increases in state anxiety, which was not subsequently reflected in changes in attention. This suggested that those with greater increases in anxiety may be more likely to underestimate their ability to complete the driving task successfully. However, findings from the SDLP and skin conductance data indicated that with increases in demand, those who show greater increases in anxiety may be more likely to invest less mental effort in the task, or show more dangerous driving behaviours. Additionally, interactions between visual complexity and vehicle handling, without the influence of state anxiety, suggested that different driving behaviours and attentional patterns are evident depending on the type of demand that increases.

Some of the previous research into the use of ego-threatening instructions has suggested that the subsequent increases in anxiety make the driver or pilot less able to efficiently process the visual scene (Allsop & Gray, 2014). Alternatively, it suggests that those who show increases in anxiety are able to perform the driving task to the same degree, but must use additional

effort to do so (Wilson et al., 2006). These inferences are associated with processing efficiency theory and attentional control theory (Eysenck et al., 2007). These theories are discussed in Chapter 8, and the effects of anxiety on driving performance and attentional control are investigated with respect to environments with different levels of both visual complexity and vehicle handling.

# Chapter 8. The effects of trait anxiety and central executive demands on frontal lobe activity: implications for Attentional Control Theory.

## 8.1 Introduction

Chapter 7 suggests that a common finding between studies using ego-threatening manipulations to induce state anxiety is that predictions and results are associated with levels of processing efficiency. Processing efficiency refers to the relationship between the quality of performance on a task and the amount of resources required to complete it. It is suggested that levels of efficiency decrease as more resources or effort is invested in task performance (Eysenck et al., 2007), for example scanning patterns may become less efficient (Allsop & Gray, 2014). This finding has been supported in general research also using ego-threatening instructions to induce anxiety levels (Cocks, Jackson, Bishop, & Williams, 2016).

### 8.1.1 Processing Efficiency Theory and Attentional Control Theory

Whilst these studies focus on the effects of increasing state anxiety, the two main theories investigating the effects of anxiety on efficiency are focused on trait anxiety. The first, Processing Efficiency Theory (PET- Eysenck & Calvo, 1992), makes a clear distinction between performance effectiveness and processing efficiency. The former refers to the quality of performance on a task and can be measured with variables such as accuracy; the latter refers to the amount of resources required to complete the task, and can be measured with variables such as reaction times. PET suggests that one component of anxiety, worry, is most likely to occur in those with high levels of trait anxiety. As this results in an internal focus on worrisome thoughts, this limits the amount of attentional resources available within working memory, meaning that attention is less available for any additional tasks. However,

the individual compensates for this by enhancing the amount of effort utilised, and if resources are available, the individual will be able to perform on the tasks to the same effectiveness as those with lower levels of anxiety. However, processing efficiency will be reduced.

A main assumption of PET is that effects of processing efficiency are said to involve the central executive component of working memory. However, the theory does not specifically state which central executive functions are required. PET was therefore extended into Attentional Control Theory (ACT- Eysenck et al., 2007). ACT extends PET by suggesting that anxiety disrupts the influence of top-down, goal-oriented resources and instead increases attention towards bottom-up, stimulus-driven resources. The main hypotheses assume that adverse effects of anxiety on processing efficiency would be greater with increased central executive demands, and that effects would be even greater with increased load. With regards to central executive functions, ACT proposes that the inhibition, shifting and updating functions outlined by Miyake and colleagues (Miyake et al., 2000) are particularly affected by trait anxiety.

Since ACT was proposed research has consistently demonstrated support for its assumptions. Studies using tasks such as the Wisconsin Card Sorting Task (WCST) and the Stroop task, both said to reflect shifting and inhibition functions, show increases in reaction times and increases in reported effort with increased trait anxiety, indicating less efficient processing of resources (Darvishzadeh, Aguilar-Vafaie, & Moradi, 2012). Studies have also used emotional faces as distractors to demonstrate that effects of anxiety are particularly prevalent with threat-related distractors. Higher anxiety is associated with a poorer ability to make saccades away from angry faces in anti-saccade tasks, suggesting that the features of the stimulus

increase the influence of bottom-up resources in this context (Derakshan, Ansari, Hansard, Shoker, & Eysenck, 2009). In an odd-one-out task also using emotional faces as distractors, reaction times were even slower and scanning patterns were far less efficient when the amount of distractors on screen increased (Berggren, Koster, & Derakshan, 2012). The authors suggested that the increased amount of distractors on screen made anxious individuals doubt their choices in choosing the correct stimulus, hence eye movements were made more frequently towards incorrect choices.

A recent review of ACT has emphasised the need to combine behavioural with neurological measures of processing efficiency, as previous research has solely relied on using behavioural data (Derakshan & Eysenck, 2009). Overall, neuroimaging evidence suggests that activity related to the completion of central executive tasks is found within the frontal lobes. Frontal lobe activity is often associated with the regulation of cognitive and executive control, particularly in lateral areas such as the ventrolateral prefrontal cortex (VLPFC) and the dorsolateral prefrontal cortex (DLPFC). Studies using fMRI methods have found activation within the DLPFC in tasks such requiring updating and shifting functions, such as the n-back task (Jaeggi et al., 2003) and the WCST (Lie, Specht, Marshall, & Fink, 2006). Additionally, the frontal lobes have also been associated with levels of emotional processing. One fMRI study looking at the effects of emotional words found bilateral increases in DLPFC activity (Herrington et al., 2005), leading the authors to suggest that tasks requiring executive function may at least in part be influenced by affect.

Recent findings investigating the effects of trait anxiety on frontal lobe activity would support this theory. For example, one study initially looking at state anxiety effects found smaller increases in DLPFC and VLPFC recruitment in a matching task, suggesting that high

levels of anxiety may reduce the recruitment of top-down resources (Bishop, Duncan, & Lawrence, 2004). An extension of this study also found that trait anxiety was associated with even greater disruptions in the DLPFC activity (Denkova et al., 2010). Neuroimaging findings associated with anxiety have also been associated with reduced processing efficiency. For example, one fMRI study using the Stroop task found a strong correlation between trait anxiety levels and the strength of incongruent-related activation in the left DLPFC, and reduced connectivity with other brain areas; the reduced functional connectivity was said to suggest less proficient processing, and the left DLPFC showed increased activation in order to compensate for this reduced connectivity (Basten, Stelzel, & Fiebach, 2011).

### 8.1.2 Executive functions and driving

Both levels of attentional control and executive functions are important and applicable to the field of driving. A high level of overall attentional control is required in order to avoid an accident. Three main executive functions are also required for certain responses; certain behaviours must be inhibited in order to enable safe driving and compliance with driving laws, attention may need to switch between different types of driving task or vulnerable road user, and the driver must constantly update their memory to remember the amount and position of other cars surrounding them. Research using tests of executive function have found poorer performance is associated with a greater likelihood of previous accident involvement (Daigneault, Joly, & Frigon, 2002), a greater likelihood of speeding convictions (O'Brien & Gormley, 2013) and a greater amount of errors and lapses on the DBQ after controlling for age and gender (Tabibi, Borzabadi, Stavrinos, & Mashhadi, 2015). Simulator and on-road research has provided behavioural data suggesting that poorer executive function is associated with a greater number of mistakes and overall poorer performance (Adrian,

Postal, Moessinger, Rascle, & Charles, 2011; Babika, 2014), and has been able to discriminate between at-risk drivers from those who are safer (Ranchet et al., 2013). Overall this suggests that poorer levels of executive functioning make a driver more dangerous.

Only one study to date has researched driving behaviour within the context of ACT. Wong and colleagues asked participants to complete the Go/No Go Task and the n-back task as well as the Driver Behaviour Questionnaire (DBQ- Wong, Mahar, & Titchener, 2015). Findings suggested that trait anxiety, as well as reaction times on these tasks, was related to the amount of errors and lapses reported on the DBQ. This provides support for ACT on the basis that trait anxiety was positively correlated with these reaction times, indicating less efficient processing. However, trait anxiety still predicted the amount of lapses reported on the DBQ even when processing efficiency was controlled for. The authors suggested that anxiety may also have an influence on dual task coordination, and as driving often requires performing multiple tasks, this would explain the positive relationship between trait anxiety and lapses. Whilst dual task coordination was not suggested as a main executive function in Miyake's (2000) original research, a subsequent review of the neuroimaging literature suggests that dual task-coordination should in fact be included as a fourth main executive function (Collette & Van der Linden, 2002).

One criticism of studies looking into the effects of executive functioning on driving behaviours is that performance on executive tasks is often associated solely with questionnaire responses; studies conducted in the simulator or on real roads also complete the executive task in question separately to the driving task. Whilst these studies provide interesting findings, research should also investigate the effects of manipulating central executive load in an online fashion, to measure how changes in central executive recruitment

directly affect driving. One simulator study has done this by adapting shifting and updating tasks within real driving scenarios (Ranchet, Paire-Ficout, Marin-Lamellet, Laurent, & Broussolle, 2011). Participants completed an updating task whilst driving in which they had to recall information about the last three road signs they had previously seen. In the shifting task, participants had to recall the shape or colour of road signs depending on what side of the road the signs were on. Results suggested that only updating resulted in potentially more dangerous driving behaviours; when participants had to simultaneously complete the updating task, speed variability was higher and mean speeds were slower. Whilst slower speeds may indicate a compensatory change as a result of the updating task, they were also less able to maintain a consistent speed.

### 8.1.3 Functional near infra-red spectroscopy (fNIRS)

To summarise, theories such as ACT suggest that individuals with higher levels of trait anxiety may perform on a task to the same level of quality as others, but with less efficient use of processing resources. Evidence from neuroimaging studies may provide further evidence relating to the theory, and investigating this within the driving environment would provide a test of the theory within a novel context. However, the majority of previous research has used methods such as fMRI, which would be impractical within a driving simulator; due to being in a supine position during fMRI tasks, this often makes any driving 'tasks' passive rather than active, making it more difficult to apply findings to real-world driving (Graydon et al., 2004). One emerging neuroimaging method that could overcome this caveat is functional near infra-red spectroscopy (fNIRS). fNIRS is a safe, portable and low-cost method of imaging that consists of sources and detectors (Boas, Elwell, Ferrari, & Taga, 2014). Like fMRI, it is interested in the hemodynamic properties of brain activity. However,

whilst fMRI focuses the magnetic properties of haemoglobin, fNIRS is focused on its optical properties.

Near infra-red (NIR) light is transparent to skin and tissue in the spectrum of between 650-1000nm (Cutini, Moro, & Bisconti, 2012). However, oxygenated haemoglobin (HbO) and deoxygenated haemoglobin (HbR) are strong absorbers of NIR light in this spectrum. Light sources on fNIRS devices emit NIR light at two different wavelengths to interact with HbO and HbR. The lower of these wavelengths is predominantly absorbed by HbR and the higher of these is predominantly absorbed by HbO (Nishiyori, 2016). Any light that is unabsorbed is scattered back through the scalp. This scattered light is picked up by detectors, which capture and estimate the change in HbO and HbR levels relative to an initial baseline level. Total HB changes can also be calculated as a sum of HbO and HbR changes.

Depending on their location on the device, sources and detectors can pair up and be considered a measurement channel. Often, multi-channel fNIRS devices are used across the scalp and can be used to detect changes in specific areas of the brain, depending on the location of channels. fNIRS devices can have as little as 2 (Ikeda, Ikeda, Shiozaki, & Hirayasu, 2014) to as many as 52 (Heilbronner & Muente, 2013) channels. The device used in the current study is a 16-channel headband that measures activity across the PFC. The advantages of fNIRS include increased temporal resolution and allowance for head movement compared to fMRI, increased spatial resolution compared to EEG, and increased portability compared to multiple methods. However, fNIRS is disadvantaged in that it can only measure HbO and HbR levels in comparison to a baseline recorded prior to commencing a study. Additionally, NIRS light can only measure activity at a cortical level, whilst methods such as fMRI can measure activity in deeper brain structures.

A typical finding from fNIRS research is that in response to cognitive tasks, HbO levels increase and HbR levels decrease (Cutini et al., 2012). Several studies have found this pattern in the responses to tasks requiring working memory and executive functioning resources, particularly within the PFC. Bilateral activation of the PFC is observed when participants are performing the Trail-Making Task B, a task that requires individuals to shift responses in order to complete a sequence (Shibuya-Tayoshi et al., 2007). Bilateral activation when performing this task has particularly been found within the DLPFC (Hagen et al., 2014); activation in this area on other tasks, such as the backward span task, has led to the conclusion that DLPFC activity may reflect high levels of cognitive functioning and processing (Contini et al., 2013). Others have also suggested that different parts of the lateral PFC may be active according to the type of executive task to be completed, suggesting that different executive functioning tasks initiate different types of PFC activity (Lague-Beauvais, Brunet, Gagnon, Lesage, & Bherer, 2013). Nonetheless, results also consistently suggest that increasing levels of difficulty on central executive tasks make the pattern of HbO increases and HbR decreases more prevalent within the PFC (Herff et al., 2014), and some have suggested that when a task becomes too difficult, HbO changes become smaller (Izzetoglu, Bunce, Onaral, Pourrezaei, & Chance, 2004; Izzetoglu, Yurtsever, Bozkurt, & Bunce, 2003).

A small number of studies have also conducted fNIRS research whilst completing driving tasks, and have found significant changes in PFC activity. For example, greater PFC activity has been found in less experienced drivers, suggesting that greater use of central executive resources and attentional control is required (Harada, Nashihara, Morozumi, Ota, & Hatakeyama, 2007). Greater bilateral PFC activation has also been found when drivers have been asked to navigate around left curves (Oka et al., 2015); it was argued that because

participants were driving on the left hand side of the road, more information was required from the environment in order to navigate the curve safely, hence PFC activation was greater. A recent study conducted within the NITES facility measured PFC activity whilst completing an overtaking task (Foy, Runham, & Chapman, 2016). Overtaking can be seen as a naturalistic inhibition task, as the driver must suppress their desire to overtake if it is not safe to do so. Results from this study suggested that changes in PFC activation, as measured by changes in HbR, were greater when overtaking compared to a control condition. This was also reflected in self-reported scores of mental demand and inhibitory control. However, PFC activity did not significantly change as a function of traffic density, which was used to manipulate the need to inhibit an overtaking response, suggesting that changes in activity were due to levels of mental workload as opposed to changes in inhibitory control.

### 8.1.4 Aims of the study

In summary, PET and ACT suggest that levels of processing efficiency may reduce when trait anxiety levels are higher, but performance effectiveness may remain the same across participants. This suggestion has been supported in numerous behavioural and neuroimaging studies. The aim of the current research is to investigate the main assumptions of ACT within the context of driving in a series of naturalistic driving tasks. These driving tasks differed in two ways. Firstly, driving scenarios with two different levels of environmental demand were used. Participants either drove along a straight, rural road with little traffic, or they had to navigate through an urban environment with a higher traffic density. Secondly, participants were also required to complete the Random Number Generation (RNG) Task, a task which is related to central executive activity (See Section 8.2.2), whilst driving. The use of a central executive task aimed to divide attentional resources between completion of the driving task and completion of the additional task. On the basis that levels of demand are known to have

an influence on physiological variables (Collet et al., 2005; Cooper et al., 2013; Lenneman & Backs, 2009), measures of heart rate, HRV and skin conductance were also taken. Whilst the driving tasks were taking place, PFC activity was measured using fNIRS.

Based on the assumptions made by ACT, it was predicted that driving performance may not necessarily differ between participants according to their levels of trait anxiety. However, with increasing levels of trait anxiety, it was predicted that there would be evidence of less efficient processing as measured by fNIRS, which would be exacerbated with increased levels of demand.

