Testing models of driver behaviour

Lewis Evans, B.L.E.

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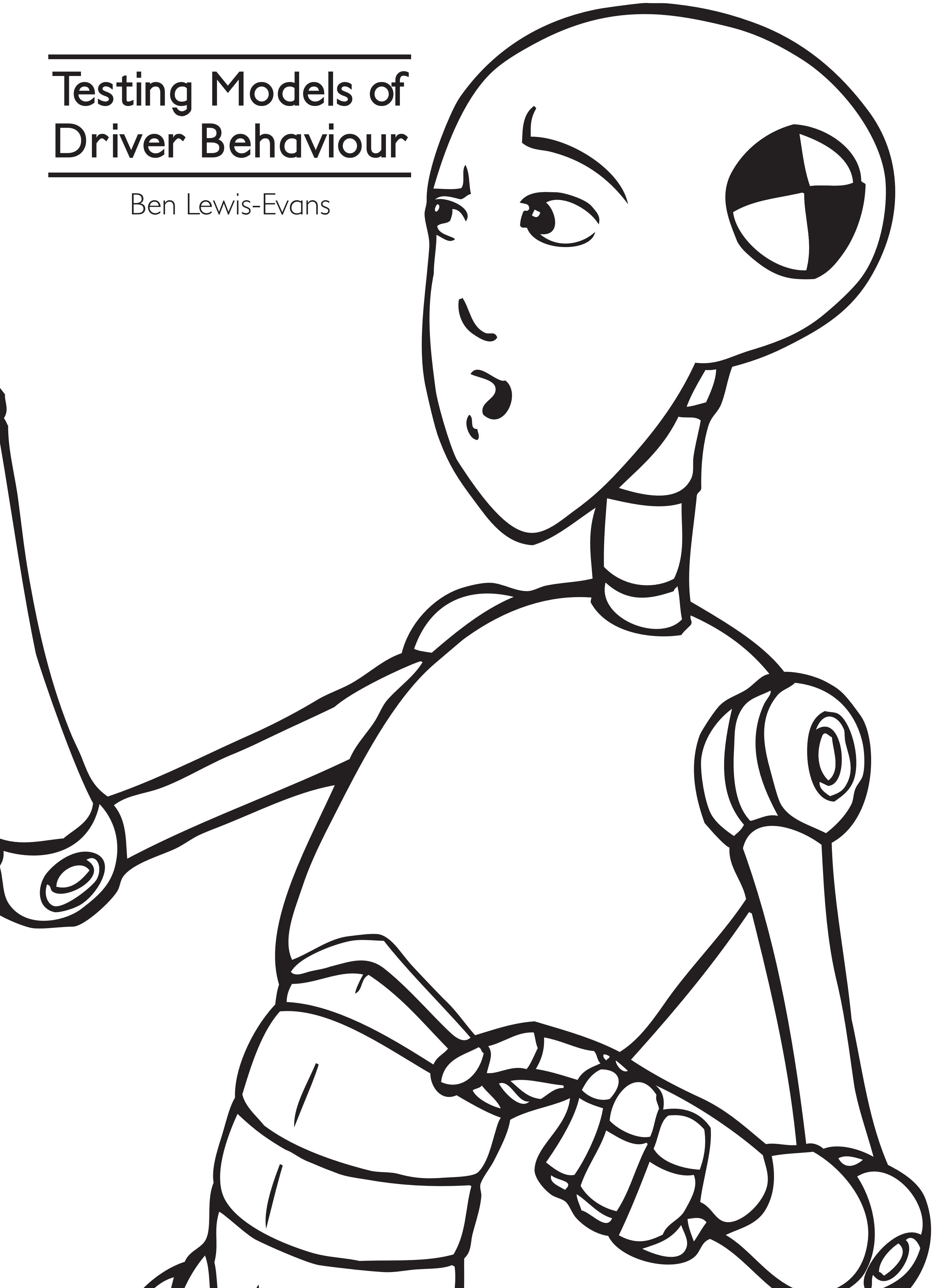
Ben Lewis-Evans



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CHAPTER 1 **INTRODUCTION**

Using the road system is a part of everyday life for people all over the world. Most people drive their whole life with minimal (if any) formal training, perhaps speeding at times, or fatigued and distracted at others, and will never be involved in a serious accident. This is quite an achievement if you consider that our perceptual and cognitive ability evolved under conditions where the average running speed of a human was under 30km/h and has not had time to adapt since the invention of the car.

However, while the individual risk of an accident may be small, it does add up across the population. In fact, using the road system it is one of the most common everyday ways for someone to be injured or killed. As such, road accidents are the number one cause of death worldwide for people aged 15-29, and the 9th leading cause of death internationally if all age groups are considered (World Health Organization, 2009). Even soldiers are more likely to be killed in a non-combat motor vehicle accident than by enemy action (Fear et al., 2008). These tragic statistics are stated again and again in the introductions of reports, books, web sites, theses and journal articles on road safety and traffic psychology. As such, it almost seems redundant to repeat them. However, these statistics must still be repeated as the majority of these road accidents are preventable; a fact that is represented by the gains that have been made in road safety in the last 50 or so years. There is still room for further improvement however, and traffic psychology as a field is generally dedicated towards this, with traffic psychologists striving to understand the behaviour of drivers and other road users. The hope is that this knowledge can be passed on and used by policy makers and system designers to save lives, increase mobility, reduce the environmental impact of transport, and to generally improve transport networks.

Despite this goal, traffic psychology does not have a widely-used guiding theory or model of driver behaviour. In fact, one analysis of over 1400 traffic psychology papers that were published between 1998 and 2008 found that only 15% of these papers used any type of recognisable theoretical framework or model at all. Furthermore, if a paper did use a model or framework, it was likely the only time that particular model would appear in the literature (Glendon, 2011). This creates a fragmented and atheoretical approach, which not only has the potential to hamper further research, but also means that mixed messages are being communicated to those with the power to guide and shape the road system.

For instance, how should a governmental Minister react when one traffic psychologist tells her that, according to the Theory of Planned Behaviour (TPB)(Ajzen, 1991) it is all about making sure people have the right attitude and social marketing is the way to go. But then the next expert promotes zero-risk theory (Näätänen & Summala, 1974; Summala, 1988;

Summala, 1996; Summala, 1997), or Threat avoidance theory (Fuller, 1984; Fuller, 1988; Fuller, 1990a; Fuller, 1992), that are primarily behavioural learning models and advocate structural and regulatory measures. Then the following week the Minister is tapped on the shoulder by another expert promoting the neo-liberal and anti-regulation rhetoric of Peltzman's (1975) driving intensity model, stating that the government should leave well alone and let the market handle it. This is an extreme example, but it does highlight the potential risks to the creation of effective interventions on the road of this fragmented and atheoretical approach in traffic psychology.

An often stated reason for the lack of consensus in models of driver behaviour is the lack of experimental testing that has been carried out to examine the models (Michon, 1985; Michon, 1989; Ranney, 1994; Rothengatter, 2002). Therefore the following thesis attempts to address this issue. To do so the stage must be set and the predictions of the various models made clear. Therefore Chapter 2 features a summary of previous notable reviews of models of driver behaviour, followed by a review of many of the more recent, post year 2000, driver behaviour models. In particular Task Difficulty Homeostasis theory (TDH) (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh, & Pender, 2008), its successor Risk Allostasis Theory (RAT) (Fuller, 2008; Fuller, 2011), the Risk Monitor Model (RMM) (Vaa, Glad, & Sagberg, 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011) and the multiple comfort zone model (Summala, 2005; Summala, 2007), will be discussed. These models also represent the primary models that will be tested in later chapters.

Chapter 3 contains an experiment designed to test the results of one of the primary supporting studies for TDH and RAT (Fuller, McHugh et al., 2008). In particular the experiment examines whether variables such as feelings of risk and task difficulty are constantly monitored and experienced by drivers, or if they operate in more of a threshold fashion, only occurring once certain conditions are met. This was done through the use of a driving simulator, with the primary independent variable being set changes in speed.

Chapter 4 is similar to Chapter 3, and again addresses the issue of the continuous versus threshold perception of subjective variables and their influence on driver behaviour. This chapter also examines whether this perception differed between inexperienced and experienced drivers, and whether task familiarity had an impact on these variables. In this case however, due to concerns about models of driver behaviour being overly focused on speed (Carsten, 2009), following distance was the primary independent variable in the simulator study.

Chapter 5 returns to the use of speed as a primary independent variable and also examines the issue of threshold versus constant perception. However, this chapter also seeks to more closely examine the relationship between drivers' preferred driving speed and these subjective variables. This was done by basing the experimental manipulations around each individual participant's own preferred speed, rather than the set speed categories used in the experiment described in Chapter 3. Furthermore the experiment described in Chapter 5 also seeks to examine the impact of a secondary task on the variables examined, and whether it has any impact on how they are perceived.

Chapter 6 differs somewhat from the empirical chapters preceding it. It describes an experiment to test the idea that unconscious or implicit body states or emotions can influence behaviour without having to become feelings and therefore be made conscious. This idea has been referenced by several modern theories of driver behaviour (Fuller, 2005; Fuller, McHugh et al., 2008; Fuller, 2011; Kinnear, 2009; Ljung Aust & Engström, 2011; Summala, 2005; Summala, 2007; Vaa, 2003; Vaa, 2011) and was tested through the use of emotive masked images being presented to drivers in a simulator.

Chapter 7 contains a general discussion of the four empirical chapters. In particular the significance of the findings will be discussed in reference to the models which are outlined in chapter 2.

It should be noted that due to the fact that Chapters 3-6 are based on previously published journal articles there is some overlap between them. In addition, the content of these chapters may also somewhat overlap with the review in Chapter 2 and the discussion in Chapter 7. However, attempts have been made to keep this to a minimum while also providing comprehensive coverage of the important issues.

CHAPTER 2 **MODELS OF DRIVER BEHAVIOUR**

A version of some parts of this chapter will be published as Lewis-Evans, B., de Waard, D., and Brookhuis, K.A. *Contemporary theories of behavioural adaptation*. In Jamson, S. and Rudin-Brown, C. (Eds) Behavioural adaptation: Theory, Evidence and Action. To be released in 2012.

Concern about the atheoretical and fragmented nature of traffic psychology is not new but major published reviews of driving behaviour models and theories aimed at trying to guide and unify the area are relatively scarce. Some do exist however, and in particular the reviews by Michon (1985; 1989), Ranney (Ranney, 1994), Huguenin and Rumar (2001), and Rothengatter (2002) are worthy of mention.

Michon's 1989 review is a somewhat more focused restatement of an earlier review (Michon, 1985), and approaches models of driver behaviour by characterising them in terms of what made them 'move'. In doing so Michon divided theories of driver behaviour into those which move 'magically' based on curve fitting, and those rational or functional models which are driven by explicitly stated concepts and rules. It was in this latter category of rational models, which were also described as models which can adapt and learn, where Michon (1985; 1989) saw the most promise.

The category of functional models was further split into those which Michon described as motivational and those which are rule based. The motivational models include Taylor's risk-speed compensation model (Taylor, 1964), RHT (Wilde, 1976), Threat avoidance theory (Fuller, 1984) and zero-risk theory (Näätänen & Summala, 1974), although the latter model is only mentioned by Michon in his earlier 1985 review. Michon admires these models for moving away from the magical curve fitting that accompanied earlier models, but critiques RHT for containing circular explanations and Threat Avoidance Theory for not handling nested behaviour. In his earlier review Michon (1985) also critiqued the motivational models for being over concentrated on risk and road safety, rather than explaining the normal everyday basis of driving. Furthermore, Michon (1985; 1989) views the explanations and mechanisms of the motivational models as not sufficiently identifying the underlying cognitive mechanisms that they rely on.

Instead, Michon promotes rule based theories, which drew most of his attention in the latter parts of the 1985 and 1989 reviews. Rule based theories are based on the influence of cognitive science and the idea of schema or scenarios. This means that rule based theories state that behaviour operates along the lines of finding a correct rule, and then applying it in a "IF THEN" fashion. For example, IF I feel that my wheels are slipping on the road THEN I begin to drive cautiously. As an example of the rule based type of theoretical approach Michon (1989) referred to the SOAR cognitive architecture (Laird, Newell, & Rosenbloom, 1987), and indeed finishes his review by promoting SOAR as a way forward for understanding driver behaviour.

Ranney's review in 1994 presents model development in terms of a historical evolution, an approach also taken in Michon's earlier 1985 review. As such he begins by examining models based around individual differences such as the previously popular theory of accident proneness, which is the idea that some individuals are simply statistically more likely to be in accidents than others (see Haight (2001) for an excellent review of this idea). According to Ranney, model development then moved on to the examination of various individual factors or traits and their influence on accident probability. These included visual ability, perceptual style, reaction time, gender, age, marital status, traffic conviction record, and socio-economic status, amongst others. These variables had varying levels of success in predicting accidents and behaviour, but as Ranney points out, do not offer actual a priori explanations as to why accidents occur, but rather are based on aggregate post-hoc explanations. Therefore such models are more descriptive than predictive. Ranney also points out that these earlier models were aimed primarily at trying to explain only why people are involved in accidents rather than explaining the entirety of normal everyday driving. In his earlier review, Michon (1985) also spends a considerable amount of time describing these earlier trait based models, and spends some time on more mechanical task analysis based models. However, in Michon's later review trait based models hardly get a mention with Michon largely dismissing them as being too rigid and unable to move by themselves (Michon, 1989).

Ranney then moves on to discuss the models which Michon had identified as functional, again splitting them between motivational models and the more cognitive rule based models which Ranney refers to as information-processing theories. Like Michon, Ranney praises the motivational models for incorporating motivational aspects into their accounts of driver behaviour, mainly referencing RHT (Wilde, 1976), Threat Avoidance Theory (Fuller, 1984) and zero-risk theory (Näätänen & Summala, 1974). However he raises concerns that motivational models have been somewhat unclear as to how they operate, leading to a lack of testable hypotheses, and therefore, a lack of productive research into the operation of these theories. Ranney also comments, as Michon did (1985), that there has been an over emphasis on the idea of risk as a controlling variable in behaviour. He also adds that a quite protracted debate over the total risk compensation mechanism proposed by RHT had stalled progress in the area of model development.

Ranney also sees more potential in the use of information processing theories to explain driver behaviour but notes that cognitive information processing theories had not made much of an impact on driver behaviour models at the time. Ranney therefore introduces the idea of hierarchical control models, particularly through the use of the Skill-Rule-Knowledge framework put forward by Ramussen (1987a), the Generic Error-Modelling System (GEMS) proposed by Reason (1990) and Michon's Three Level Control hierarchy (Michon, 1985). In association with the idea of automaticity Ranney praises information processing models as moving away from a concentration on risk, and through the use of hierarchies, a move towards modelling driver behaviour in the frame of a more complex systems view.

The review by Huguenin and Rumar (2001) is generally critical of the idea of a single unifying model of driver behaviour. They state that the models which have been put forward have tended to be either so broad as to be unusable for generating useful predictions or so specific as to only explain certain small parts of the driving task. They do however present a classification of models of driver behaviour as either driver task related, functional control, or motivational (Rothengatter, 1997) but then reject it as being overly simplistic and not capturing the full complexity of driver behaviour.