## 8.2 Methods

### 8.2.1 Participants

Forty-seven participants initially volunteered to complete the study. After screening for simulator sickness, 41 participants (33 female, eight male) took part; they were aged between 18-56 years, with an average age of 20 (*sd*= 6.01). They were all undergraduate students from the University of Nottingham, who were recruited online and received course credit as inconvenience allowance. All of them had a full driver's licence, and had been in possession of it for an average of 2.59 years (*sd*=6.05). Seven had previously been in a minor road accident, four had been in a major accident, and two had previously received driving convictions. Ethical approval was obtained from the University of Nottingham, and participant consent was obtained prior to experimentation.

### 8.2.2 Design

This was a mixed design study. The first independent variable measured was the level of trait anxiety expressed by the participants, according to their scores from STAI-Y2. As with the previous studies, this was treated as a continuous variable and total scores could range from 20 to 80, with higher scores indicating higher levels of trait anxiety.

The first within-subjects factor manipulated was the level of demand within the driving environments presented to participants; these were similar to two of the simulated scenarios presented in Chapter 7. Participants were exposed to either low or high levels of environmental complexity and vehicle handling. In low levels, participants were required to drive along a straight single-lane rural road with a national speed limit, which contained minimal levels of traffic. In high levels of demand, participants were required to drive within an urban environment with a speed limit of 30mph. This contained several buildings and heavy traffic, and at the same time participants were required to make two left and two right turns. Both scenarios took approximately 3 to 5 minutes to complete, depending on driver speed.

The second within-subjects variable manipulated was the simultaneous inclusion of the Random Number Generation (RNG) Task. The RNG task is one that has been used in previous research to increase load on the central executive. The task is one that is commonly used in studies of frontal lobe activity, and requires executive functions such as the inhibition of pre-potent responses and the constant updating of information in working memory (Miyake et al., 2000). Evidence from PET research shows that DLPFC activation is associated with performance on the RNG task (Jahanshahi, Dirnberger, Fuller, & Frith,

2000), and TMS research demonstrates that disruption of the DLPFC, compared to medial frontal cortex, results in an increase in habitual counting responses (Jahanshahi et al., 1998).

For the purposes of the current study, the participant would hear an audio-generated beep every 1000 milliseconds, at which point they would have to state one random number between one and nine, which could include the numbers one and nine. Using the same method that has been consistently used in previous research (Dirnberger & Jahanshahi, 2010; Miyake et al., 2000), the concept of randomness was initially explained using the 'Hat Analogy'. Participants were told to imagine that they were picking a random number out of a hat, then placing it back into the hat before randomly choosing another number. Participants were also encouraged to be consistent in their responses. A set of 10 practise RNG trials were administered before entering the simulator, to familiarise the participant with the pace of the task.

A total of four simulated drives were completed. Two of these were in low or high demand driving environments without the inclusion of an additional task, and two of the drives were completed in low or high demand driving environments with the additional requirement of completing the RNG task. These four drives were counterbalanced across participants.

A variety of dependent variables were extracted from each drive. Firstly, in order to assess that the tasks were reliably increasing levels of workload by manipulating levels of environmental and secondary task demand, the NASA-TLX (Hart & Staveland, 1988) was administered after the completion of each drive. The NASA-TLX was structured in the same way as Chapter 7 (See Section 7.2.3.1), which meant that the additional scale measuring visual demand was also included in this study.

During the drives, as with Chapters 6 and 7, measures of skin conductance and heart rate were also taken. This included mean skin conductance levels (in μS) and mean heart rate (in BPM). As heart rate variability has also previously been associated with changes in workload and demand, measures of low-frequency (LF-HRV) and high frequency (HF-HRV) were also measured, along with the LF/HF ratio. Additionally, as the main purpose of the study was to assess effects of trait anxiety on processing efficiency, measures of prefrontal cortex (PFC) activity were taken using functional near infra-red spectroscopy (fNIRS). Based on theories of workload outlined in the literature, this measured the changes in levels of oxygenated (HbO) and deoxygenated haemoglobin (HbR) in the PFC (in μM), compared to a six-second baseline measured before commencing with driving.

Behavioural measures taken during the drive were similar to those from Chapter 7. Thus, this included speed variability and standard deviation of lane position (SDLP). Whilst there was a confound in the speed limits between demanding and undemanding drives, there was still an interest in comparing speed across different levels of central executive task inclusion, therefore average speed (in mph) was also measured for this purpose.

An overall 'randomness' score was also taken based on the responses participants made whilst completing the RNG task in the undemanding and demanding drives. This score is the frequency that response alternatives follow each other, and is based on a formula created by Evans (1998). Scores on this range from 0 to 1, with 0 suggesting a perfect distribution of randomness, and 1 implying complete predictability of responses. In addition to this, specific scores that were taken from Towse & Neil's (1998) RgCalc program (See Section 8.3) included coupon scores (the mean number of responses produced until all response

alternatives have been given), mean repetition gaps (the mean distance between repetition of numbers) and adjacency scores (expressed as the percentage of number pairs that are adjacent to each other in a generated sequence). These scores were chosen to investigate specific response biases that are common in RNG research, such as the tendency to overexpress adjacent responses and possible avoidance of immediate repetition (Dirnberger & Jahanshahi, 2010).

### 8.2.3 Materials/Stimuli

#### 8.2.3.1 fNIRS device

Frontal lobe activity was measured using a continuous wave fNRIS system (Biopac Model 1100) situated within NITES 2. This consisted of a control box placed behind the participant that sampled data an acquisition rate of 2Hz, and a 180x60x8mm sensor placed on the participant's forehead, the centre of which was in line with the nasion. In order to minimise the chances of noise due to outside light, a bandage was also wrapped around the participant's head, and care was taken to remove hair from the forehead which may interfere with the signal.

The sensor was fitted with four light sources and ten detectors; along with a light source separation of 2.5cm, this means that a total of 16 channels are simultaneously measuring haemoglobin changes in the PFC. The LEDs emitted NIR light at wavelengths of 730 & 850 nm. Information on HbO and HbR changes was acquired using Cognitive Optical Brain Imaging Studio (COBI) Version 1.2.0.111 (fNIR devices, Potomac, MD, USA), which ran on a Dell laptop connected to the control box. This laptop was then remotely connected to a computer outside of NITES 2, on which the researcher could control the fNIR software. The placement of souces and detectors for the device is outlined in Figure 8-1.

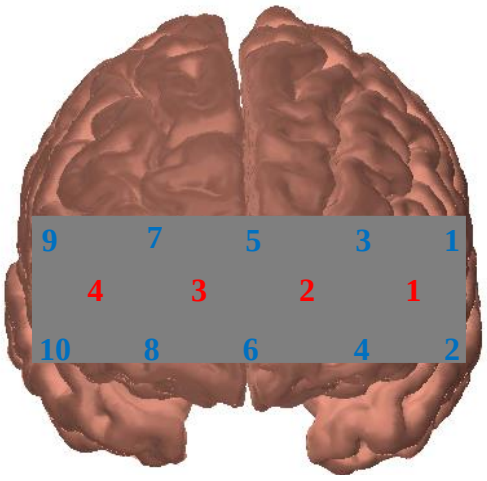



*Figure 8-1: Light source and detector placement on the fNIRS device. The four light sources are highlighted in red whilst the ten detectors are highlighted in blue. These source-detector pairs make up 16 channels in total.*

#### 8.2.3.2 Driving Simulator

As with Chapter 7, NITES 2 was used to complete the simulated drives. However, due to software issues, eye tracking was not recorded in the current study. For completion of the RNG task, audio beeps were played through a Bolse SZ-801 Bluetooth speaker placed to the side of the driving rig, and audio beeps were played through the speaker using an iPhone 6s.

Physiological data were recoded using the same procedures as those described in Chapter 7. However, heart rate was recorded from an ear clip attached to the participant's right earlobe, as opposed to a finger strap.

#### 8.2.3.3 Questionnaires

As with the previous four studies, the STAI was used to measure state and trait anxiety. Average levels of state anxiety were 32 (*sd*=6.2) and average levels of trait anxiety were 40.1 (*sd*= 8.88). Reliability of scoring was found to be high for both state and trait (Cronbach's α= .86 and .91 respectively).

Participants were also required to complete a driver demographics questionnaire, the SSQ (Kennedy et al., 1993) and the Driving Cognitions Questionnaire (DCQ- Ehlers et al., 2007). Additionally, as the study was looking at the relationship between trait anxiety and attentional control, participants also completed the Attentional Contol Scale (Derryberry & Reed, 2002) (See Appendix 'M'). The Attentional Control Scale is a questionnaire designed to assess the ability to focus and shift attention when necessary, and flexibly control thoughts. The scale consists of 20 items that are measured on a 4-point Likert scale. Participants are asked to read the statements and indicate how much each statement applies to them by choosing the appropriate number on the Likert scale. Level of applicability can range on the scale from 'Almost never' ('1' on the Likert scale) to 'Always' ('4' on the Likert scale). As with the STAI, participants can gain a minimum score of 20 and a maximum score of 80, with higher scores indicating higher levels of attentional control. Previous research has indicated that this measure of attentional control is internally consistent (α=.88; Derryberry & Reed, 2002). The data from the present study indicated that the average attentional control score was 50.29 (*sd*=8.05), and that reliability of the scale was high (Cronbach's α=.85). Reliability for the

accident and social subscales of the DCQ were good (α=.75 and .73 respectively), as was the overall DCQ scale (α=.82); however, scores from the panic subscale of the DCQ were less reliable (α=.6).

### 8.2.4 Procedure

After participants completed the consent form, they completed the STAI, the driver demographics questionnaire, the DCQ and the Attentional Control Scale. The researcher then informed them that they may have to complete an RNG task during some of the driving scenarios, before explaining it to them and allowing them to complete 10 practice trials. The participant was then taken into the simulator, where the physiological and fNIR equipment was attached, and they were allowed a practice drive. After this drive, the first SSQ was completed, and then, providing that the participant felt well enough to continue the experiment, the four experimental drives were completed according to the counterbalancing order assigned to the given participant. After each scenario, the NASA-TLX was completed to assess their perceptions of workload. Once the four drives had been completed, the physiological and fNIR equipment was removed and participants completed a second SSQ and a post-trial consent form, before they were debriefed.

## 8.3 Results

Driving data were extracted from XPI ISO using the IOS Data Extraction Tool, using the same methods as the ones described in the previous two chapters. The same automated program as the one described in Chapter 4 was used to extract HRV data, using the same pre-processing filters. Physiological data were then pasted into an Acqknowledge journal, before being uncounterbalanced using Excel.

fNIRS data were pre-processed using HomER2 (Huppert, Diamond, Franceschini, & Boas, 2009), an fNIRS software package which ran in MATLAB R2012a. Firstly, the hmrprunechannels function was used to indicate any channels with signals that were too high or too low, or had standard deviations that were too great. These channels were then removed form pre-processing and further analysis. A motion detection algorithm was then applied to identify any signal changes with a standard deviation greater than 50, or an amplitude greater than 5, over a time period of at least 0.5 seconds. This signal was then identified as a motion artefact and masked for 1 second. A low order Butterworth filter of 0.5Hz was also applied to reduce any high frequency noise such as cardiac oscillations. Finally, changes in oxygenated haemoglobin (HbO), deoxygenated haemoglobin (HbR) and total haemoglobin compared to baseline were calculated for each channel; for the purposes of analysis, only data related to HbO and HbR changes were used. All values are reported in micromoles (μM).

Due to the slow nature of the hemodynamic response, and an interest in comparing directly across drives, behavioural, physiological and fNIRS data were extracted at the point at which the participant had first exceeded 20mph for each drive, and then two minutes of continuous data were taken from this point for analyses. As RNG data were recorded by hand, these data were processed with regards to performance across the entire drive. These were placed into an Excel file, before being processed by RGCalc (Towse & Neil, 1998), an automated program designed to generate a wide variety of RNG scores.

All data, unless stated otherwise, were analysed using a 2x2 mixed ANCOVA, with levels of environmental demand and central executive task inclusion as within-subjects factors, and centred trait anxiety scores as a continuous covariate.

### 8.3.1 Measures of driving cognitions and attentional control

To assess whether trait anxiety had any significant effects on levels of attentional control and self-reported driving concerns, scores from the Driving Cognitions Questionnaire (DCQ) and the Attentional Control Scale (ACS) were placed into a MANCOVA, with centred trait scores as a continuous covariate. This was on the basis that all DCQ scores significantly correlated with each other (all *r*s>.38, all *p*s<.05), and scores from the ACS negatively correlated with both accident-related concerns (*r*= -.35, *n*=41, *p*=.025) and total DCQ scores (*r*= -.36, *n*=41, *p*=.022). Results from the MANCOVA suggested that trait anxiety significantly influenced self-reported accident concerns ($F(1,39)=6.97$, $p=.012$, $\eta p^2=.152$), total DCQ scores ($F(1,39)=4.12$, $p=.047$, $\eta p^2=.091$), and attentional control scores ($F(1,39)=9.12$, $p=.004$, $\eta p^2=.19$). A series of simple linear regression analyses assessed the strength of these relationships with trait anxiety, and are presented in Table 8.1. To summarise the table, trait anxiety positively predicted accident and overall driving concerns, but negatively predicted attentional control scores.