Having rejected this classification, and made their objections clear to the existing models of driver behaviour, Huguenin and Rumar then proceed to never-the-less discuss the models in a somewhat historical fashion. They begin with Gibson & Crooks (1938), who claimed that driving was just an extension of the walking task, making it primarily a perceptual matter of identifying the appropriate visual stimuli in order to navigate safely through the environment. Then they briefly discuss personality or trait based approaches to traffic psychology, mostly dismissing this area, before moving to discuss the variable of risk. A variable they consider to be a "key factor in the explanation of driver behaviour" (Huguenin & Rumar, 2001), p 32).

Huguenin and Rumar (2001) discuss risk in terms of objective versus subjective risk comparisons by drivers and the occurrence of behavioural adaptation. Behavioural adaptation is the idea that drivers tend to adapt their behaviour to changes in the environment and may therefore end up reducing or negating any potential safety gains which these changes may have brought about (see OECD (1990) for a review of behavioural adaptation). When discussing the role of risk in behavioural adaptation the authors reference RHT (Wilde, 1976), zero-risk theory (Näätänen & Summala, 1974) and the hierarchical risk model for traffic participants (Van Der Molen & Bötticher, 1988). However they do not seem to favour any of these models, pointing out that RHT is largely unfalsifiable and the hierarchical risk model is mainly descriptive. In terms of zero-risk theory the authors describe the model, but do not seem to offer any concrete objections against it, only suggesting that it contradicts RHT which the authors state is supported by "a considerable number of studies" (Huguenin and Rumar, 2001, pg 39).

Huguenin and Rumar then briefly mention that systematic approaches towards road safety have been attempted, where driver behaviour is seen as arising out of an interaction of many factors. After stating this, they proceed to discuss what they class as motivational models. The models differ from those described as motivational by Michon (1985; 1989) and Ranney (1994) in that they seem to take a more low level approach. This is manifested by an explanation of motivational models as those that state that there are expectancies for action, and then certain valences (or benefits) which are applied to different acts. Therefore, under this classification, behaviour is determined in a kind of utility fashion where the expected results of behaviour are weighted with the expected benefits and then the most beneficial option is taken. The upshot of this is that due to the relatively low accident likelihood associated with most on-road behaviours, and the high valence of unsafe behaviour, that unsafe behaviours (for example speeding) may be chosen more often than objectively safer alternatives.

Finally, Huguenin and Rumar attempt to collate the existing models into a model of driver behaviour that states that driver's actions are a function of their situation, their predispositions towards the action and their level of assimilation of the relevant perceptual information in the environment. They end their review by stating that while many models of driver behaviour are, traditionally speaking, impossible to falsify, that never-the-less they are useful as guidelines or heuristics. They also state that they would like to see more inclusion of emotional and social psychology aspects in driver behaviour modelling.

By 2002 it would seem that Rothengatter agrees with the idea of more inclusion of social psychology into models of driver behaviour. However he also appears to be considerably less in favour of information processing models and discussion of them hardly features in his review at all. With the exception of a reference to Wicken's Multiple Resource Model (1992) near the end of the paper, and some comment on the importance of automaticity in driving. He also dismisses hierarchical models, such as zero-risk theory (Näätänen & Summala, 1974; Summala, 1988) or the hierarchical risk model for traffic participants (Van Der Molen & Bötticher, 1988), as not reflecting the reality of the complex control environment that in which driving occurs. Rothengatter does, however, spend time covering motivational models, particularly what he refers to as Risk Theories. He criticizes them on their lack of testable hypotheses, their over reliance on risk as a controlling factor, and on their often circular nature.

Rothengatter's review is also the only one to discuss attitude theories in any depth, such as the Theory of Planned Behaviour (TPB)(Ajzen, 1985), which were not mentioned at all by Michon (1985; 1989) and Ranney (1994), and only in passing as part of drivers predispositions by Huguenin and Rumar (2001). This is perhaps because of Rothengatter's previous work in the area of attitude-behaviour research (Rothengatter, De Bruin, & Rooijers, 1989; Rothengatter, 1996; Rothengatter, 1982; Rothengatter, 1988; Rothengatter, 1991; Rothengatter, 1992; Rothengatter, 1997). Rothengatter is generally positive towards the attitudinal theories, although he does point out that, methodologically speaking, their use within driver research has been problematic in terms of an over reliance on self-report. Furthermore, he states that when attitude theories have been used to predict actual observed behaviour that their predictive power is greatly reduced. This is a well known issue with attitude theories, and in particular the TPB (Armitage & Conner, 2001), but it is worth nothing that the TPB is still probably the most referenced model in traffic psychology today (Glendon, 2011). However, this is likely due to its continued popularity in social psychology, rather than its validity in terms of explaining the breadth of driver behaviour.

Rothengatter also singles out the idea of Calibration (Kuiken & Twisk, 2001) and Task Difficulty Homeostasis Theory (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008)(TDH) as showing promise, due to their move towards more of a task performance approach to driving. However he does point out that TDH falls into the same circular reasoning trap that RHT does through the use of a comparator. He concludes, much like Huguenin and Rumar (2001), that the focal point for traffic psychology, and therefore for the development of theories of driver behaviour, should be where performance theories and social-psychology theories meet.

These four reviews do a good job of describing the major models and theories in traffic psychology in their time, as well as highlighting the lack of consensus in the field. They all seem to agree that older trait and skill based models of driver behaviour will not get the field any further in terms of understanding normal everyday driving behaviour. They also all put forward, in one way or another, the most common argument against the models of driver behaviour that existed at the time, the argument of unfalsifiability. This argument states that many of the existing models are too vague in their underlying mechanisms and, therefore, it is difficult to form useful predictions from them and to then test these predictions.

The development of models aimed at describing driving behaviour has not ceased since Rothengatter's 2002 review was published. In fact, it could be argued that there has been an increase in new models, especially in models aimed at explaining the behavioural adaptation of drivers to driver assistance features. Examples of these include the Driver-in-Control model (Hollnagel, Nåbo, & Lau, 2003), the qualitative model of behaviour adaptation (Brown & Noy, 2004; Rudin-Brown & Parker, 2004), the situational control framework (Ljung Aust & Engström, 2011), and the Unified Model of Driver behaviour (Oppenheim, Shinar, Carsten et al., 2010; Oppenheim, Shinar, Enjalbert et al., 2010).

However, there are four more general models which have dominated theoretical discussions in the last decade or so. These are Task Difficulty Homeostasis theory (TDH) (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008), its successor, Risk Allostasis Theory (RAT) (Fuller, 2008; Fuller, 2011), the Risk Monitor Model (RMM) (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011) and the multiple comfort zone model (Summala, 2005; Summala, 2007). All four of which claim to be movements away from the older, unfalsifiable theories, a claim that will put to the test in chapters 3-6.

The rest of this chapter will be primarily dedicated to covering these four models. However, some time will also be devoted to reviewing, to a lesser extent, other models that have appeared in the literature during this time. The aim is to highlight the trends in model development in recent times and set the scene for the following chapters. One such trend was an initial movement away from theories that relied on concepts of 'Risk'. This was initially hailed as a long overdue step forward (Rothengatter, 2002), however, this trend did not necessarily continue.

2.1 How Task Difficulty became a RAT.

As mentioned above, the most common criticism of models of driver behaviour is that they do not produce testable hypotheses and that they are descriptive rather than predictive (Carsten, 2009; Michon, 1985; Michon, 1989; Ranney, 1994; Rothengatter, 2002). In an attempt to correct this situation, Fuller (Fuller, 2000) proposed the model of Task-Capability Interface (TCI) as a representation of the driving task, and Task Difficulty Homeostasis (TDH) as an explanation of driver behaviour (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008).

2.1.1 Task-Capability Interface (TCI)

TCI has remained relatively similar over time but the version discussed in this chapter is based on the most comprehensive version available (Fuller et al., 2008). As shown in Figure 2.1 the model contains two vital components: Capability and Task Demands.

2.1.1.1 Capability

Under TCI drivers are said to possess a certain level of capability which is constructed in a hierarchical fashion. The initial level of capability is labelled as the constitutional features. This level consists of base physiological characteristics and includes factors such as reaction time and speed of mental processing.

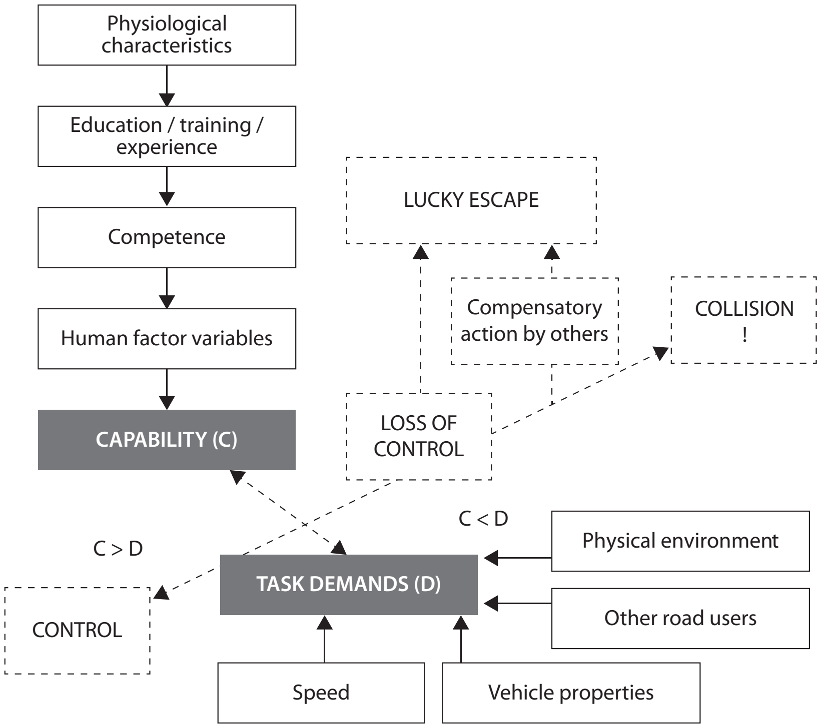

Figure 2.1. The Task-Capability Interface Model (from Fuller et al., 2008)

Added onto the base constitutional factors are the effects of training, education and experience. Experience is different from training and education in that experience is intended to mean experience gained through driving, rather than through formal training. Therefore this level reflects the learnt components of the driving task. The combination of the learnt and physiological components is then referred to as the driver's competence. Both competence and the proceeding constitutional factors are seen as theoretical maximums and relatively stable (Fuller, 2000; Fuller & Santos, 2002).

However, given the resource limited nature of human performance it is unrealistic to expect people to operate at their full level of competence all of the time, so the final step in the creation of capability is to subtract human factors from competence. Human factors is somewhat of a catch-all term and refers to situation-dependent attributes such as motivations, attitudes, and state-conditions such as intoxication, fatigue and emotional state. Therefore in contrast to the components of capability that come before it, human factors are relatively unstable.

The result of this hierarchical process is capability, which reflects the current situational ability of the driver to respond to task demands. This is not simply the amount of effort a driver has available at any particular moment. Rather, it is the amount of effort available plus the knowledge and experience of how to best use and apply this effort, minus any relevant situational-dependent factors.

2.1.1.2 Task demands

Task demands sit on the other side of the TCI and reflect the environment in which the driver is currently operating. Task demand, as laid out by TCI, is not created in a hierarchical fashion but is rather a combination of environmental factors, including: the road environment, behaviour of other road users, weather conditions, vehicle characteristics, road position, and the trajectory of the driver's car and its travelling speed.

The environmental factors that make up Task demands are both in and outside of the driver's control. For instance, there is very little outside of high level strategic route decisions a driver can do to affect the current road environment or weather conditions. However, road position, trajectory and travel speed are mostly under the control of the driver. It is this control of speed and road position by the driver that leads to driving often being referred to as a self-paced task (Michon, 1985; Michon, 1989; Näätänen & Summala, 1974; Ranney, 1994; Taylor, 1964). This means that the speed and trajectory of the driver are also linked to their capability. Fuller (2005) appears to have attempted to represent this in an earlier version of TCI where human factors were added to the task demand side of the diagram, impacting on speed, road position and trajectory. However, this addition disappeared from TCI after this date.

2.1.1.3 Task difficulty and the loss of control

Within TCI, task difficulty is produced by the interaction of task demands and capability. Task demands can be seen as representing the minimum amount of capability required to retain control of the vehicle. Therefore if task demands exceed capability then loss of control occurs. Furthermore, as task demand approaches capability then performance loss begins to occur (Fuller, 2000; Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008).

However, in the end, TCI is just a description of the driving task and does not really generate many testable hypotheses. It also does not detail how drivers determine that their choices will not place them in a situation where their capability cannot match the demands of the task, and does not particularly help to explain behavioural adaptation. To address these issues Fuller proposed Task Difficulty Homeostasis theory (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008).

2.1.2 Task Difficulty Homeostasis theory (TDH)

TDH was first proposed by Fuller and Santos (Fuller & Santos, 2002), and states that people have a set range of experienced task difficulty at which they prefer to operate at. This range of task difficulty is not static, but rather determined by a driver's perceived capability, effort motivation, and trip goals, and can therefore vary between, and even within, trips. Perceived task difficulty, a product of the interaction between perceived capability and task demand, is then compared with preferred task difficulty and action is taken if the currently perceived task difficulty falls outside of the target range. This leads to task difficulty being constantly maintained in a homeostatic way. This means that behavioural adaptation should occur whenever drivers detect that they are operating at a level of task difficulty outside of their preferred range.

As stated above, this formulation of TDH, with perceived task difficulty as the central factor, led to TDH being praised by Rothengatter (2002) as moving away from an over concentration on risk as a controlling factor in driving. However, the model did not stand still and continued to evolve eventually incorporating nearly the entire TCI model within TDH itself.

2.1.2.1 Proximal and Distal determinants of Task Difficulty

The incorporation of TCI into TDH was mainly carried out through the addition of distal and proximal determinants. These determinants act on different parts of the core comparison between perceived task difficulty and preferred task difficulty, and are intended to make the model more comprehensive. The most comprehensive version of the model to date (Fuller et al., 2008), is therefore shown in Figure 2.2.