**Table 8.1: Simple linear regression analyses of Driving Cognitions Questionnaire and Attentional Control Scale Scores.**

| | $R^2$ | B | SE B | β |
|---|---|---|---|---|
| **DCQ- Panic** | | | | |
| (Constant) | | .87 | 1.36 | |
| Trait Anxiety | .012 | .023 | .033 | .109 |
| **DCQ-Accident** | | | | |
| (Constant) | | .032 | 2.32 | |
| Trait Anxiety | .152 | .149 | .057 | .389* |
| **DCQ-Social** | | | | |
| (Constant) | | 3.06 | 2.4 | |
| Trait Anxiety | .031 | 0.65 | .058 | .176 |
| **DCQ-Total** | | | | |
| (Constant) | | 3.96 | 4.76 | |
| Trait Anxiety | .097 | .238 | .116 | .312* |
| **Attentional Control Scores** | | | | |
| (Constant) | | 66.12 | 5.36 | |
| Trait Anxiety | .19 | -.395 | .131 | .435** |

*$p$<.05

**$p$<.01

### 8.3.2 Measures of workload

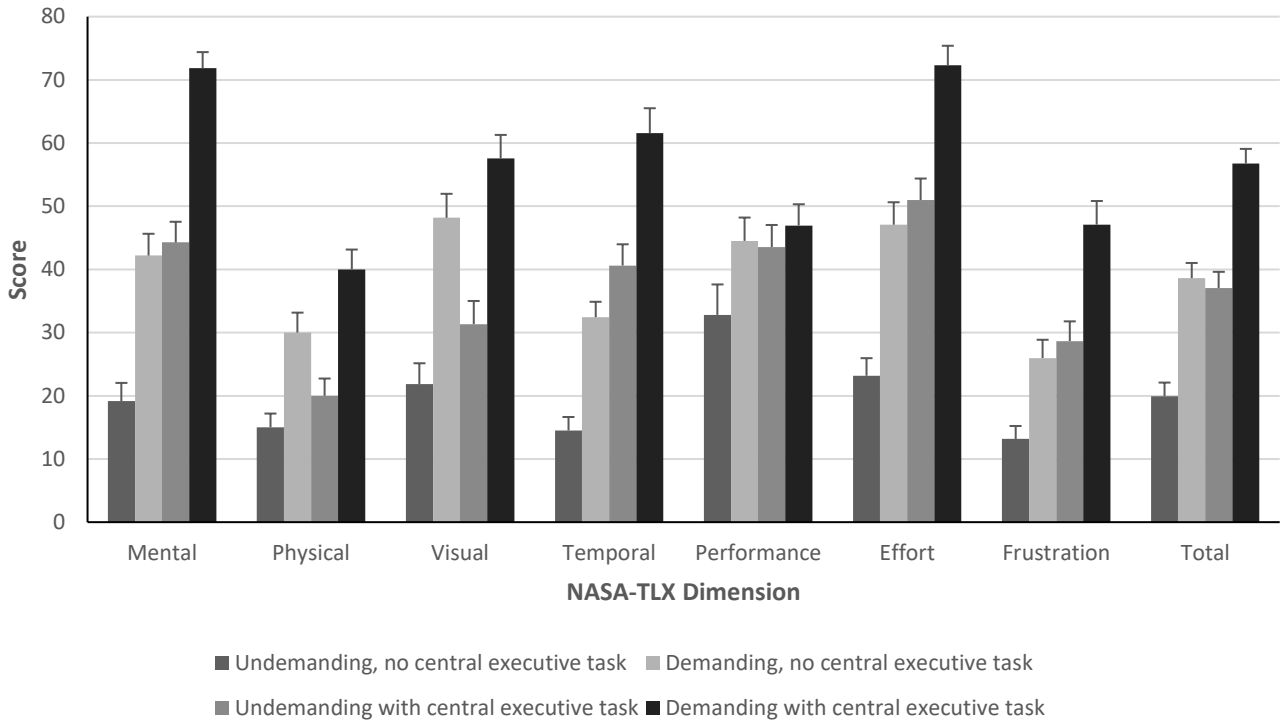



*Figure 8-2: NASA-TLX Scores according to levels of demand and inclusion of a central executive task.*

The scoring procedure described in Chapter 7 was also used in the current study; scores for each subscale were converted into a score out of 100, and an average of all subscales provided a total workload score. Significant main effects were found for levels of workload on the majority of subscales, plus the total score. Higher levels of demand within the environment produced significantly higher ratings on all subscales (all $p$'s<.05). The total score was also significantly higher in demanding environments ($p$<.001). The same pattern was found for the inclusion of the RNG task with the exception of scores on the performance subscale [$p$=.059]. All remaining subscales were significantly higher when the RNG task was performed whilst driving (all $p$s<.001), and the total score was also significantly higher ($p$<.001). There were no interactions between demand and RNG task inclusion (all $p$s>.05).

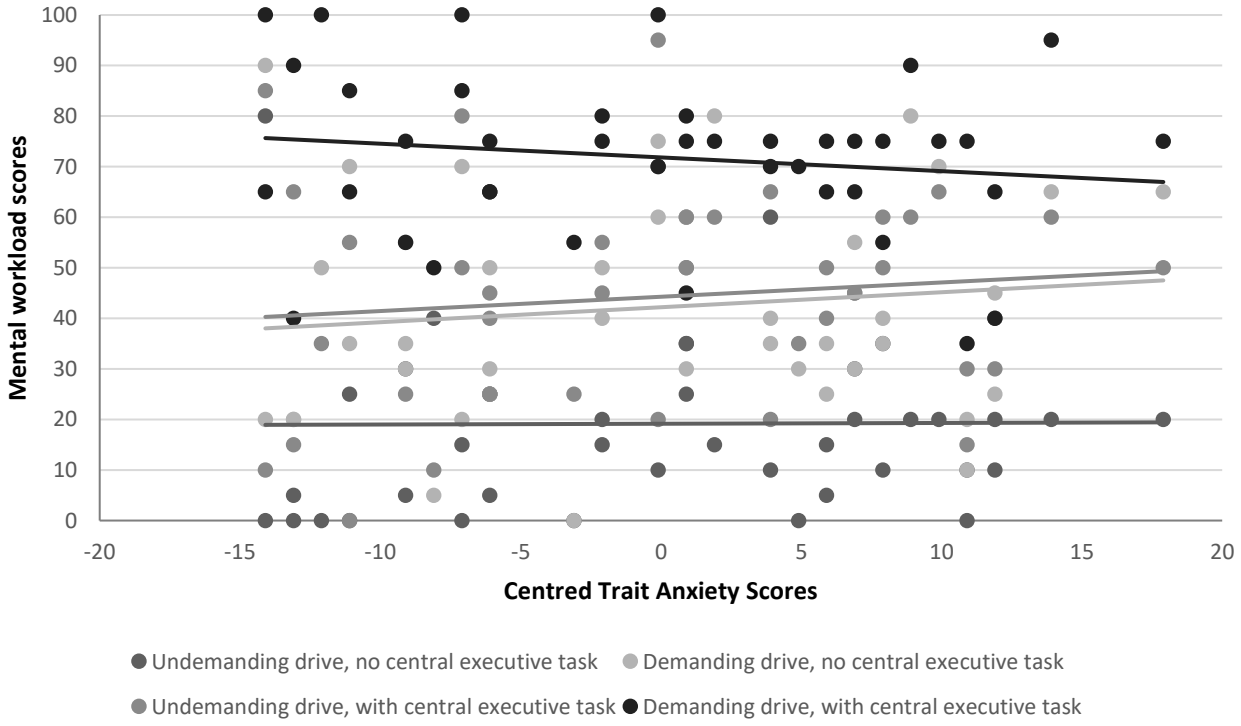
A significant main effect of trait anxiety was found for overall frustration scores ($F$(1,39)=5.23, $p$=.028, $\eta_p^2$=.118). Linear regression analyses suggested that higher levels of trait anxiety predicted higher frustration scores, regardless of driving task ($R^2$=.118, $\beta$=.559).

Interactions were also found between trait anxiety and levels of environmental demand for self-reported performance scores ($F$(1,39)=4.19, $p$=.047, $\eta_p^2$=.097). Linear regression analysis suggested that trait anxiety was a significant predictor of perceived performance in undemanding environments ($R^2$=.1, $\beta$=.84) (F(1,39)=4.33, $p$=.044). Higher levels of trait anxiety predicted higher scores on the performance subscale; as a higher score indicated perceptions of 'Failure', those with higher levels of trait anxiety were more likely to feel that they had not performed well on undemanding driving tasks. However, trait anxiety was a non-significant predictor of performance scores in demanding environments ($p$=.89).

An interaction was also found between trait anxiety and the inclusion of the RNG task for self-reported performance scores ($F$(1,39)=5.01, $p$=.031, $\eta_p^2$=.114). Linear regression analysis suggested that trait anxiety was a significant positive predictor of perceived performance when the RNG task was not performed ($R^2$=.1, $\beta$=.876) ($F$(1,39)=4.34, $p$=.044). Higher levels of trait anxiety predicted higher scores on the performance subscale, suggesting they did not believe they had performed as well when completing driving tasks without inclusion of the RNG task. However, trait anxiety was not predictive of performance scores when the RNG task was performed whilst driving ($p$=.97).

A significant three-way interaction between driving demands, RNG task inclusion and trait anxiety was also found with regards to perceived mental workload ($F$(1,39)=4.76, $p$=.035,

$\eta_p^2$=.109). This interaction suggests that when participants completed an undemanding drive without an additional central executive task, there is little association between trait anxiety and levels of mental workload. When participants drove in a demanding environment without an additional central executive task, or when they drove in an undemanding environment with an additional central executive task, there was a positive association between trait anxiety and levels of mental workload. However, when participants drove in a demanding environment and simultaneously completed the RNG task, trait anxiety scores were negatively associated with levels of perceived mental workload (See Figure 8-3).




*<u>Figure 8-3:</u> The relationship between trait anxiety and mental workload scores on the NASA-TLX, according to environmental demand and inclusion of the RNG task.*

### 8.3.3 RNG Scores

A mixed ANCOVA (environmental demand x trait anxiety levels) was conducted on coupon, repetition gap and adjacency scores, as well as the overall RNG score. Significant main effects of environmental demand were found for coupon scores ($F(1,39)=5.54$, $p=.024$, $\eta_p^2=.124$), adjacency scores ($F(1,39)=25.68$, $p<.001$, $\eta_p^2=.4$), and overall RNG scores ($F(1,39)=17.06$, $p<.001$, $\eta_p^2=.304$). Higher levels of environmental demand were associated with higher coupon scores ($m=21.44$; $m$ for undemanding environments=17.69), a higher percentage of generating adjacent pairs ($m=41.79\%$; $m$ for undemanding environments=35.89%), and a higher overall RNG score ($m=0.4$; $m$ for undemanding environments=0.36). A significant main effect of trait anxiety was also found for adjacency scores ($F(1,39)=4.24$, $p=.046$, $\eta p^2=.098$). Regression analyses revealed that trait anxiety scores positively predicted adjacency scores ($R^2=.098$, $\beta=.494$). No significant interactions between trait anxiety and environmental demand were found (all $p$s>.05).

### 8.3.4 Driving behaviour

For speed variability, no main effects of trait anxiety were found. However, there were significant main effects of both environmental demand ($F(1,39)=31.23$, $p<.001$, $\eta_p^2=.445$) and inclusion of central executive task ($F(1,39)=4.61$, $p=.038$, $\eta_p^2=.106$). Speed variability was significantly greater during undemanding drives ($m=9.29$) than demanding drives ($m=7.22$), but also significantly greater when the RNG task had to be completed ($m=8.55$) than when driving without completing the RNG task ($m=7.97$). There were no significant interactions between variables. (all $p$s>.05).

For SDLP, no main effects of trait anxiety were found. However there were significant main effects of environmental demand ($F(1,39)=97.46$, $p<.001$, $\eta_p^2=.714$) and inclusion of central executive task ($F(1,39)=4.75$, $p=.035$, $\eta_p^2=.109$). SDLP was significantly higher during demanding drives ($m=0.56$) than undemanding drives ($m=0.4$). However, SDLP was also significantly lower when the RNG task was simultaneously completed ($m=0.46$) than when driving without the RNG task ($m=0.49$). No significant interactions between variables were found (all $p$s>.05).

Whilst driving speed across conditions was confounded by the available speed limits in each scenario, there was still an interest in analysing the effects of including a central executive task. Therefore, an additional ANCOVA was conducted on average speed. As predicted, there was a significant main effect of speed ($F(1,39)=3054.01$, $p<.001$, $\eta_p^2=.987$), with significantly higher average speeds in the undemanding drives ($m=53.33$mph) than the demanding drives ($m=22.85$mph). However, whilst there were no significant main effects of central executive task or trait anxiety, there was a significant interaction between environmental demand and central executive task inclusion ($F(1,39)=4.68$, $p=.037$, $\eta_p^2=.107$). This suggested that during the undemanding drives, having to simultaneously complete the RNG task resulted in a reduction in speed. However, during the demanding drives, simultaneously completing the RNG task resulted in an increase in mean speed (See Figure 8-4).

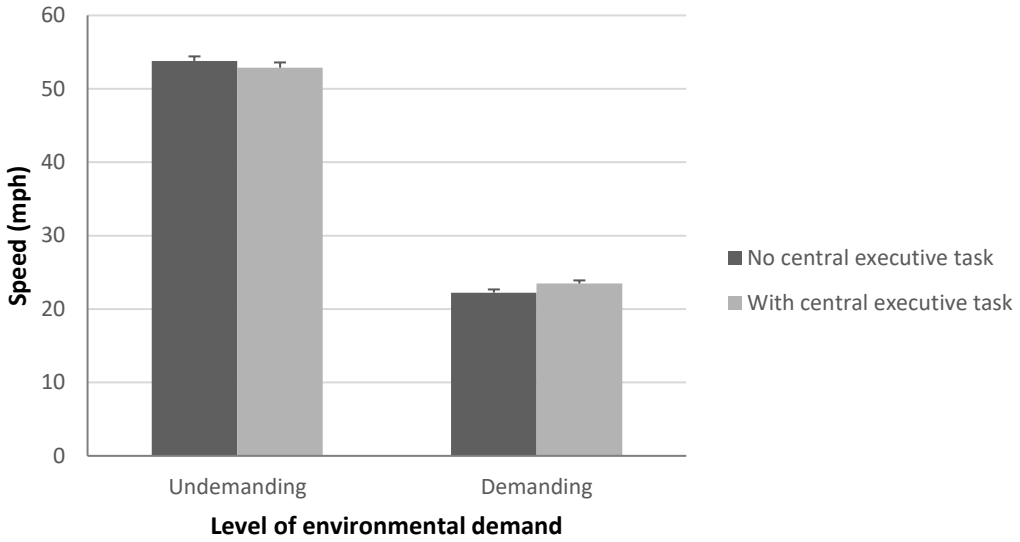



*Figure 8-4: Speed (in mph) according to levels of environmental demand and inclusion of a central executive task.*

### 8.3.5 Physiology

ANCOVAs were conducted on skin conductance levels, heart rate, LF-HRV, HF-HRV and the LF/HF ratio. However, there were no significant main effects or interactions for heart rate or HRV data (all *p*s>.05). For skin conductance data, significant effects were only found for levels of environmental demand ($F(1,34)=30.38$, $p<.001$, $\eta_p^2=.472$), where skin conductance levels were significantly higher during demanding drives ($m=8.26$ µS) than during undemanding drives ($m=7.77$ µS). There were, however, marginal main effects of central executive task inclusion [$F(1,34)=3.84$, $p=.058$, $\eta_p^2=.102$] and trait anxiety [$F(1,34)=3.01$, $p=.092$, $\eta_p^2=.081$], as well as a marginal interaction between environmental demand and central executive task inclusion [$F(1,34)=3.79$, $p=.06$, $\eta_p^2=.1$].

### 8.3.6 fNIRS data

Due to hardware errors, there were issues with recording data from several channels. Prior to analysis, participants whose pre-processed data indicated that fewer than 50% of channels were producing a reliable signal were excluded from final analysis. This meant that data from 16 participants was excluded and data from 25 participants was analysed. Additionally, the hmrprunechannels function indicated that individual channels needed to be removed for some participants. The amount of data retained for each channel is described in Table 8.2.

**Table 8.2: The amount of data discarded for each channel prior to averaging across medial and lateral channels.**

| Channel | Amount of data discarded (out of 25) | Percentage retained |
|---|---|---|
| 1 | 0 | 100 |
| 2 | 1 | 96 |
| 3 | 10 | 60 |
| 4 | 11 | 56 |
| 5 | 0 | 100 |
| 6 | 2 | 92 |
| 7 | 6 | 76 |
| 8 | 8 | 68 |
| 9 | 0 | 100 |
| 10 | 1 | 96 |
| 11 | 3 | 88 |
| 12 | 6 | 76 |
| 13 | 0 | 100 |
| 14 | 1 | 96 |
| 15 | 11 | 56 |
| 16 | 12 | 52 |

A 2 x 2 ANCOVA (environmental demand x RNG task inclusion x centred trait anxiety scores) was conducted. No significant main effects of environmental demand, central executive task inclusion or trait anxiety levels were found.

However, a significant interaction between RNG task inclusion and trait scores was found for HbO levels ($F(1,23)=5.76$, $p=.025$, $\eta_p^2=.2$). This suggested that when the RNG task was not completed, higher levels of trait anxiety were associated with higher levels of HbO; however, when the RNG task was simultaneously completed whilst driving, higher levels of trait anxiety were associated with lower levels of HbO (See Figure 8-5). The opposite pattern was observed for HbR levels, however this effect was only marginally significant [$F(1,23)=3.09$, $p=.092$, $\eta_p^2=.119$].