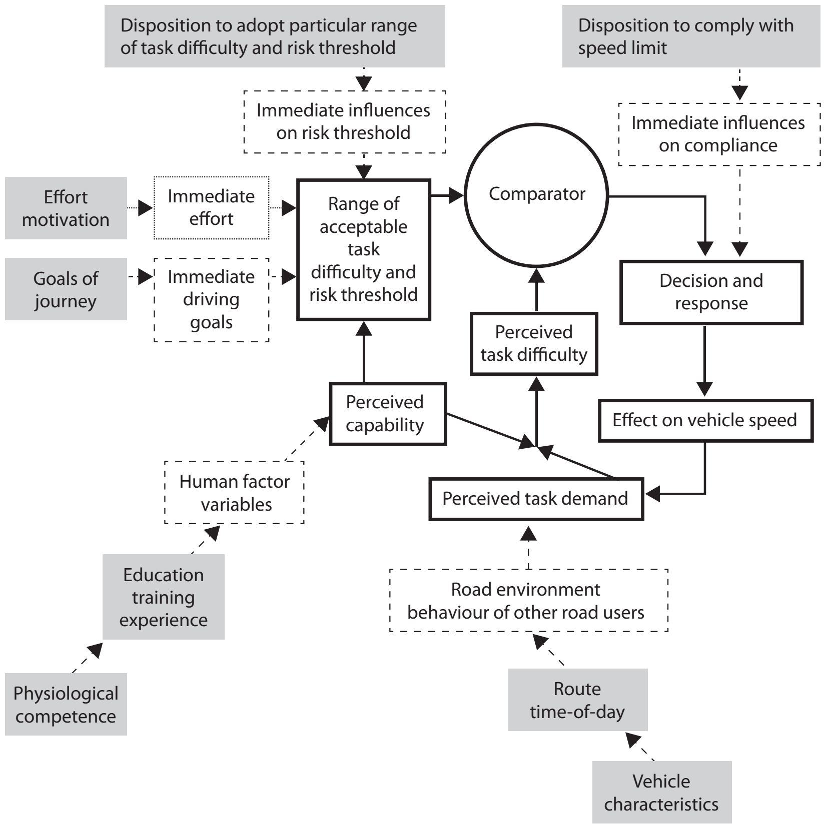

Figure 2.2. Task Difficulty Homeostasis theory (From Fuller et al., 2008)

As shown in Figure 2.2, the hierarchical formation of perceived capability from TCI is now spelled out within TDH. However, unlike in TCI, perceived task demand now also appears to be constructed in a hierarchical fashion. This appears somewhat illogical. If we treat this formulation in the same way as the construction of perceived capability, it seems that the only way that the 'distal' element of vehicle characteristics can interact with perceived task demand is to interact first with the route and time-of-day, and then come in contact with the proximal road environment and behaviour of other road users. However, in reality these environmental factors form a complex system and are not necessarily dependent and moderated by each other in such a linear hierarchical fashion.

Another addition is the distal element of a disposition to comply with the speed limit and a proximal element of immediate influences on compliance. These enforcement related elements are not explicitly stated in TCI, and are shown as influencing driver's decisions and responses outside of the normally described comparison process. However, it seems that these enforcement elements could easily be covered within the initial comparison between perceived capability and perceived task difficulty. Surely the level of enforcement in the environment is part of task demand, making it harder or easier to avoid detection. Then the intention to comply could arise out of an individual's capability to react to this external demand, given that capability already includes motivational factors and predispositions from driver's biology and experience. It therefore seems inconsistent to consider that a demand/capability comparison is said to occur as a reaction to other road user's behaviour, but not to the presence of enforcement, which is essentially just a special type of other road user.

2.1.2.2 Risk Threshold

Another part of TDH is the idea of a risk threshold. This risk threshold was conceptualized as being similar to that already proposed by earlier theories, such as zero-risk theory (Näätänen & Summala, 1974), and triggers when drivers are near the limit of their preferred range of task difficulty. In this way it can act as a warning, in addition to the constant comparison of perceived and preferred task difficulty, that the preferred range of task difficulty is about to be exceeded (Fuller, 2005; Fuller et al., 2008). Importantly, the risk threshold within TDH does not refer to crash risk as detailed in earlier theories of driver behaviour, such as Risk Homeostasis theory (Wilde, 1976), but rather to a 'feeling of risk'.

2.1.3 Risk Allostasis Theory (RAT)

Risk as a variable of import within TDH did not stop with the risk threshold however. Rather in 2008 Fuller reconceptualized TDH into Risk Allostasis Theory (RAT)(Fuller, 2008; Fuller, 2011). This new form of the model is summarized in Figure 2.3.

While not shown in Figure 2.3, in RAT the acceptable range of task difficulty is accompanied by, and essentially interchangeable with, a range of preferred feeling of risk. Similarly, drivers now constantly monitor feeling of risk as an indicator of perceived task difficulty. This development can be summed up like this:

"…the effects of risk feelings on decision making are not binary (one moment they are irrelevant, the next they become salient): task difficulty and feelings of risk are continuously present variables which inform driver decisions (whether consciously or not). However, only when some threshold point is reached may risk feelings become particularly salient in driver consciousness" Fuller et al, 2008, page 31

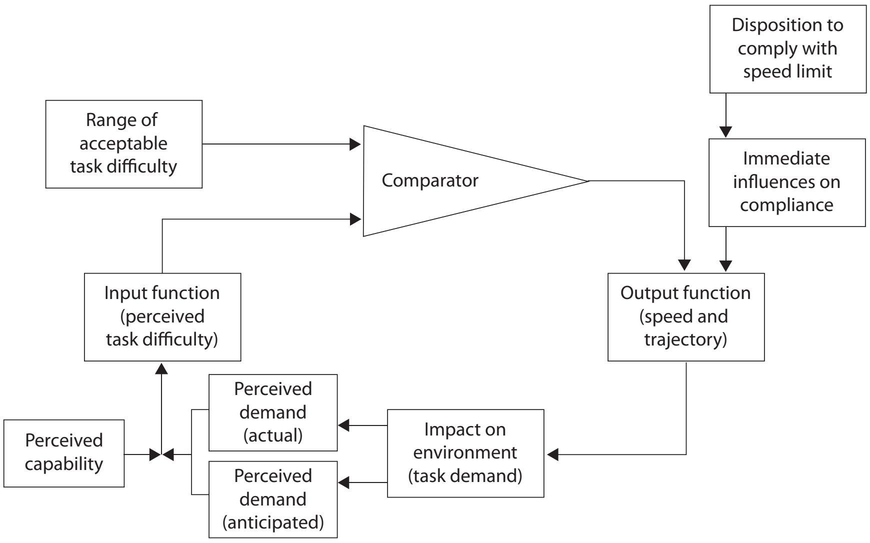

Figure 2.3. Risk Allostasis Theory (from Fuller, 2011)

This shift towards the constant monitoring of feelings of risk seems to have occurred for two main reasons; the influence of the Somatic Marker Hypothesis (Damasio, 1994; Damasio, 2003; Fuller, 2007), and on the basis of one experimental study by Fuller, McHugh et al., 2008. It is also worth noting that Fuller also indicates that RAT is simply a catchier name for the model (Fuller, 2008; Fuller, 2011).

2.1.3.1 Allostasis

Before getting into this evidence, what is meant by allostasis should be briefly mentioned. Allostasis refers to a process of achieving stability in a system through making changes. This is in contrast to homeostasis which refers to achieving stability in a system by staying the same (Fuller, 2011).

2.1.3.2 The Somatic Marker Hypothesis

The Somatic Marker Hypothesis was put forward by Damasio (1994; 2003) as a way of viewing the influence of emotions and feelings on the decision making process. It is based in neurological theory and is still somewhat speculative and largely experimentally untested (Damasio, 2003). It suggests that unconscious body states, labelled as emotions, can control or bias behaviour towards rational[1] decisions even without entering into consciousness, i.e. becoming feelings. The definition of emotions as unconscious body states, and feelings as the conscious awareness of emotions, has been labelled by Damasio (1994; 2003) and others (Fuller, 2007; Fuller, 2011; Vaa, 2007; Vaa, 2011) as somewhat unconventional. However, both the APA Dictionary of Psychology (VandenBos, 2006) and the Penguin Dictionary of Psychology (Reber, 2009) also define emotions and feelings in this fashion. Furthermore, while feeling and emotion are sometimes used interchangeably in everyday language, the word 'feeling' at least does carry with it the connotation of being 'felt', and therefore implies conscious awareness.

The Somatic Marker Hypothesis also ties in with a relatively recent view of risk assessment where it is suggested that there are two forms of risk based decision making (Slovic, Finucane, Peters, & MacGregor, 2004). The first is referred to as 'affect heuristics' and is similar to the Somatic Marker Hypothesis in that it refers to learnt, fast and automatic 'gut' emotional reactions which can be used to guide decision making. The second form of decision making is referred to as analytic and is seen as the more traditional slow, deliberate, subjective utility maximization process where the benefits and costs of a particular behaviour are weighed up.

2.1.3.3 The Fuller, McHugh and Pender Study

Fuller et al (2008) cites several studies as experimentally supporting various aspects of TDH (e.g. Couyoumdjian, Di Nocera, & Ferlazzo; Gregersen & Bjurulf, 1996; Hogema, Veltman, & van't Hof, 2005; Larsen, 1995; Lewis-Evans & Charlton, 2006; Uzzell & Muckle, 2005). But by 2008 only one study had been published specifically examining TDH; an experiment carried out by Fuller, McHugh and Pender (2008) themselves.

In this study the participants were shown several videos of different road environments being driven at speeds which differed in increasing 5 mph increments. The different speeds were created through digital manipulation of the video clip to either speed up or slow down the perceived speed of travel. After watching each clip, participants were asked to provide ratings of task difficulty, feeling of risk, and crash probability. In line with the state of TDH at the time (Fuller & Santos, 2002; Fuller, 2005; Fuller, McHugh et al., 2008), it was hypothesized that ratings of task difficulty would systematically increase with speed, and that ratings of felt risk and crash risk would show a threshold relationship. This expected threshold relationship meant that risk ratings should have only increased once a certain speed was exceeded.

[1] Rational in terms utility – i.e. the best choice for the least loss.

What actually occurred appears to have surprised the researchers (Fuller, McHugh et al., 2008). Ratings of task difficulty did indeed systematically increase with speed and indications of crash risk showed a threshold relationship as predicted. However, ratings of feeling of risk were found to also systematically increase with speed (r^2 = .98), and in fact were highly correlated (r = 0.81) with ratings of task difficulty. This indicated to the researchers that feelings of risk could be being used by participants as an indication of task difficulty. The Fuller, McHugh and Pender (2008) study was later replicated by Kinnear, Stradling, McVey (2008) who found similar results.

2.1.3.4 Feelings of Risk Homeostasis

Kinnear (2009) also proposed a risk based modification to TDH with the Feelings of Risk Homeostasis model (FRH). This model also attempted to incorporate the Somatic Marker Hypothesis and a 'risk as feelings' form of decision making in terms of making risk (feeling of, but also objective estimate of) the primary variable and is shown in Figure 2.4. Another change is the separation of sensory perception and working memory out from capability and placing them as their own separate factors within the model.

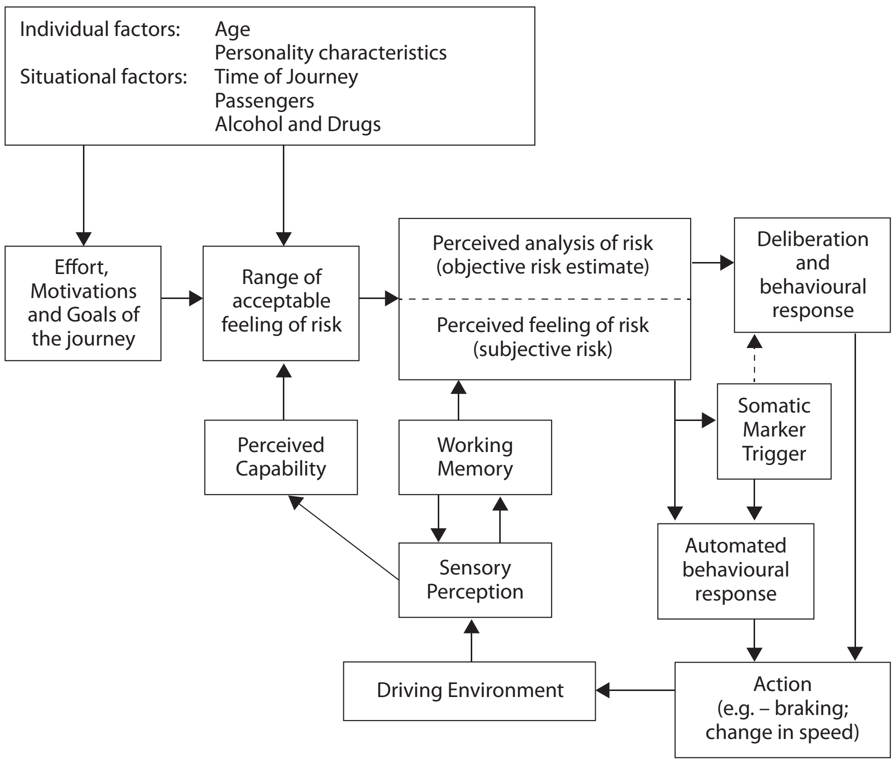

Figure 2.4. Feelings of Risk Homeostasis model (from Kinnear, 2009)

FRH also attempted to make some of the psychological processes behind driver decision making more prominent by including separate response types; automated and deliberative. This change also has the effect of removing the somewhat vague 'comparator' box featured by TDH and RAT.

2.1.4 Commentary on TDH and RAT

The fact that TDH and RAT both seem to rely on the monitoring of a subjective variable such as perceived task difficult or feeling of risk is in conflict with other models of driver behaviour such as zero-risk theory, or the more recent multiple comfort zone model (Summala, 2005; Summala, 2007) – see section 2.3). These other models state that uncomfortable feelings, such as feelings of risk, only occur once a certain performance threshold has been crossed. In this sense they act as warnings, and are indeed binary, only impacting on driver decision making when certain set situations or stimuli are encountered. As mentioned above, the initial formulations of TDH also took this threshold view for feelings of risk (Fuller, 2005; Fuller, McHugh et al., 2008). Indeed the earlier work discussing TDH appears to reject the idea of risk perception having a constant role in driver decision making (Fuller & Santos, 2002; Fuller, 2005).

Furthermore, despite its connection to RAT (Fuller, 2007; Fuller, 2011) a threshold account for feelings is actually more in line with the predictions of the Somatic Marker Hypothesis, in that in the Somatic Marker Hypothesis changes in emotions only occur when certain learnt (or in some rare cases innate) stimuli are present and then only become feelings once attention is directed to them (Damasio, 1994; Damasio, 2003). Similar to RAT, FRH claims that automatic risk appraisal occurs through unconscious unfelt feelings (Kinnear, 2009). However, this appears to be because, despite its use of the Somatic Marker Hypothesis, the FRH model does not make a distinction between feelings and emotions; a problem that Kinnear suggests should be addressed.

It is not just the constant monitoring of a feeling of risk that is an issue, as task difficulty is also thought to be constantly monitored (Fuller, McHugh et al., 2008). However, according to the mental workload literature, this may not be the case. While people do have a tendency to operate at an optimal level of workload, this level of workload is defined, not by people typically being aware of a specific feeling of optimal workload, but rather is indirectly inferred by the absence of under or over load. This principle is well demonstrated in Figure 2.5 below, which shows various subjective and objective measures of workload and their inability to detect optimal workload directly. Since task difficulty has been suggested to be analogous to mental workload (Fuller, 2005) this is a challenge to the assumption that task difficulty is continuously able to be monitored and a set range targeted.