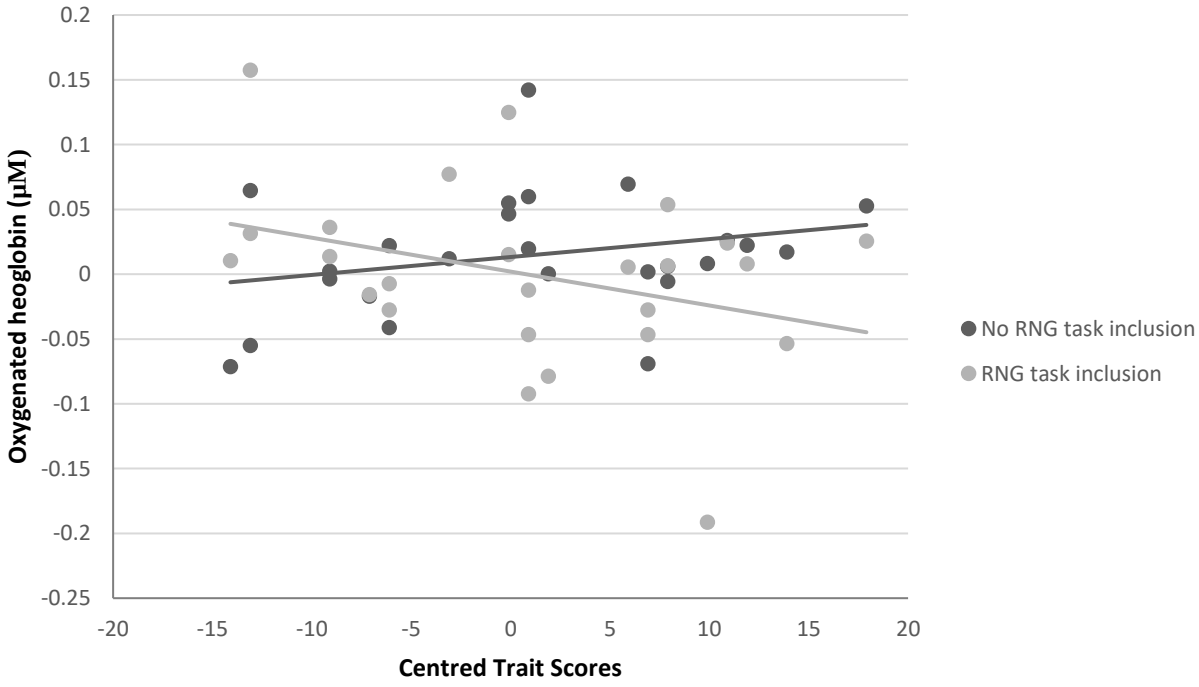



*Figure 8-5: The relationship between trait anxiety and HbO levels, depending on inclusion of the RNG task.*

## 8.4 Discussion

To our knowledge, this is one of the first studies to investigate the assumptions of ACT by asking participants to drive in simulated environments and simultaneously complete a task requiring the use of executive functions. The theory was tested by measuring changes in HbO and HbR in the PFC during driving tasks using fNIRS, an optical-based method of brain imaging. Results suggested that whilst behavioural performance on the driving and central executive tasks was not affected by trait anxiety, it did affect self-reported responses, adjacency responses to the central executive task, and changes in HbO levels depending on the demand imposed. Overall, these findings suggest that support could be made for the main hypotheses proposed by ACT.

### 8.4.1 Findings

#### 8.4.1.1 Self-report data

Firstly, self-report evidence provided support for the idea that trait anxiety is associated with poorer maintenance of attentional control. Regression analyses suggested that trait anxiety levels could negatively predict scores on the ACS; this indicates a self-awareness of poorer concentration levels and an increased likelihood of distraction in those with higher levels of anxiety. Findings from the DCQ also suggested that trait anxiety predicted accident-related concerns and overall driving concerns, rather than panic or social-related concerns. It is possible that those with higher anxiety levels are specifically concerned about having an accident due to their perceived lack of attentional control, whilst behaviours that lead to social and panic-concerns may not necessarily be a result of poor attentional control. For example, one of the items on the accident-concern subscale suggests that “I will not be able to react fast enough”; those with high anxiety may feel that they may not be able to react fast

enough due to a belief they have poor concentration levels, and this would subsequently cause an accident in their opinion. Future research may want to investigate the relationship between trait anxiety, and all DCQ subscales whilst completing different driving tasks. It would be interesting to observe how encountering driving situations that address the three types of driving concerns affect subsequent behaviours and perceptions of capability.

Data from the NASA-TLX suggested that for the majority of perceived subscales, levels of perceived workload increased with increasing levels of both environmental and central executive demand. This indicates that manipulation of both of these independent variables as successful in increasing levels of self-reported workload. Furthermore, a significant interaction between trait anxiety levels and frustration scores was reported regardless of the task to be completed. Along with the findings from Chapter 7, this indicates a potential relationship between levels of frustration and anxiety. Future simulator research may want to further investigate the relationship between anxiety and frustration, and perhaps assess whether anxiety levels, both state and trait, may eventually lead to frustration or anger-based responses whilst driving.

Other findings from the NASA-TLX data found significant interactions between trait anxiety and environmental demand, and trait anxiety and central executive demand, on performance scores. When participants drove in undemanding environments, or did not have to simultaneously complete the RNG task, trait anxiety was positively associated with higher scores on the ‘performance’ subscale, however, when environments were demanding or the RNG task had to be simultaneously completed, there was no association between trait anxiety and scores on this subscale. It is worth emphasising at this stage that higher scores on this subscale indicate perceptions of failure on a task. When it is considered that trait anxiety did

not affect driving behaviours in the current study, it would perhaps support previous research in suggesting that those with higher levels of anxiety are more conservative in their judgements regarding their own performance (Graydon et al., 2012). The fact that there is no relationship between trait anxiety and performance scores when the driving task becomes demanding may suggest the participant is aware they are less able to predict their performance on the driving task in these circumstances.

Findings from the three-way interaction between trait anxiety, environmental demand and central executive task inclusion on mental workload scores may support this idea. When only one type of demand is imposed on the participants, those with higher anxiety may acknowledge that the task is more mentally demanding. However, when both types of demand are imposed on the participant, those with higher levels of anxiety report that the task is less mentally demanding. It is possible in this case that the demands of completing the driving and RNG task simultaneously are too great at this point, so those with higher levels of anxiety may be attempting to alleviate any concerns they may have by perceiving the task as less demanding. Thus this may extend the literature into anxiety and task capability by suggesting that greater levels of demand may result in the use of a defence mechanism in those with higher levels of trait anxiety. Future research, both generally and within the driving context, may want to investigate this suggestion by comparing trait anxiety and NASA-TLX scores in situations that place excessive demand on the participant.

#### 8.4.1.2 Behavioural data

Behavioural data were collected from both the RNG data and from the driving simulator. However, only data from the RNG task found any differences according to levels of trait

anxiety. Firstly, a comparison of scores between environments with different levels of demand indicated that in more environmentally demanding environments, RNG scores were higher, as well as coupon and adjacency scores. Overall this suggests that in this context, participants were more likely to produce non-random number sequences, and use habitual responses such as repeating previous numbers before producing all response alternatives, and counting in sequences (Dirnberger & Jahanshahi, 2010); therefore the current findings extend previous research by suggesting that increased levels of demand can exacerbate effects of bias in random sequence generation. Additionally, interactions implied that those with higher trait anxiety levels use less efficient strategies to generate random sequences, specifically due to an increased likelihood of producing adjacent pairs of responses. Because trait anxiety did not affect overall RNG scores, this provides behavioural support for previous theories by suggesting that those with high trait anxiety were capable of performing the RNG task, but may have been more likely to use inefficient strategies to do so.

As mentioned, trait anxiety did not affect driving behaviours. However, there were changes in behaviour according to levels of environmental demand and central executive task inclusion. Some of these changes may be made in order to compensate for the effects of completing the RNG task; however whether these changes increase safety or increase accident risk is another question. For example, in both environments simultaneous completion of the RNG task resulted in reductions in SDLP, indicating that participants were compensating for additional central executive processing by maintaining their lane position. However, speed variability also increased, indicating a poorer ability to maintain a constant speed. This may be particularly dangerous in a more demanding driving environment, as speed in this environment increased when the RNG task was also completed.

#### 8.4.1.3 PFC activity

Support for the main assumptions made by ACT and PET is provided by the significant interaction between trait anxiety levels and central executive task inclusion, according to HbO levels. Trait anxiety did not significantly affect either driving performance or overall scores of randomness. However, HbO data suggested that increases in trait anxiety were associated with increases in HbO when the RNG task was not completed, but decreases in HbO when the RNG task was completed. Both of these effects may indicate inefficient processing strategies. Firstly, the positive association between trait anxiety and HbO when the RNG task was not completed would suggest an over-recruitment of PFC resources during a simple driving task, and would support previous research indicating an over-recruitment of the PFC with higher levels of trait anxiety (Basten et al., 2011). Secondly, decreases in HbO activity when the RNG task was also completed would actually suggest an under-recruitment of PFC resources with increasing levels of central executive demand. Whilst findings regarding HbR levels were only marginal, these effects were the opposite of those found for HbO, which may support this suggestion.

Interestingly, the over-recruitment of the PFC according to increasingly anxiety levels has previously been found when completing tasks requiring the use of central executive resources (Ansari & Derakshan, 2009; Basten et al., 2011). However, results from the current study indicate increased PFC activation when a participant is driving without the inclusion of a central executive task. This may support suggestions from previous research that driving is a task that requires a dual-task component, and that dual-task coordination should be considered as an executive function in its own right (Wong et al., 2015). This would suggest that driving is a task that requires a substantial amount of central executive functioning, hence a positive relationship was found between trait anxiety and HbO levels, in the absence

of any clear central executive task. Additionally, if we consider dual-task coordination as a central executive task, then it may suggest that subsequent decreases in HbO levels when the RNG task is included are due to excessive demands placed on the central executive. This would support previous research which has made similar conclusions (Izzetoglu et al., 2003), Furthermore, it implies that those with different anxiety levels use different compensatory strategies according to levels of central executive demand. When there are sufficient resources, there is over-recruitment of the PFC. However, when central executive demand exceeds the attentional resources available, there is under-recruitment of the PFC.

What is less clear is the lack of relationship between demand, anxiety and physiological variables. This is particularly surprising for the heart rate and HRV data, which has previously been used to detect changes in mental workload alongside fNIRS data (Durantin, Gagnon, Tremblay, & Dehais, 2014). However, a significant main effect was found for SCLs on levels of environmental demand, which may reflect an increase in invested mental effort with an increase in demands from the environment, and marginal effects of central executive task inclusion would also imply a potential increase in mental effort with inclusion of the RNG task.

### 8.4.2 Limitations

Firstly, the average age of participants in the current study was 20, indicating that the sample was relatively young. This issue is particularly important in the context of PFC development. The frontal lobes are one of the last areas of the brain to develop, and are not fully developed until the age of around 25 (Johnson, Blum, & Giedd, 2009). To support this, research has demonstrated that PFC activity is reduced in younger compared to older drivers (Foy et al., 2016). Whilst age was not investigated in the current study, it would be interesting for future

research to compare PFC activation in younger and older drivers and assess whether levels of anxiety make any contribution to this effect.

Another limitation of the study concerns the limitations of fNIRS imaging, in that it only has the potential to measure surface level activity, and in the context of the current study only within the PFC. Previous neuroimaging research looking at attentional control has consistently demonstrated the recruitment of additional areas when completing central executive tasks, particularly the anterior cingulate cortex (Bishop et al., 2004; Lee & Grafton, 2015; Lie et al., 2006). Additionally, increases in trait anxiety have also been associated with reduced functional connectivity between the DLPFC and other areas of the brain (Basten et al., 2011). As the anterior cingulate is often responsible for error monitoring and correction, information regarding activity in this area may be able to provide information as to whether anxious individuals are more likely to show signs of also maladaptively recruiting this area. Future research into the area of anxiety and attentional control should therefore consider using devices or methods that are able to simultaneously measure anterior cingulate cortex activity.

Finally, it should be noted that the effects of state anxiety were not considered in the current study. Previous research looking into the effects of state anxiety on processing efficiency have consistently used ego-threatening instructions to induce higher levels of anxiety (Cocks et al., 2016; Murray & Janelle, 2003; Wilson et al., 2006) . As no such instructions were used in the current study, the effects of state anxiety were not considered. However, it should be noted that recent research investigating the effects of trait anxiety on processing efficiency found that this was dependent on levels of situational stress induced by ego-threatening instructions, both in a backwards span task (Edwards, Edwards, & Lyvers, 2016) and in the

WCST (Edwards, Edwards, & Lyvers, 2015). Therefore future research may also want to consider the effects of state stress or anxiety, in addition to trait anxiety, on processing efficiency levels.

### 8.4.3 Conclusions

Theories such as ACT and PET suggest that those with higher levels of trait anxiety are more likely to be preoccupied with worrisome thoughts, which occupy some levels of attentional control. This means that less processing resources are available for additional tasks. However, any potential effects on performance can be alleviated with an increased amount of effort on a primary task, meaning that performance effectiveness is maintained at a cost of processing efficiency resources.

The aim of the current study was to test this core assumption within the driving context, by asking participants with varying levels of trait anxiety to drive through environments with different levels of demand, and simultaneously complete a central executive task. Results suggested that driving behaviour and overall performance on the RNG task were not affected by levels of trait anxiety. However, PFC activity increased with increasing levels of trait anxiety in environments where the RNG task did not need to be completed. This indicates poorer efficiency on the basis of over-recruitment of PFC resources to maintain the same level of driving and RNG performance. On the other hand, PFC activity decreased with increasing levels of trait anxiety when the RNG task had to be completed, suggesting poorer processing efficiency on the basis of under-recruitment of PFC resources. This provides support for the theories of ACT and PET; furthermore, it suggests that a lack of behavioural differences in previous research investigating the relationship between anxiety and driving could have been explained with evidence of poorer processing efficiency. From a practical

perspective, which is discussed in greater detail in Chapter 9, these findings not only highlight the usefulness of safe, portable neuroimaging methods such as fNIRS, they also imply that those with higher trait anxiety may benefit from training that particularly focuses on improving attentional control skills.

# Chapter 9. General Discussion

## 9.1 Introduction

There is an emerging body of literature on the relationship between anxiety and driving. Whilst some of this research focuses specifically on those who report driving anxieties and fears, a smaller proportion of the literature focuses on the relationship between general anxiety, in both its state and trait forms. The previous literature has been based on a mixture of self-report and simulator studies, the conclusions to which have been mixed. Therefore, the aim of the thesis was to assess the effects of both state and trait anxiety on driving behaviours and reactions, primarily within laboratory and simulator settings. There was an additional focus on patterns of autonomic activity as a function of anxiety levels; this is important as this can provide information on internal levels of arousal and attention, and can be linked to self-report and behavioural data in order to provide a more comprehensive assessment of the effects of general anxiety on driving.

Whilst this multifaceted approach was adopted for the majority of the thesis, Chapter 2 aimed to investigate the effects of general anxiety on driving thoughts and behaviours, and the degree of anxiety within specific situations. This was approached using self-report methods, in an online study. The studies presented in Chapters 3 and 4 used a laboratory-based approach to investigate the effects of trait anxiety on behavioural and autonomic responses; whilst Chapter 3 attempted to distinguish between fear and anxiety on the basis of bottom-up and top-down processing mechanisms, Chapter 4 focused on the relationship between trait anxiety and task capability. Chapters 6, 7, and 8 discussed studies conducted within the NITES facility. Chapters 6 and 7 investigated the impact of threatening instructional sets on state anxiety, driving behaviour and autonomic activity. Chapter 8 focused on anxiety within

the framework of PET and ACT, and used fNIRS to measure differences in processing efficiency in the PFC, according to trait anxiety.

This chapter aims to discuss the overall findings from the previous studies. As the aim of the thesis was to investigate the effects of anxiety on driving, only findings associated to emotion and anxiety are discussed here. Specific findings are discussed for each chapter, alongside their theoretical and practical implications. This is presented alongside general comments, limitations, and a brief discussion of how these findings may apply to future research and practical applications.

## 9.2 Chapter Two

The aim of the Chapter 2 was to provide self-reported data that investigated how anxiety reflects driving behaviours and thoughts. Both state and trait anxiety were measured, alongside responses from the Driving Cognitions Questionnaire (DCQ), Driving Behaviour Survey (DBS), and ratings of anxiety and avoidance on a series of driving situations that have been established as anxiety-inducing in the literature. The findings of these provided methodological implications for use of the DCQ and DBS in a non-clinical sample, and also suggest that whilst driving anxiety is an overall strong predictor of anxiety related thoughts and behaviours, there are instances where trait anxiety provides an additional, substantial influence on similar behaviours.

Findings regarding the relationships between anxiety and overall responses provide practical implications regarding the types of training that should be prioritised for those with different types of anxiety. For those who show greater levels of driving anxiety, a wide range of

training methods may be able to reduce levels of anxiety. However, those with higher levels of trait anxiety may benefit more from more specific training programs. For example, as trait anxiety was a strong predictor of social concerns on the DCQ, it may be beneficial to focus on challenging the driver's thoughts about how others perceive them. This in turn may help to reduce levels of worrisome thoughts whilst driving, which in turn may reduce the frequency of self-reported attention-based performance deficits. Theoretically, the fact that trait anxiety was a predictor of attention-based performance deficits but not exaggerated safety-cautious behaviours suggests that any behavioural changes as a function of trait anxiety may be due to poorer levels of attentional control. Whilst Chapter 8 did not find any differences in driving behaviour as a function of trait anxiety, the findings from Chapter 2 may highlight what could happen if someone with higher trait anxiety levels was not able to effectively maintain attentional control in a driving situation.

The results from the DCQ and DBS subscales give practical implications as to how therapeutic interventions may wish to reduce levels of anxiety. However, findings from ratings of anxiety and avoidance provide implications as to where these interventions may need to take place. Again, those with greater levels of driving anxiety would benefit from an overall training program across different anxiety-inducing situations. For those with higher levels of trait anxiety, however, particular focus could be made on situations such as night-time and residential driving. Exposure therapy within the former of these two contexts may be particularly important, as trait anxiety was also a strong predictor of avoiding night-time driving. Whilst night-time driver training is offered as part of the UK's Pass Plus scheme, this is often targeted at younger and more inexperienced drivers in order to improve their skills. As the current findings are based on a sample from a wider age and experience range, this implies that such interventions should also target those who have higher levels of anxiety.

This may alleviate negative feelings, and potentially reduce the rate of dangerous driving behaviours as a result.

Whilst the findings from Chapter 2 provide several practical applications, it is acknowledged that they are based on self-reported data. As previously discussed, there are several examples in which the implications of dangerous driver behaviour as a function of self-reported anxiety have not been reflected in conclusive behavioural data. The aim of the subsequent chapters was to use findings from both behavioural and autonomic data to provide a more detailed explanation of what changes occur as a function of both trait and state anxiety.

### 9.3 Chapter Three

The aim of the study conducted in Chapter 3 was to assess whether participants with differing levels of trait anxiety would have differential reactions to driving clips with varying levels of associated arousal. This idea was based on the possibility that fear and anxiety could be seen as influencing bottom-up and top-down processes respectively. Participants watched clips which were uneventful, contained a hazard or contained a crash. Whilst watching, they had to continuously rate the degree of fear they would feel as the driver of the car. Additional autonomic and self-report measures were taken to assess any effects of trait anxiety or clip type on internal processes and self-perceptions of feelings and coping strategies whilst driving. Findings suggested that clips with increasing levels of threat increased reported feelings of fear across time, and this was accompanied by similar increases in skin conductance. Additionally, whilst most findings were not affected by trait anxiety, it strongly predicted negative feelings and maladaptive coping strategies.

The finding that skin conductance responses were associated with increases in fear perception is consistent with the notion of skin conductance as a somatic marker. The somatic marker hypothesis (Damasio, 1996) argues that making decisions on a purely rational basis is time-consuming, and autonomic feedback could increase the speed at which such decisions are made. Hence, decisions on risk can be processed as a feeling rather than a rational analysis (Slovic & Peters, 2006). Support for the use of skin conductance as a somatic marker during driving has been found in studies focusing on experience; both police drivers and generally more experienced drivers produce a greater number of skin conductance responses than less experienced drivers, despite having similar cognitive evaluations of risk perception (Crundall et al., 2003; Kinnear et al., 2013). Recent models of driver behaviour, such as the Risk Allostasis Theory (Fuller, 2011) already emphasise that feedback loops are constantly used during driving to inform of risk and guide decisions. On the basis that skin conductance increased with increasing levels of threat, it could be argued that it is acting as a somatic marker for risk perception; however, fear is also a correlate of risk perception (Schmidt-Daffy, 2013), and the similar pattern of perceived fear and skin conductance in Chapter 3 could indicate that skin conductance also acts as a somatic marker for fear perception.

Trait anxiety was also a significant predictor of some of the Driver Stress Inventory and Driver Coping Questionnaire (Matthews et al., 1997) subscales. Whilst it was a positive predictor of adaptive coping strategies such as task focus and reappraisal, it was also a strong positive predictor of levels of dislike of driving and a use of emotion-focused coping. A relationship between dislike of driving and emotionally-focused coping has previously been found in the literature (Kontogiannis, 2006). However, based on simulator research it is difficult to establish whether higher levels of these two traits will reflect a more dangerous driving style. Some of the research attributes a dislike of driving to a more cautious driving

style (Matthews et al., 1998), and a recent simulator study found that a greater dislike of driving was associated with a greater likelihood of staying behind slow moving vehicles, as well as a greater distance from the lead car when eventually overtaking (Emo, Matthews, & Funke, 2016). Whilst the authors of the latter study concluded that this was indicative of a more cautious driving style, they also found that dislike of driving predicted a shorter distance between the driver and the oncoming car when commencing the overtake, which could be seen as dangerous. Additionally, a greater dislike of driving has been associated with a greater number of reported accidents (Öz et al., 2010).

Emotionally-focused coping is a pessimistic appraisal strategy that is associated with anxiety in the general emotion literature (Bennett, Lowe, & Honey, 2003), and in the driving literature it has been argued to generate a negative mood state that results in a preoccupation with worry that interferes with task performance (Susilowati & Yasukouchi, 2012). Therefore levels of emotionally-focused coping could result in increased worry which takes up attentional resources; the use of this coping strategy could explain the relationship between trait anxiety and anxiety-based performance deficits described in Chapter 2, and could also explain differences in processing efficiency in Chapter 8. This provides useful implications regarding therapies and training interventions; those with higher levels of trait anxiety could be taught to place more emphasis on effective coping strategies such as task focus and reappraisal, which in turn could free up attentional resources that are important for driving.

### 9.4 Chapter Four

Chapter 4 argued that trait anxiety could have more of a substantial effect on thought-related processes, such as perceptions of driving capability. Participants watched the same clips as

those from Chapter 3, and answered a series of questions based on the Task Capability Interface model (Fuller, 2005). Additionally, participants were asked to rate themselves, as well as average and very good drivers, on a series of capability scales (McCormick et al., 1986). Results suggested that whilst all drivers showed evidence of an overall self-enhancement bias, and all drivers provided similar ratings of capability for driving clips, there were some effects of trait anxiety. Specifically, there was a relationship between trait anxiety and the differences in ratings between selves and very good drivers on the 'state' scale, and there was an overall negative relationship between trait anxiety and HF-HRV.

The negative association between trait anxiety and HF-HRV provides support for the Polyvagal Theory (Porges, 2007), which suggests that a higher level of HF-HRV is indicative of an increased ability to regulate emotions. Previous research has consistently supported this notion (Dimitriev & Saperova, 2012; Miu et al., 2009), and has argued that a limited amount of emotion regulation strategies may make a unique contribution to this link (Gerardo et al., 2016). However, the current studies also suggest that this reduction in HF-HRV may also be associated with a conscious awareness of a poorer ability to regulate emotions whilst driving. This is due to the fact that participants with a higher level of trait anxiety were more likely to have greater differences between themselves and very good drivers on the 'state' part of the McCormick (1986) scale. This awareness of a poorer ability to stay calm on the roads could be due to a conscious use of coping strategies such as blaming themselves for being too upset whilst driving, or worrying about their own shortcomings. This suggestion could be supported from the results from Chapter 3, which suggest that trait anxiety is a strong, positive predictor of emotionally-focused coping strategies. Nonetheless, the findings from Chapter 4 indicate that cardiovascular measures of emotional regulation, with regard to trait anxiety, may be associated with self-reported awareness of poorer regulation abilities.

## 9.5 Chapters Six and Seven

Chapters 6 and 7 aimed to explore the effects of manipulating state anxiety on driving behaviours and autonomic activity. In Chapter 6, participants were given instructions related to safety regulations within the simulator. Whilst these instructions increased anxiety compared to a control group, it did not have any impact on behavioural or autonomic variables. In Chapter 7, the instructions were altered to make them more ego-threatening, based on the methods used in previous research. However, these instructions were not successful in increasing levels of state anxiety. When spontaneous increases and decreases in state anxiety were considered, however, it was suggested that increases in state anxiety were associated with changes in perceived mental workload, changes in skin conductance levels, and changes in SDLP under visually complex conditions.

The first issue to consider is the differing effects of instructional sets, and their influences on anxiety levels. Instructions that were deemed to be more focused on ego-threat, which have been consistently successful in manipulating anxiety in previous research, were not effective in Chapter 7. However, using a safety-related instructional set was successful in Chapter 6. This may be due to the difference in simulators used across the studies. Because NITES 1 is a high fidelity simulator based on a motion platform, it may be perceived by the participant as more technologically advanced, therefore they may already have a perception that there is a real threat of an emergency occurring, which is reinforced in the experimental group's instructional set. This provides one methodological implication regarding anxiety-inducing instructional sets; it is possible that instructional sets aiming to increase state anxiety may only need to be relevant to the task in question in order to achieve the desired effect.

Alternatively, these findings may raise the question of whether instructional sets necessarily need to be relevant to the task in question in order to alter anxiety levels and subsequently alter driver behaviours. Ideally, to answer this question research would compare driving and control instructional sets within the same driving environment, in order to assess behavioural changes and answer this research question. This would allow the study to control for potential effects of simulator fidelity. However, based on a combination of previous research and the current findings, it could be argued that instructions need not necessarily be relevant. For example, whilst the driving-related instructions in Chapter 6 were sufficient in increasing levels of state anxiety, in Chapter 7, this effect was not present. Additionally, in the literature, instructions that have not been relevant to driving have still resulted in changes in anxiety and subsequent driving behaviours (Morton & White, 2013).

Additionally, the participants in this research may have perceived the instructions as irrelevant to themselves. Due to a lack of experience or driving frequency for example, participants may have accepted the fact that they may not be highly ranked in comparsion to other participants, and as a result may have perceived the instructions as irrelevant to themselves. Instructions associated with driving were used in this research to be relevant to the task in question, and correspond with some of the instructions provided in previous research; however, the findings invite future research to compare relevant and irrelevant instruction sets in driving compared to control tasks.

In studies with medium levels of simulator fidelity, such as the study presented in Chapter 7, ego-threatening instructions are often used. However, unlike Chapter 7, the previous literature has consistently found increases in state anxiety when using such instructional sets. The main difference between the previous literature and the study presented in Chapter 7 is

the additional use of a motivational instructional set, such as a cash prize. This provides a second methodological implication regarding instructional sets. It implies that studies that include an additional motivational instruction may be particularly important in increasing levels of state anxiety. It may also be possible that they are important in modifying behaviours. For example in Chapter 6, an increase in state anxiety was found without any associated behavioural changes. The use of an additional motivational set may have also modified behaviours in this case. As discussed in Chapter 7, future research may wish to investigate the effects of adding motivational instructions, and potentially compare this effect across ego-threatening and non-ego-threatening instructions.

Alternatively, the findings from Chapters 6 and 7 imply that demands of the driving task may be important in determining changes in behaviour as a function of anxiety. Motorway driving can be seen as a monotonous task, and is statistically one of the safer types of roads to drive on (Driver and Vehicle Standards Agency, 2014). This would explain the lack of behavioural effects observed in Chapter 6. When levels of environmental complexity and vehicle handling were considered in Chapter 7, a positive association between state anxiety changes and SDLP were observed. This may generally imply that changes in emotional state may be associated with changes in driving skill, but only in specific contexts. Further research investigating additional types of demand may allow us to identify if other specific driving behaviours may be affected with increases in demand. This in turn may provide recommendations regarding intervention strategies, in that specific behaviours could be trained in certain circumstances. For example, based on the current findings, those providing interventions to anxious drivers may wish to focus on the driver's lane-keeping skills when traffic levels are heavier.

In Chapter 7, significant three-way interactions were found between state anxiety changes, environmental complexity and vehicle handling for levels of mental workload and skin conductance. Increases in state anxiety were associated with higher levels of mental workload when the task included at least one level of demand. There was also a positive association between state anxiety changes and skin conductance levels when at least one type of demand was high, but when both environmental complexity and vehicle handling levels were high, increases in state anxiety were associated with decreases in skin conductance. Whilst it does not imply a direct relationship, they could reflect an inverted U-shaped relationship between levels of perceived difficulty and levels of levels of mental effort invested in the task.

This is similar to Hebb's theory of arousal and performance, which suggests that optimal levels of performance are found when arousal on a task is moderate, and suboptimal when arousal levels are too low or high (Hebb, 1955). In the context of the findings from Chapter 7, this suggests that at low levels of demand, minimal amounts of mental effort are required to complete the driving task, hence there is no observable relationship between state anxiety changes and levels of mental workload or skin conductance. When only visual complexity or vehicle handling levels were high, there were positive associations between state anxiety, and both mental workload and skin conductance levels. This implies that those who show greater increases in state anxiety are more aware of how difficult they perceive the task, and this is accompanied by an increased autonomic response to invest more mental effort into the task, which may be beneficial to someone who is anxious whilst driving. However, when both visual complexity and vehicle demanding become high, the positive association between state anxiety and mental workload is also associated with lower levels of skin conductance. This may imply that whilst those with higher changes in anxiety are more aware that the task is difficult, they show a poorer ability to invest levels of mental effort into the task, as indicated

by autonomic changes. Overall, this implies that those with bigger increases in anxiety show an inverted U-shaped pattern of autonomic activity according to levels of task difficulty. However, whilst this implies a poorer ability to invest mental effort, this is not accompanied by changes in driving behaviour; this could suggest that additional working memory resources are being used to perform the driving task to a similar level. However, as no measures of processing efficiency were recorded in Chapter 7, this is a purely speculative suggestion.

From a practical perspective, the current findings may also provide justification for the use of relaxation or acclimatisation to driving conditions with varying levels of demand. It has already been suggested in state anxiety research that professional bodies may wish to consider the use of relaxation techniques for those experiencing high levels of anxiety whilst driving (Fairclough et al., 2006). The cumulative findings of behavioural changes with increased visual complexity highlight the potential for dangerous driving behaviour as a function of increased anxiety, and changes in skin conductance suggest that increased levels of state anxiety decrease the levels of invested mental effort into the task. Whilst not found in Chapter 7, this could eventually lead to changes in behaviour or attention that subsequently lead to an accident. Therefore the use of relaxation techniques could reverse these detriments in driving skill and autonomic changes, leading to overall safer driving behaviour.