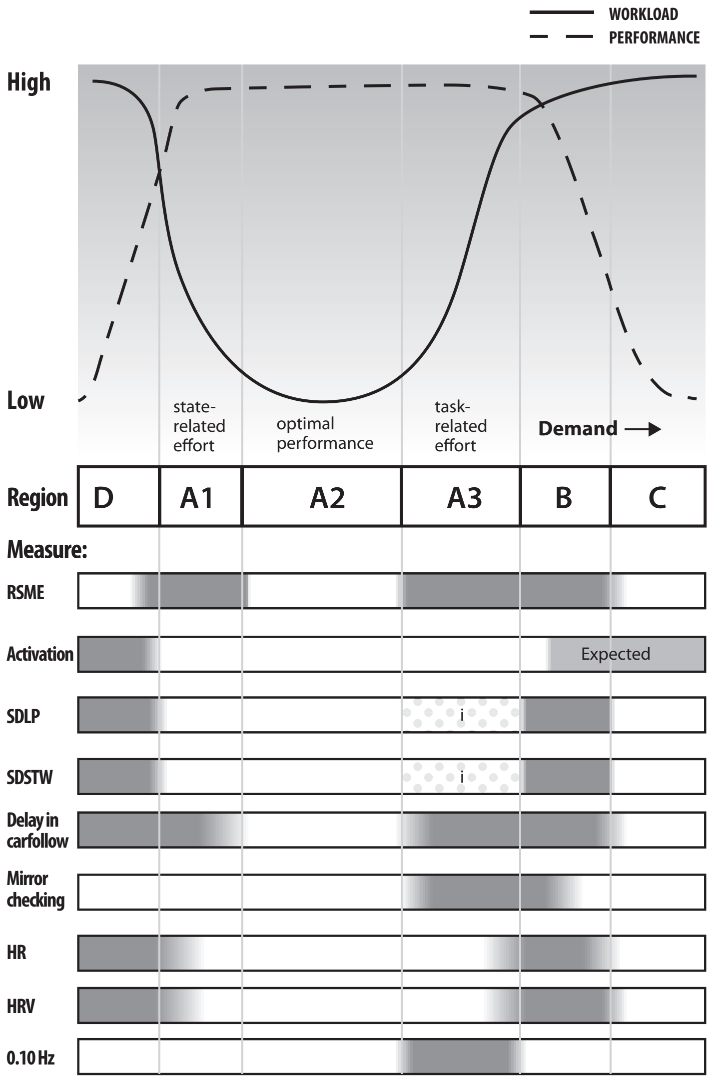

Figure 2.5. The sensitivity of various measures to detect which region of workload and performance an individual is operating at (from de Waard, 1996). The shading indicates the measure is sensitive to workload in this region. RSME and Activation are self-report measures and SDLP and SDSTW are primary task performance measures. 'Delay in carfollow' and 'Mirror Checking' are both secondary task performance measures. Finally Heart Rate (HR), Heart Rate Variability (HRV) and .10 Hz are all cardiac measures.

Summala (2007) has also challenged the finding from Fuller, McHugh and Pender (2008) that ratings of task difficulty and feelings of risk are highly correlated. He instead suggests that this correlation may be due to semantic confusion of the two terms during rational evaluation by participants. Although it should be noted that since risk is defined as the probability of an occurrence (which is effectively the difficulty of a task) which is then multiplied by the consequence of that occurrence (Nordgren, Van Der Pligt, & Van Harreveld, 2007), it is easy to see how feelings of risk and task difficulty could come to correlate.

TDH and RAT have also been criticized as concentrating overly on speed and vehicle trajectory as the only way that drivers are able to change task demand (Carsten, 2009). This does seem to be the case with a focus on 'effects on speed choice' in the models (see Figures 2.2 & 2.3). This is a challenge to the validity of TDH/RAT, which as a comprehensive model of driver behaviour should be able to explain the whole driving task. FRH deals with this issue by being somewhat vaguer about its specific operational pathways, suggesting that the process of risk comparison leads to 'action' (Kinnear, 2009). This unfortunately opens FRH up to the criticism that has been applied to earlier theories of behavioural adaptation, in terms of being vague about the pathways through which they operate (e.g. Carsten, 2009; Michon, 1985; Michon, 1989; Ranney, 1994; Rothengatter, 2002).TDH and RAT themselves can also be criticized on these grounds due to their somewhat vague 'comparator' box (Fuller et al., 2008; Fuller, 2008; Fuller, 2011). Another difficult aspect of TDH and RAT is that they refer to a target range of feeling of risk or task difficulty, rather than one set level. While this seems reasonable, it does somewhat add to the difficulty of falsifying the theory, as exactly how wide or narrow this range is, or how the range is set, has not yet been clearly established. It has been suggested however that there are different driver types which have different ranges (Fuller et al., 2008; Fuller, 2011). However, at the moment, any lack of reaction to a change in feeling of risk or task difficulty on behalf of a driver could be put down to the change not being large enough to move outside of their preferred range.

Some of the above factors even led Carsten (2009) to criticize RAT as being no more useful than, and even extremely similar to, the earlier Risk Homeostasis Theory (RHT) of Wilde (1976). This is a charge that Fuller has defended by pointing out that RHT relies on a target level of objective accident risk arising from a utility decision making process. Whereas objective accident risk plays no role in RAT and utility decisions do not affect the setting of the preferred level of feeling of risk (Fuller, 2011).

Finally a study by Broughton et al (2009) should be considered. This study claims to demonstrate that TDH can be used to generate specific predictions and provide the behavioural pathways through which these predictions will occur. To do so, motorcycle riders and car drivers' self-reported behaviour was compared. The authors predicted that due to motorcyclists' aversion to braking and their problems with being seen by other road users, motorcyclists would have a higher perceived task difficulty in urban areas. Therefore, according to TDH they would speed less in urban areas than car drivers. The results of Broughton et al (2009) initially do seem to support TDH, with motorcyclists reporting less speeding in urban areas. However, if real world speed data is examined for the UK (Fuller et al., 2008) it is found that motorcyclists' speed at about the same rate as car drivers' in urban areas. Furthermore, motorcyclists are more often found to be excessively speeding in urban areas. Broughton et al. (2009) explained this by questioning the methodology of how speed data was collected by the Department of Transport in the UK and speculating about the influence of different personality types of motorcycle driver. However, other studies looking at on-road speed measurement in the UK, Italy, and Cambodia have all found that motorcyclists drive faster than car drivers in urban areas (Horswill & Helman, 2003; Kov & Yai, 2010; Perco, 2008). This presents a difficult situation for TDH, in that seemingly valid predictions generated by the model have been supported by self-reports but are not well supported by actual real world speed data.

2.2 Monitoring the RMM

Another model of interest is the Risk Monitor Model (RMM) (Vaa, 2011). The RMM was originally referred to as simply the Monitor Model (Vaa et al., 2000; Vaa, 2003; Vaa, 2007) and was proposed in Norwegian reports aimed at developing a model of driver behaviour (Vaa et al., 2000; Vaa, 2003). It was not until 2007 that a comprehensive account of the Monitor Model was published in English (Vaa, 2007), and it is only recently that it was renamed to become the Risk Monitor Model (Vaa, 2011). However, with exception of the initial report, which outlined a very early draft version of the model (Vaa et al., 2000), the model's structure has remained relatively unchanged[2]. Therefore the version discussed here will be that of the RMM, which can be seen in Figure 2.6.

[2] With RMM adding only a distinction between 'primary' or innate emotions, and 'secondary' or learnt emotions into the text of the model itself (Vaa, 2003; 2007; 2011).