### 9.6 Chapter Eight

The aim of the study conducted in Chapter 8 was to explore the implication that anxiety may be affecting levels of processing efficiency, rather than performance effectiveness. This could potentially explain why some of the literature on anxiety's relationship with driving,

particularly trait anxiety, may be unconsidered. The effects of trait anxiety on processing efficiency were measured using functional near infra-red spectroscopy (fNIRS), an emerging neuroimaging technique that measures levels of oxygenated (HbO) and deoxygenated (HbR) haemoglobin.

This study showed that whilst trait anxiety did not affect overall levels of performance, as measured by driving behaviour and overall randomness scores, it did reduce levels of processing efficiency. This was due to the fact that participants were less efficient in specific random number generation techniques, and showed over or under-recruitment of the PFC, depending on the levels of central executive demand required. Overall, this provides support for theories such as Processing Efficiency Theory (PET- Eysenck & Calvo, 1992) and Attentional Control Theory, and supports previous suggestions that a lack of behavioural differences in drivers with different levels of anxiety may be due to an increased amount of invested effort (Taylor et al., 2008).

However, what is interesting about this suggestion is that there were no significant interactions between trait anxiety and levels of self-reported effort, according to the NASA-TLX scores. It is possible that the additional effort invested in a more demanding task is performed unconsciously. This could explain the differences between performance scores and any changes on perceived mental workload. Because those with higher levels of anxiety may have been investing additional effort in the driving task when additional demands were placed on them, they were less likely to believe they had 'failed' the task itself. Additionally, when the driving task was particularly demanding, the additional effort invested resulted in a lower likelihood of perceiving the task as mentally demanding. Therefore, this suggests that whilst levels of increased effort may not have been explicitly found, the effects of

unconsciously increased mental effort may be reflected in a decrease in self-reported difficulty, as measured by performance and mental workload scores.

Nonetheless, the results provided suggest support for the assumptions made by PET and ACT, and provide two main practical applications within the field of driving. Firstly, whilst it has been emphasised in previous sections that exposure therapy and training may be useful in reducing anxiety, for those with high trait anxiety, training that particularly focuses on improving attentional control or working memory skills may be useful. This becomes important as PET suggests that is sufficient working memory resources are not available to complete a task, performance effectiveness as well as processing efficiency may be affected. Additionally, Chapter 2 highlighted how trait anxiety is a significant predictor of self-reported anxiety-based performance deficits, and previous literature suggests that poorer levels of attentional control are associated with an increased amount of self-reported errors and lapses (Wong et al., 2015). Previously implemented programs have been found to be effective in adolescents, who show increased levels of inhibitory control after completing a working memory training program (Hadwin & Richards, 2016). By using similar methods in the field of driving, this may improve levels of processing efficiency. The effectiveness of such interventions could be measured by comparing levels of anxiety-based performance deficits, or levels of activation in the PFC, before and after training.

Secondly, the study presented in Chapter 8 highlights the usefulness of fNIRS as a technique within the field of driving simulation. It is acknowledged that previous fMRI research has provided evidence of cortical and sub-cortical activity of several areas of the brain, including frontal, parietal and motor regions (Bernardi et al., 2014; Chung et al., 2014). However, fMRI has a practical limitation, in that the way in which fMRI data is collected means that the

degree of control that is usually required in natural driving is often compromised. The nature of lying down within a scanner and remaining as still as possible is substantially different to being in a driver's seat and maintaining control of the car. Because of these requirements, driving 'tasks' in fMRI studies are often passive (Chung et al., 2014; Graydon et al., 2004). Similarly, their findings may be difficult to translate to real-world driving behaviours due to limited head movements in driving situations which require an increase in head movements, such as turning at a junction (Schweizer et al., 2013). Whilst methods such as magnetoencephalography have been recently used, and arguably provide good spatial and temporal resolution, combined simulator and MEG scanners are expensive and require a lot of adaptation of existing simulator software packages, and they also still require the participant to provide minimal head movements (Bowyer et al., 2009; Fort et al., 2010).

In contrast, fNIRS can be seen as a more desirable neuroimaging method in the field of driving for several reasons. Whilst the aforementioned methods are non-invasive, fNIRS has the additional advantage of being a safe and portable technique that allows for larger body movements. The portability of the fNIRS device is highlighted in the fact that it has been used across both simulator (Foy et al., 2016; Oka et al., 2015) and on-road research (Yoshino, Oka, Yamamoto, Takahashi, & Kato, 2013a, 2013b). Additionally, it provides improved temporal resolution compared to fMRI, and improved spatial resolution compared to methods such as EEG (Nishiyori, 2016). Overall, this implies that the method is particularly useful when studying the neural processes behind driver behaviour. Whilst its spatial resolution may not be as high as fMRI, fNIRS is still able to localise activity to specific cortical areas, and the findings from Chapter 8 highlight how findings from fNIRS data can be used to provide support for well-established theories such as PET and ACT.

## 9.7 General comments

As well as some of the implications already suggested, general implications can be made based on the information gathered across all of the discussed studies. One common finding was that anxiety, in both state and trait forms, was associated with increased levels of anger and aggression. The exception to this would be Chapter 3, where trait anxiety was not found to be a significant predictor of aggression or confrontive coping responses. It is possible that participants in this study were responding to items on the questionnaire based on social desirability; for example, on the Driver Coping Questionnaire, the average confrontive coping score was 22.4, whilst the average score for task focusing was 75.8. These scores could indicate that participants wanted to seem more socially desirable by giving the impression they were safe, cautious drivers that were less prone to aggressive responses. Whilst this highlights one of the issues that can arise when collecting self-reported data, the overall suggestion from the thesis is that those who are more anxious are more likely to show frustration and report producing aggressive responses. As noted throughout each chapter, these findings add to the previous literature suggesting that anxiety is associated with anger and aggressive behaviours (Deffenbacher et al., 2000; Lucidi et al., 2010). As those who report higher driving anger also report less safe driving behaviours (Deffenbacher et al., 2003), future interventions may wish to consider training those with anxiety to reduce any feeling of anger, which may in turn increase on-road safety.

Another implication that can be made from the current results is that both state and trait anxiety both affect the driving experience, but in different ways. State anxiety affected self-reported responses of avoidance and anxious reactions in Chapter 2, as well as behavioural and autonomic responses in Chapter 7. Trait anxiety, on the other hand, did not have any effects on behavioural responses, but did affect levels of cardiovascular activity in Chapter 4,

and levels of PFC activity in Chapter 8, as well as self-reported driving thoughts throughout the thesis. It could be suggested, on this basis, that state anxiety may have a more direct and immediate effect on driving behaviours and autonomic responses associated with sympathetic activity such as skin conductance. Trait anxiety, on the other hand, may have a more direct effect on the worrisome thought processes associated with driving, and subsequent levels of emotional regulation and processing efficiency, as measured by levels of HF-HRV and PFC activity. This may explain why some of the previous literature has found mixed conclusions regarding trait anxiety's direct effects on driving behaviour; future research may wish to focus on the attentional and processing resources required in order to find significant effects of trait anxiety. This does not mean, however, that trait anxiety would not have an eventual effect on driving behaviour. It is possible that due to a limitation in processing resources, higher levels of trait anxiety could eventually result in some of the attentional-based performance deficits described in Chapter 2.

## 9.8 General limitations

Whilst the findings present some interesting theoretical and practical implications, there are some general limitations of the research that can be applied across the thesis. Firstly, for theoretical reasons, either state or trait anxiety alone was chosen for the focus of each study. For example, ego-threatening instructions have been consistently associated with increases in state anxiety, hence there was a focus on state anxiety in Chapters 6 and 7. Theories such as PET and ACT, however, have been implicated in those with higher levels of trait anxiety, hence trait anxiety was chosen as the focus of Chapter 8. However, despite a lack of interaction between state and trait anxiety in Chapter 6, the possibility of interaction between the two is not ruled out. As noted in Chapter 8, studies investigating the effects of trait

anxiety on processing efficiency have found interactive effects of state (Edwards et al., 2015; Edwards et al., 2016). Future driving research may wish to consider this issue, particularly when null or mixed conclusions are found.

Another issue that is acknowledged is the use of the STAI throughout the majority of the thesis. A noted in Chapter 1, the STAI has been criticised for potentially having low levels of validity, and additional factors such as depression are often found when measuring the questionnaire's validity (Andrade et al., 2001; Bados et al., 2010). The STAI was chosen as the main measure of anxiety throughout the thesis based on the fact that it is one of the most widely used anxiety inventories in research. However, considering its issues with validity, it may have also been useful to include a depression inventory, in order to control for additional types of negative affect. Whilst it could be recommended to use a questionnaire more closely related to the construct of anxiety, such as the STICSA, some of these are also argued to relate to depression, due to a shared component of negative affect (Clark & Watson, 1991). If a purer inventory of anxiety is not available, then future research may wish to consider screening and controlling for additional types of negative affect such as depression.

There are issues with the samples used in the research. Through chapters 3, 4, 6, 7, and 8, the majority of participants were young, female undergraduate students. It is acknowledged that females in particular are prone to expressing a more anxious driving style (Gwyther & Holland, 2012), and additional factors such as youth and a lack of experience may have had an additional effect on some of the reported anxiety levels. Whilst the questionnaire study conducted in Chapter 2 could be argued to be a more representative sample due to the wide range of both age and experience in respondents, there are some justifications for questioning how well the sample represents the general population. Firstly, there was again a larger

proportion of females, which contrasts with the suggestion that a greater proportion of males hold a UK driving licence (Department for Transport, 2015a). Secondly, the average annual mileage was higher across all genders and age groups when compared with national statistics (Department for Transport, 2015b). Thus, whilst the sample of participants were convenient for the current research, future studies may wish to consider recruiting samples which may be more representative of the population. This may be achieved by recruiting more males or expanding the age and experience range of participants.

There are also methodological issues to consider regarding the collection of data related to both anxiety and physiological measures. Firstly, it is possible for physiological measures to be affected by driving fatigue levels. Whilst the effects of fatigue on skin conductance have not been as extensively researched, electrical measures such as skin resistance have shown increases over time which have been attributed to fatigue levels (Dureman & Boden, 1972). Recent preliminary research has also attempted to use skin conductance measures as an indicator of fatigue (Bundele & Banerjee, 2009). Changes in cardiovascular measures such as heart rate have also increased over time (Apparies et al., 1998), and whilst it has previously been implied that this effect is due to an increase in workload, there may also be reason to suggest that fatigue levels increased over time, and subsequently increased levels of heart rate. Moreover, a recent review of the effects of fatigue on psychophysiological measures has suggested that negative mood states such as anxiety may influence driving fatigue (Lal & Craig, 2001). Therefore, not only is there justification for considering levels of fatigue in future driving psychophysiology research, but it is also possible to suggest that levels of anxiety may have affected levels of fatigue, and this anxiety-induced fatigue may have had adverse effects on physiological responses in the current research. For example, the study discussed in Chapter 3 found a positive association between trait anxiety and levels of

fatigue; however it is also worth noting that no significant effects of anxiety were found on physiological responses, making the speculation of anxiety and fatigue effects more tentative.

It is also possible that self-reports may have been subject to social desirability biases. As discussed in Section 9.7, for example, it is acknowledged that participants were responding to items on the Driver Coping Questionnaire with high hazard monitoring and low aggression scores in order to be seen as a safer driver to the researcher. An additional source of social desirability bias that perhaps received less consideration was through the use of debriefing at the end of each study. Despite full debriefings at the end of each study and the use of a mood repair method in Chapter 7, participants may have verbally reported feeling less anxious despite this not being the case. This may have been in order to be seen as able to cope with the demands of experiment participation. This overall provides methodological and ethical implications. It is implied that much more stringent measures may need to be taken in order to ensure participants leave the study in the same state they arrived in. This can be done, for example, through additional anxiety questionnaires, or through more extensive debriefing. However, the use of these self-report methods may still be subject to social desirability biases.

The use of advanced technological equipment could have also had an impact on levels of anxiety. Prior to placing the equipment on, participants were informed of what each piece of equipment would do, and were instructed to inform the researcher if they felt uncomfortable with any of the equipment being used. Whilst this was perceived as appropriate at the time, and no participants reported being uncomfortable with the equipment, it is acknowledged these responses may have been due to social desirability effects. In turn, any associated anxiety with having the equipment on may have contributed towards what is known as a

'white coat effect'. Commonly discussed in the clinical and blood pressure literature, the white coat effect refers to a phenomenon in which patients exhibit a blood pressure level above the normally expected range in a clinical setting, but not other settings such as at home or in an office (Tsai, 2002). Moreover, it has been shown to have positive associations with anxiety (Jhalani et al., 2005), and females are more likely to show signs of the white coat effect (Myers & Reeves, 1995). Whilst the phenomenon has not been explored within other domains, it is entirely possible that any unreported symptoms of anxiety regarding wearing the equipment may have potentially altered physiological readings. Therefore, future researchers may wish to administer additional anxiety questionnaires after placing equipment on participants, to ensure that it has not unexpectedly increased levels of anxiety. Again, however, this could still be subject to social desirability biases.

## 9.9 The future of driving anxiety research and practice

The general consensus based on the practical implications discussed is that exposure therapy would be beneficial for those with higher levels of both state and trait anxiety. Such exposure therapy may help to alleviate previous memory structures that may be seen as anxiety-provoking (Foa & Kozak, 1986). Additionally, it would be a suitable alternative to current treatments for anxiety such as medication, the side effects of which can induce dangerous driving behaviours (Daurat et al., 2013; Takahashi et al., 2010). However, if anxiety is suggested to make someone a more dangerous driver due to their behaviours or thought-related processes, then it may be more desirable to implement such therapy in a safe and more controlled environment in comparison to real roads. A small body of research has investigated the effects of using Virtual Reality Exposure Therapy (VRET) to reduce feelings of anxiety in those with clinically diagnosed driving phobia. VRET is similar to simulator

research in that a safe and simulated driving environment is provided in order for the driver to practise their skills and expose themselves to situations they would typically feel anxious in.

The research conducted into VRET so far has suggested that therapy can be effective even at lower levels of simulator fidelity. One case study, for example, included a female with driving phobia who completed a course of therapy in a simulated environment with $30^{o}$ horizontal field of view and basic car components (Wald & Taylor, 2000). She was gradually exposed to different driving environments which had previously been ranked from least to most anxiety inducing, and reported lower levels of both driving anxiety and avoidance after intervention. Whilst this provides promising evidence of the use of VRET, it has been noted that levels of immersion may be particularly important in order to be effective. Research has shown that not all participants given the opportunity to complete such interventions feel completely immersed within the virtual environment (Wald & Taylor, 2003; Walshe, Lewis, O'Sullivan, & Kim, 2005), and particular recommendations have been made to reduce any distractions from the environment which may reduce feelings of immersion (Wiederhold & Wiederhold, 2010). Additional findings have also suggested that a reduction in self-reported driving anxiety does not always result in an increase in driving frequency (Wald & Taylor, 2003). Along with the potential costs of running a simulated exposure therapy and current limited availability within the clinical population, this has led to suggestions that it may be just as useful as an initial part of an intervention, which takes place before a driver is then exposed to real roads (Costa, Carvalho, & Nardi, 2010).

Whilst previous research has focused on those with a history of clinically diagnosed driving phobia, the current research indicates that this may also be useful for drivers who show high state anxiety, or those who are generally anxious. It may therefore be particularly beneficial

for future research to pilot intervention programs within simulated environments. Based on the type of anxiety in question, different methods of intervention may also be beneficial. For example, the results of Chapter 2 indicate that those with higher levels of driving anxiety may benefit from exposure to driving environments known in the literature to induce anxiety. Those who generally experience high levels of state anxiety may also benefit from using relaxation methods prior to, or during, driving in environments with greater levels of demand. Finally, those with higher levels of trait anxiety may benefit from training to reduce worrisome thoughts and improve processing efficiency, before assessing whether this improves driving behaviours that may arise as a result of poor attentional control such as lane drifting.

From the simulator research conducted in the thesis, recommendations can be made on the practicalities on simulator-based exposure therapy. Whilst it is acknowledged that simulator sickness does occur, dropout rates were an average of 15% across the thesis's studies. This is a low dropout rate, meaning that intervention programs could be made with minimal concern for simulator sickness. However, dropout rates were lowest in Chapter 6 (at 7%), which used a high fidelity simulator. There could be two reasons for this. Firstly, the physical fidelity of the simulator may have increased feelings of immersion and reduced feelings of sickness. Whilst NITES 1 does contain 360$^{o}$of visual field and also has a motion base, the study discussed in Chapter six only used 180$^{o}$of vision and did not use motion, meaning that changes in visual or motion feedback could not explain differences in sickness rates between NITES 1 and 2. In this case, simulators may wish to create a simulator with higher physical fidelity in order to increase feelings of immersion and reduce sickness levels. Alternatively, some of the scenarios described in Chapters 7 and 8 required participants to make a series of turns at junctions. This resulted in dropout rates of 17% and 20% respectively. Therefore,

when creating scenarios to expose drivers to stressful situations, a minimal amount of turns may also be recommended.

Finally, researchers wishing to test the efficacy of intervention programs should take additional care when measuring physiological data. Because drivers are required to use their hands to move the steering wheel, this results in a much greater likelihood of finding motion artefacts. In order to minimise this effect, researchers should either be vigilant in detecting motion artefacts when collecting data from the fingertips, or attempt to take recording from alternative places on the body. For example, Chapters 7 and 8 both measured heart rate; Chapter 7 measured it using fingertip-based PPG, whilst Chapter 8 measured it using an ear clip-based PPG recorder. The latter of these methods resulted in a greater retention of data.

## 9.10 Conclusions

The aim of the thesis was to contribute to the literature on anxiety and driving by exploring the effects of state and trait anxiety on driving behaviours and reactions. An additional focus was given to autonomic reactions, which may provide additional information as to which processes are affected by different types of anxiety. Previous research has focused primarily on those with driving phobia or anxiety due to motor vehicle crashes, whilst little has previously been known about those who are generally fearful or anxious (Taylor, Deane, & Podd, 2007a). Using a series of self-report, laboratory and simulator studies, possible distinctions were made regarding the effects of state and trait anxiety. Whilst state anxiety was more likely to reflect changes in driving behaviours and autonomic reactions that reflect sympathetic activity, trait anxiety had more of an influence on worrisome thoughts, processing efficiency and vagal activity that reflects emotional regulation. These findings not

only provide support for previously established theories, they also translate into practical applications. Overall support is found for the use of interventions and exposure therapies, and findings from each specific chapter argue that this could be tailored depending on the type of anxiety in question. Such interventions could be piloted in virtual environments, which may provide a safer alternative compared to initial exposure therapy on roads. It is possible that if such research were to be conducted in future, this may lead to a more enjoyable driving experience for those with anxiety, as well as a reduction in dangerous behaviours and potential on-road accidents.

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## Appendices

Appendix A: State Trait Inventory for Cognitive and Somatic Anxiety (STICSA- Ree, French, MacLeod, & Locke, 2008)

### STICSA: Your mood at this moment.

Below is a list of statements which can be used to describe how people feel. Beside each statement are four numbers which indicate the degree with which each statement is self-descriptive of mood (1= *not at all*, 4=*very much*). Please read each statement carefully and mark the number which best indicates how you typically feel right now, at this very moment, even if this is not how you usually feel.

Please choose the appropriate response for each item:

| | 1- Not at all | 2- A little | 3- Moderately | 4- Very much so |
|---|---|---|---|---|
| My heart beats fast | ○ | ○ | ○ | ○ |
| My muscles are tense | ○ | ○ | ○ | ○ |
| I feel agonised over my problems | ○ | ○ | ○ | ○ |
| I think that others won't approve of me | ○ | ○ | ○ | ○ |
| I feel like I'm missing out on things because I can't make up my mind soon enough | ○ | ○ | ○ | ○ |
| I feel dizzy | ○ | ○ | ○ | ○ |
| My muscles feel weak | ○ | ○ | ○ | ○ |
| I feel trembly and shaky | ○ | ○ | ○ | ○ |
| I picture some future misfortune | ○ | ○ | ○ | ○ |
| I can't get some thought out of my mind | ○ | ○ | ○ | ○ |
| I have trouble remembering things | ○ | ○ | ○ | ○ |
| My face feels hot | ○ | ○ | ○ | ○ |

| | | | | |
|---|---|---|---|---|
| I think that the worst will happen | ○ | ○ | ○ | ○ |
| My arms and legs feel stiff | ○ | ○ | ○ | ○ |
| My throat feels dry | ○ | ○ | ○ | ○ |
| I keep busy to avoid uncomfortable thoughts | ○ | ○ | ○ | ○ |
| I cannot concentrate without irrelevant thoughts occurring | ○ | ○ | ○ | ○ |
| My breathing is fast and shallow | ○ | ○ | ○ | ○ |
| I worry that I cannot control my thoughts as well as I would like to | ○ | ○ | ○ | ○ |
| I have butterflies in the stomach | ○ | ○ | ○ | ○ |
| My palms feel clammy | ○ | ○ | ○ | |

## State-Trait Inventory for Cognitive and Somatic Anxiety: Your General Mood State

Below is a list of statements which can be used to describe how people feel. Beside each statement are four numbers which indicate how often each statement is true of you (e.g. 1= *not at all*, 4= *very much so*). Please read each statement carefully and mark the number which best indicates how often, in general, the statement is true of you.

Please choose the appropriate response for each item:

| | 1- Not at all | 2- A little | 3- Moderately | 4- Very much so |
|---|---|---|---|---|
| My heart beats fast | ○ | ○ | ○ | ○ |
| My muscles are tense | ○ | ○ | ○ | ○ |
| I feel agonised over my problems | ○ | ○ | ○ | ○ |
| I think that others won't approve of me | ○ | ○ | ○ | ○ |
| I feel like I'm missing out on things because I can't make up my mind soon enough | ○ | ○ | ○ | ○ |
| I feel dizzy | ○ | ○ | ○ | ○ |
| My muscles feel weak | ○ | ○ | ○ | ○ |
| I feel trembly and shaky | ○ | ○ | ○ | ○ |
| I picture some future misfortune | ○ | ○ | ○ | ○ |
| I can't get some thought out of my mind | ○ | ○ | ○ | ○ |
| I have trouble remembering things | ○ | ○ | ○ | ○ |
| My face feels hot | ○ | ○ | ○ | ○ |
| I think that the worst will happen | ○ | ○ | ○ | ○ |
| My arms and legs feel stiff | ○ | ○ | ○ | ○ |

| | | | | |
|---|---|---|---|---|
| My throat feels dry | ○ | ○ | ○ | ○ |
| I keep busy to avoid uncomfortable thoughts | ○ | ○ | ○ | ○ |
| I cannot concentrate without irrelevant thoughts intruding | ○ | ○ | ○ | ○ |
| My breathing is fast and shallow | ○ | ○ | ○ | ○ |
| I worry that I cannot control my thoughts as well as I would like to | ○ | ○ | ○ | ○ |
| I have butterflies in the stomach | ○ | ○ | ○ | ○ |
| My palms feel clammy | ○ | ○ | ○ | |

Appendix B: Driving Cognitions Questionnaire (DCQ- Ehlers et al., 2007)

**Driving Cognitions Questionnaire (DCQ)**

ID: _____ INITIALS: _____ DATE: _____

Below are some thoughts or ideas that may pass through your mind when you are driving. Please indicate ***how often*** each thought occurs when you are driving. Please circle the appropriate number using a scale from 0 to 4 as described below.

0 The thought never occurs.
1 The thought rarely occurs.
2 The thought occurs during half of the times I drive.
3 The thought usually occurs.
4 The thought always occurs when I am driving.

| | Never | Rarely | Half the time | Usually | Always |
|---|---|---|---|---|---|
| 1. I will not be able to react fast enough | 0 | 1 | 2 | 3 | 4 |
| 2. People I care about will criticize me | 0 | 1 | 2 | 3 | 4 |
| 3. I will be unable to catch my breath | 0 | 1 | 2 | 3 | 4 |
| 4. I cannot control whether other cars will hit me | 0 | 1 | 2 | 3 | 4 |
| 5. Other people will notice that I am anxious | 0 | 1 | 2 | 3 | 4 |
| 6. I will tremble and not be able to steer | 0 | 1 | 2 | 3 | 4 |
| 7. I will be injured | 0 | 1 | 2 | 3 | 4 |
| 8. People will think I am a bad driver | 0 | 1 | 2 | 3 | 4 |
| 9. I will injure someone | 0 | 1 | 2 | 3 | 4 |
| 10. I will not be able to think clearly | 0 | 1 | 2 | 3 | 4 |
| 11. I will die in an accident | 0 | 1 | 2 | 3 | 4 |
| 12. I will be trapped | 0 | 1 | 2 | 3 | 4 |
| 13 I will cause an accident | 0 | 1 | 2 | 3 | 4 |
| 14. I will be stranded | 0 | 1 | 2 | 3 | 4 |
| 15. I will hold up traffic and people will be angry | 0 | 1 | 2 | 3 | 4 |
| 16. My heart will stop beating | 0 | 1 | 2 | 3 | 4 |
| 17. People will laugh at me | 0 | 1 | 2 | 3 | 4 |
| 18. I will not be able to move | 0 | 1 | 2 | 3 | 4 |
| 19. People riding with me will be hurt | 0 | 1 | 2 | 3 | 4 |
| 20. I will lose control of myself and will act stupidly or dangerously | 0 | 1 | 2 | 3 | 4 |

Appendix C: Questions on the degree of anxiety and avoidance of specific driving situations

Below are a list of driving activities that are sometimes considered to be stressful. Please indicate on the scale to what degree the following situations make you feel anxious when you are driving, and also to what degree you would try to avoid the situation in question. If the situation is not applicable to you, then please tick 'N/A' next to the statement.

Please choose the appropriate response for each item:

| | Anxiety | | | | | |
|---|---|---|---|---|---|---|
| | 0- No anxiety at all | 1- Very little anxiety | 2- Some anxiety | 3- Moderate anxiety | 4- Severe anxiety | N/A |
| Performing manoeuvres such as overtaking and parking | ○ | ○ | ○ | ○ | ○ | ○ |
| Any errand that involves driving (a short journey taken in order to deliver or collect something) | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along country roads | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving in bad weather conditions (i.e. rain, snow, ice and fog) | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving in heavy traffic | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving at night-time | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving in an unfamiliar location | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along city streets | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along residential roads | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along the motorway | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving to a recreational activity (an activity that is done for enjoyment) | ○ | ○ | ○ | ○ | ○ | ○ |
| Any activity that involves driving | ○ | ○ | ○ | ○ | ○ | ○ |

| | Avoidance | | | | | |
|---|---|---|---|---|---|---|
| | 0- Do not avoid at all | 1- Avoid less than half of the time | 2- Avoid about half of the time | 3- Avoid most of the time | 4- Always avoid | N/A |
| Performing manoeuvres such as overtaking and parking | ○ | ○ | ○ | ○ | ○ | ○ |
| Any errand that involves driving (a short journey taken in order to deliver or collect something) | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along country roads | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving in bad weather conditions (i.e. rain, snow, ice and fog) | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving in heavy traffic | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving at night-time | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving in an unfamiliar location | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along city streets | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along residential roads | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving along the motorway | ○ | ○ | ○ | ○ | ○ | ○ |
| Driving to a recreational activity (an activity that is done for enjoyment) | ○ | ○ | ○ | ○ | ○ | ○ |
| Any activity that involves driving | ○ | ○ | ○ | ○ | ○ | ○ |

Appendix D: Driving Behaviour Survey (DBS- Clapp, Olsen, Beck, et al., 2011)

Often times situations occur while people are driving (e.g., weather conditions, heavy traffic, near accidents, etc.) which make them nervous. Below is a list of behaviors that may or may not be relevant to you in these situations. Based on your personal experience, please indicate how frequently you perform each of these items when a stressful driving situation occurs which makes you nervous, anxious, tense, or uncomfortable. Please indicate what you *generally* do, not what you think you should do.

Please choose the appropriate response for each item:

| | 1- Never | 2- Very infrequently | 3- Infrequently | 4- Sometimes | 5- Frequently | 6- Very frequently | 7- Always |
|---|---|---|---|---|---|---|---|
| I lose track of where I am going | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I yell at the driver/drivers who make me nervous | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I slow down when approaching intersections, even when the light is green | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I have trouble staying in the correct lane | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I drift into other lanes | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I forget to make appropriate adjustments in speed | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I let the driver who made me nervous know that I am upset | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I maintain a large distance between | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| myself and the driver in front of me | | | | | | | |
| I forget where I am driving to | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I make gestures at the driver/drivers who made me nervous | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I try to put distance between myself and other cars | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I maintain my speed in order to calm myself down | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I try to stay away from other cars | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I have trouble finding the correct lane | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I pound on the steering wheel when I'm nervous | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I decrease my speed until I feel comfortable | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I honk my horn at the driver who made me nervous | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I try to find ways to let other drivers know that they are making me nervous | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| During bad weather, I drive more cautiously than other vehicles on the road | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I swear/use profanity while I am driving | ○ | ○ | ○ | ○ | ○ | ○ | ○ |
| I have difficulty merging into traffic | ○ | ○ | ○ | ○ | ○ | ○ | ○ |

## Appendix E: Driver Stress Inventory (DSI- Matthews et al., 1997)

Section B

Please answer the following questions on the basis of your usual or typical feelings about driving. Each question asks you to answer according to how strongly you agree with one or other of two alternative answers. Please read each of the two alternatives carefully before answering. To answer, put a cross on the horizontal line at the point which expresses your answer most accurately.
Be sure to answer all the questions, even if some of them don't seem to apply to you very well: guess as best you can if need be.

Example: Are you a confident driver?

The more confident you are, the closer to the 'very much' alternative you should mark your cross. If you are quite a confident driver you might mark it like this:

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

1. Does it worry you to drive in bad weather?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

2. I am disturbed by thoughts of having an accident or the car breaking down

very rarely 0 1 2 3 4 5 6 7 8 9 10 very often ☐☐

3. Do you lose your temper when another driver does something silly?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

4. Do you think you have enough experience and training to deal with risky situations on the road safely?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

5. I find myself worrying about my mistakes and the things I do badly when driving

very rarely 0 1 2 3 4 5 6 7 8 9 10 very often ☐☐

6. I would like to risk my life as a racing driver

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

7. My driving would be worse than usual in an unfamiliar hired car

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

8. I sometimes like to frighten myself a little while driving

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

9. I get a real thrill out of driving fast

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

10. I make a point of carefully checking every side road I pass for emerging vehicles

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

11. Driving brings out the worst in people

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

12. Do you think it is worthwhile taking risks on the road?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

13. At times, I feel like I really dislike other drivers who cause problems for me

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

14. Advice on driving from a passenger is generally:

useful 0 1 2 3 4 5 6 7 8 9 10 unnecessary ☐☐

15. I like to raise my adrenaline levels while driving

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

16. It's important to show other drivers that they can't take advantage of you

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

17. Do you feel confident in your ability to avoid an accident?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

18. Do you usually make an effort to look for potential hazards when driving?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

19. Other drivers are generally to blame for any difficulties I have on the road

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

20. I would enjoy driving a sports car on a road with no speed-limit

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

21. Do you find it difficult to control your temper when driving?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

22. When driving on an unfamiliar road do you become more tense than usual?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

23. I make a special effort to be alert even on roads I know well

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

24. I enjoy the sensation of accelerating rapidly

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

25. If I make a minor mistake when driving, I feel it's something I should be concerned about

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

26. I always keep an eye on parked cars in case somebody gets out of them, or there are pedestrians behind them

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

27. I feel more anxious than usual when I have a passenger in the car

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

28. I become annoyed if another car follows very close behind mine for some distance

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

29. I make an effort to see what's happening on the road a long way ahead of me

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

30. I try very hard to look out for hazards even when it's not strictly necessary

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

31. Are you usually patient during the rush hour?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

32. When you overtake another vehicle do you feel in command of the situation?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

33. When you overtake another vehicle do you feel tense or nervous?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

34. Does it annoy you to drive behind a slow moving vehicle?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

35. When you're in a hurry, other drivers usually get in your way

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

36. When I come to negotiate a difficult stretch of road, I am on the alert

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

37. Do you feel more anxious than usual when driving in heavy traffic?

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

38. I enjoy cornering at high speed

not at all 0 1 2 3 4 5 6 7 8 9 10 very much ☐☐

39. Are you annoyed when the traffic lights change to red when you approach them?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

40. Does driving usually make you feel aggressive?

very much 0 1 2 3 4 5 6 7 8 9 10 not at all ☐☐

41. Think about how you feel when you have to drive for several hours, with few or no breaks from driving. How do your feelings change during the course of the drive?

a) More uncomfortable physically (e.g. headache or muscle pains 0 1 2 3 4 5 6 7 8 9 10 No change

b) More drowsy or sleepy 0 1 2 3 4 5 6 7 8 9 10 No change

c) Maintain speed of reaction 0 1 2 3 4 5 6 7 8 9 10 Reactions to other traffic increasingly slow

d) Maintain attention to road-signs 0 1 2 3 4 5 6 7 8 9 10 Become increasingly inattentive to road-signs

e) Normal vision 0 1 2 3 4 5 6 7 8 9 10 Your vision becomes less clear

f) Increasingly difficult to judge your speed 0 1 2 3 4 5 6 7 8 9 10 Normal judgement of speed

g) Interest in driving does not change 0 1 2 3 4 5 6 7 8 9 10 Increasingly bored and fed-up

h) Overtaking becomes increasingly risky and dangerous 0 1 2 3 4 5 6 7 8 9 10 No change

## Appendix F: Driver Coping Questionnaire (Matthews et al., 1997)

These questions are concerned with how you usually deal with driving when it is difficult, stressful or upsetting. Think of those occasions during the last year when driving was particularly stressful. Perhaps you nearly had an accident, or you were stuck in a traffic jam, or you had to drive for a long time in poor visibility and heavy traffic. Use your experiences of driving during the last year to indicate how much you usually engage in the following activities when driving is difficult, stressful or upsetting, by CIRCLING one of the numbers from 0 to 5 to the right of each question.

| | Not at all | | | | | Very much |
|---|---|---|---|---|---|---|
| 1. Relieved my feelings by taking risks or driving fast | 0 | 1 | 2 | 3 | 4 | 5 |
| 2. Cheered myself up by thinking about things unrelated to the drive | 0 | 1 | 2 | 3 | 4 | 5 |
| 3. Stayed detached or distanced from the situation | 0 | 1 | 2 | 3 | 4 | 5 |
| 4. Tried to make other drivers more aware of me by driving close behind them | 0 | 1 | 2 | 3 | 4 | 5 |
| 5. Wished that I was a more confident and forceful driver | 0 | 1 | 2 | 3 | 4 | 5 |
| 6. Ignored my feelings about the drive | 0 | 1 | 2 | 3 | 4 | 5 |
| 7. Made sure I avoided reckless or impulsive actions | 0 | 1 | 2 | 3 | 4 | 5 |
| 8. Showed other drivers what I thought of them | 0 | 1 | 2 | 3 | 4 | 5 |
| 9. Drove assertively or aggressively | 0 | 1 | 2 | 3 | 4 | 5 |
| 10. Tried to gain something worthwhile from the drive | 0 | 1 | 2 | 3 | 4 | 5 |
| 11. Showed other drivers I was in control of the situation | 0 | 1 | 2 | 3 | 4 | 5 |
| 12. Made an extra effort to drive safely | 0 | 1 | 2 | 3 | 4 | 5 |
| 13. Felt that I was becoming a more experienced driver | 0 | 1 | 2 | 3 | 4 | 5 |
| 14. Made an effort to stay calm and relaxed | 0 | 1 | 2 | 3 | 4 | 5 |
| 15. Swore at other drivers (aloud or silently) | 0 | 1 | 2 | 3 | 4 | 5 |
| 16. Thought about good times I've had | 0 | 1 | 2 | 3 | 4 | 5 |
| 17. Wished that I found driving more enjoyable | 0 | 1 | 2 | 3 | 4 | 5 |
| 18. Made sure I kept a safe distance from the car in front | 0 | 1 | 2 | 3 | 4 | 5 |
| 19. Went on as if nothing had happened | 0 | 1 | 2 | 3 | 4 | 5 |
| 20. Refused to believe that anything unpleasant had happened | 0 | 1 | 2 | 3 | 4 | 5 |
| 21. Told myself there wasn't really any problem | 0 | 1 | 2 | 3 | 4 | 5 |
| 22. Let other drivers know they were at fault | 0 | 1 | 2 | 3 | 4 | 5 |
| 23. Criticised myself for not driving better | 0 | 1 | 2 | 3 | 4 | 5 |
| 24. Thought about the consequences of having an accident | 0 | 1 | 2 | 3 | 4 | 5 |
| 25. Flashed the car lights or used the horn in anger | 0 | 1 | 2 | 3 | 4 | 5 |
| 26. Felt I was learning how to cope with stress | 0 | 1 | 2 | 3 | 4 | 5 |
| 27. Deliberately slowed down when I met a difficult traffic situation or bad weather | 0 | 1 | 2 | 3 | 4 | 5 |
| 28. Made a special effort to look out for hazards | 0 | 1 | 2 | 3 | 4 | 5 |
| 29. Blamed myself for getting too emotional or upset | 0 | 1 | 2 | 3 | 4 | 5 |
| 30. Concentrated hard on what I had to do next | 0 | 1 | 2 | 3 | 4 | 5 |
| 31. Worried about what I was going to do next | 0 | 1 | 2 | 3 | 4 | 5 |
| 32. Looked on the drive as a useful experience | 0 | 1 | 2 | 3 | 4 | 5 |
| 33. Worried about my shortcomings as a driver | 0 | 1 | 2 | 3 | 4 | 5 |
| 34. Thought about the benefits I would get from making the journey | 0 | 1 | 2 | 3 | 4 | 5 |
| 35. Learnt from my mistakes | 0 | 1 | 2 | 3 | 4 | 5 |

## Appendix G: Driver demographics questionnaire

ID:_____ INITIALS:_____ DATE_____

Age:_____

Gender: M/F

Highest Educational Qualification:_____

Occupation:_____

In what year did you obtain your full driving licence? _____

How often do you currently drive? _____

What is your estimated annual mileage (in miles OR kilometres)? _____

On what kinds of roads do you regularly drive on (please circle the ones that apply)?

a) Motorways
b) Urban roads
c) Country roads
d) Other main roads

How many minor accidents have you been involved in? (A minor accident is one where no one required treatment, and damage costs were less than £500) _____

How many major accidents have you been involved in? (A major accident is one where either someone has required medical treatment, and/or damage costs were greater than £500) _____

Have you ever been convicted for:

a) Speeding: Yes/No
b) Dangerous or careless driving: Yes/No
c) Driving under the influence of alcohol or drugs: Yes/No

Appendix H: Questionnaire on perceptions of driver capability (McCormick et al., 1986)

ID:_____ INITIALS:_____ DATE:_____

- How would you rate **the average driver** on the following scales:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Very foolish | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very wise |
| Very unpredictable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very predictable |
| Very unreliable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very |
| Very inconsiderate | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very considerate |
| Very dangerous | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very safe |
| Very tense | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very relaxed |
| Very irresponsible | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very responsible |

- How would you rate **a very good driver** on the following scales:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Very foolish | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very wise |
| Very unpredictable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very predictable |
| Very unreliable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very |
| Very inconsiderate | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very considerate |
| Very dangerous | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very safe |
| Very tense | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very relaxed |
| Very irresponsible | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very responsible |

- How would you rate **yourself as a driver** on the following scales:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Very foolish | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very wise |
| Very unpredictable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very predictable |
| Very unreliable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very |
| Very inconsiderate | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very considerate |
| Very dangerous | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very safe |
| Very tense | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very relaxed |
| Very irresponsible | 1 | 2 | 3 | 4 | 5 | 6 | 7 | Very responsible |

Appendix I: Questionnaire on perceived event frequency

How frequently do you think that this situation occurs **each month** on the roads?

Not at all 1 2 3 4 5 6 7 Almost every day

How often are you involved in one of these situations **each month** on the roads?

Not at all 1 2 3 4 5 6 7 Almost every day

## Appendix J: Task Capability Interface Questionnaire

How difficult would you find it to drive in these environments at the speeds shown?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very easy | | | | | | Very difficult |

How risky would you find it to drive in these environments at the speeds shown?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Not at all risky | | | | | | Very risky |

How much effort do you think you would have to use to keep control of your vehicle?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Not a lot of effort | | | | | | A lot of effort |

If you were driving in these environments every day for a month, how likely is it that you would lose control of your vehicle?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Very unlikely | | | | | | Very likely |

If you were driving in these environments every day for a month, what sort of speed would you prefer to be driving at?

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Well below the recommended speed limit | | | | | | Well above the recommended speed limit |

Appendix K: Simulator Sickness Questionnaire (SSQ- Kennedy, Lane, Berbaum, & Lilenthal, 1993)

**Please tick the one that applies for each symptom.**

| | None | Slight | Moderate | Severe |
|---|---|---|---|---|
| **1. General discomfort** | | | | |
| **2. Fatigue** | | | | |
| **3. Headache** | | | | |
| **4. Eyestrain** | | | | |
| **5. Difficulty focusing** | | | | |
| **6. Salivation increased** | | | | |
| **7. Sweating** | | | | |
| **8. Nausea** | | | | |
| **9. Difficulty concentrating** | | | | |
| **10. "Fullness of the head"** | | | | |
| **11. Blurred vision** | | | | |
| **12. Dizziness eyes open** | | | | |
| **13. Dizziness eyes closed** | | | | |
| **14. Vertigo** | | | | |
| **15. Stomach awareness** | | | | |
| **16. Burping** | | | | |

Appendix L: NASA-TLX Questionnaire (Hart & Staveland, 1988)

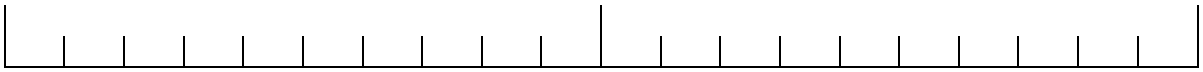
**NASA Task Load Index**

Participant ID: _____ Task: ____ Date: _____

Mental demand — How mentally demanding was the task?

Very Low — Very High

Physical demand — How physically demanding was the task?



Very Low — Very High

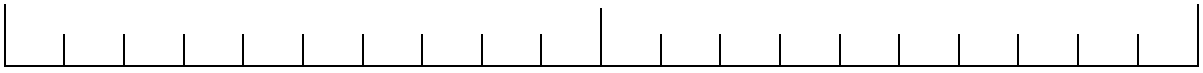
Visual demand — How visually demanding was the task?

Very Low — Very High

Temporal demand — How hurried or rushed was the pace of the task?

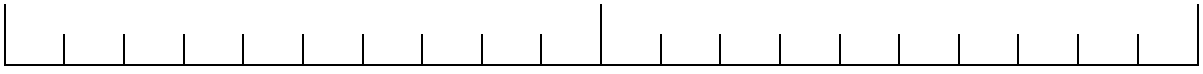
Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?



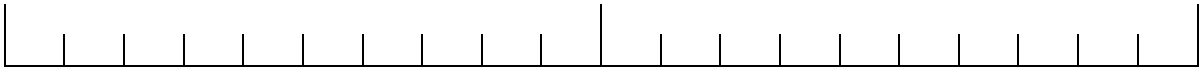
Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?



Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed and annoyed were you?



Very Low — Very High

Appendix M: Attentional Control Scale (ACS- Derryberry & Reed, 2002)

Please read the following statements and then circle the appropriate number to the right of the statement to indicate to what degree each one applies to you.

| | Almost Never | Sometimes | Often | Always |
|---|---|---|---|---|
| 1. It's very hard for me to concentrate on a difficult task when there are noises around. | 1 | 2 | 3 | 4 |
| 2. When I need to concentrate and solve a problem, I have trouble focusing my attention. | 1 | 2 | 3 | 4 |
| 3. When I am working hard on something, I still get distracted by events around me. | 1 | 2 | 3 | 4 |
| 4. My concentration is good even if there is music in the room around me. | 1 | 2 | 3 | 4 |
| 5. When concentrating, I can focus my attention so that I become unaware of what's going on in the room around me. | 1 | 2 | 3 | 4 |
| 6. When I am reading or studying, I am easily distracted if there are people talking in the same room. | 1 | 2 | 3 | 4 |
| 7. When trying to focus my attention on something, I have difficulty blocking out distracting thoughts. | 1 | 2 | 3 | 4 |
| 8. I have a hard time concentrating when I'm excited about something | 1 | 2 | 3 | 4 |
| 9. When concentrating, I ignore feelings of hunger or thirst. | 1 | 2 | 3 | 4 |
| 10. I can quickly switch from one task to another. | 1 | 2 | 3 | 4 |

| | Almost Never | Sometimes | Often | Always |
|---|---|---|---|---|
| 11. It takes me a while to really get involved in a new task. | 1 | 2 | 3 | 4 |
| 12. It is difficult for me to coordinate my attention between the listening and writing required when taking notes during lectures. | 1 | 2 | 3 | 4 |
| 13. I can become interested in a new topic very quickly when I need to. | 1 | 2 | 3 | 4 |
| 14. It is easy for me to read or write while I'm also talking on the phone. | 1 | 2 | 3 | 4 |
| 15. I have trouble carrying on two conversations at once. | 1 | 2 | 3 | 4 |
| 16. I have a hard time coming up with new ideas quickly. | 1 | 2 | 3 | 4 |
| 17. After being interrupted or distracted, I can easily shift my attention back to what I was doing before. | 1 | 2 | 3 | 4 |
| 18. When a distracting thought comes to mind, it is easy for me to shift my attention away from it. | 1 | 2 | 3 | 4 |

| | | | | |
|---|---|---|---|---|
| 19. It is easy for me to alternate between two different tasks. | 1 | 2 | 3 | 4 |
| 20. It is hard for me to break from one way of thinking about something and look at it from another point of view. | 1 | 2 | 3 | 4 |