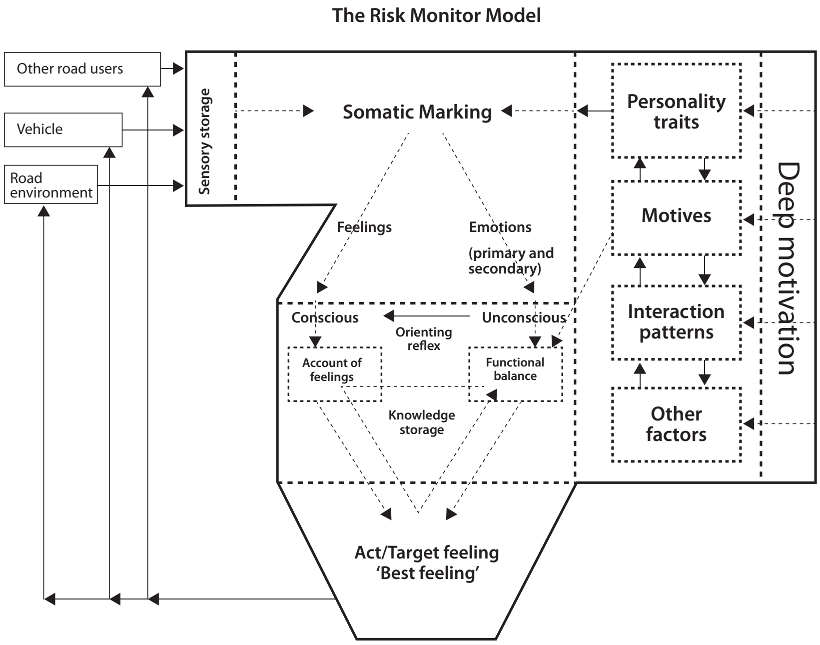

Figure 2.6. The Risk Monitor Model (RMM) (from Vaa, 2011)

The RMM is described by Vaa (2011) as a combination of several components from other older models; such as the subjective risk monitor from zero-risk theory (Näätänen & Summala, 1974), Taylor's (1964) assertion that galvanic skin response (GSR) governs drivers' decision-making, Wilde's (1976) idea of a target variable, Reason's (1990) model of information processing, and the principles of operant conditioning. However, as can be seen from Figure 2.6, the Somatic Marker Hypothesis is at the RMM's heart (Damasio, 1994; Damasio, 2003 – see section 2.1.3.2). According to the RMM, driver's personality traits, interactions with other road users and a catch all 'other factors', are all filtered via the somatic marking system before impacting on driver decisions. A driver's motives also are shown as both influencing behaviour via somatic markers, but also directly influencing functional balance. This occurs because in Vaa's (2011) view, a constant motive of all individuals is to maintain their bodies' functional balance, or in other words, physiological homeostasis. The end result of the somatic marker facilitated process described by RMM is a drive to maintain/obtain a target 'best feeling'. The target 'best feeling' is variable, in both its value and the type of feeling, but Vaa (2007) does specify several candidates for target feelings including; tension or anxiety, arousal, sensation, pleasure, relaxation, threat/difficulty avoidance, compliance, and non-compliance. Exactly how some of these rather broad concepts are 'feelings' is not really clear however. Also, while RMM does propose that there is a variety of target 'best feelings', 'feelings of risk', or at the least the monitoring of risky stimuli appear to be seen as a key factor in creating this 'best feeling' (Vaa, 2007; Vaa, 2011). Ultimately, it is through the motivation, unconscious or otherwise, to maintain or reach this target 'best feeling' that behavioural adaptation occurs.

2.2.1 An Evolutionary Model

RMM's focus on the Somatic Marker Hypothesis, functional balance, and risk is partly due to an attempt to ground it in evolutionary theory. Vaa states that, based on the Somatic Marker Hypothesis, the primary (deep) motivation of humans is to survive and, therefore, the body must have evolved as a monitor of risk in order to facilitate this survival (Damasio, 1994; Damasio, 2003; Vaa, 2007; Vaa, 2011). In fact in depictions of the RMM, the black bounding box is said to represent the body as the risk 'monitor'. The body, therefore, aims to maintain functional balance, consciously and unconsciously, and by doing so a 'best feeling' is targeted. This conclusion is also based on the research carried out by Taylor who examined drivers' GSR, and suggested that GSR peaks at sites of high accident involvement, allowing drivers to pace the driving task based on this information (Taylor, 1964).

Vaa (2011) even goes so far as to suggest that part of the reason why non-raised pedestrian crossings don't always improve safety is that a pedestrian represents a small, and rarely encountered, survival threat to a car driver. Whereas a raised pedestrian crossing, by threatening to directly damage vehicles every time it is encountered is more of a direct threat.

2.2.2 Commentary on RMM

That life, in evolutionary terms, is ultimately about survival seems hard to question. But to be more specific it is survival in order to pass on your genes to your offspring that is most important in evolution. Otherwise evolution cannot act in a selective fashion and, therefore, does not operate at all. As such, it is not enough to simply survive; rather an individual organism must also breed. Once breeding has been achieved and the reproductive age has been passed then for many organisms survival often does not continue for much longer either.

One can, therefore, question the RMM's assumption that the body is primarily a risk detector. As mentioned earlier, risk is defined as the chance of something occurring and the consequence of that occurrence (Nordgren et al., 2007). The second part of this definition, the consequences, relies largely on memory and learning. In other words an organism must either be able to remember the consequences of its actions and/or the actions of others, and then recall them, or have built up a learnt conditioned response to certain stimuli, in order to take them into account in future decisions. This makes a feeling or even an underlying learnt emotional response about 'risk' useful in some situations but less so in the day to day survival of life where the immediate consequences of actions are often not apparent.

If there is one constant however, it is that every action costs energy and energy is in limited supply. Therefore it is energy conservation that is a more credible basic guiding motivation for life. For example, when animals confront other members of their own species they usually do so through dominance displays and ritualised behaviour. These may in some cases resemble fights, however they are not. Fighting is an extremely costly expenditure of energy that can leave even the victor vulnerable and weak. Rather these rituals are a more energy efficient manner of determining fitness and dominance, and thus avoiding the costly energy expenditure of fighting. Even predatory species, which by their nature must come into conflict with other species, tend to only target the weakest prey, those that will take the least effort to bring down. The mating rituals of animals serve a similar purpose, usually allowing the female of the species to assess the evolutionary fitness of potential mates, and therefore her potential offspring, before investing the large amount of energy required to reproduce.

Furthermore, the learning of consequences of behaviour in itself is a costly exercise, and in some cases some consequences are so dire there is no chance to learn at all. However, information about the chance of failure at an action, in other words the difficulty of an action or how much energy/effort it will cost, is usually much more accessible and more apparent at a basic level.

That is not to say that risk does not play a role. That the difficulty of behaviour can also be associated with threats, and lead to a feeling of risk, is understandable in that difficult tasks are often risky tasks. As mentioned earlier, ratings of feelings of risk have indeed been found to be highly correlated with ratings of task difficulty and effort (Fuller et al., 2008; Kinnear et al., 2008). But with the exception of a few innate reactions to stimuli, a feeling of risk must be first learnt to be associated with the much more readily available information on the difficulty of the action, information that does not necessarily have to rely on memory and learning, and can become apparent simply through the limitations of our bodies.

Furthermore, from a biological perspective, homeostasis is not maintained through constant monitoring of the current state directly, but rather by reactive responses to thresholds being crossed indicating that homeostasis has been breached. For example, neurons themselves, which are important components of our bodies system for maintaining homeostasis, only fire when there are sufficient stimuli (chemicals) to cause them to do so, and even then it takes a threshold of nerve impulses to trigger a physiological response. This is a much more energy efficient way of handling the situation; to only react in the comparatively rare situation of being 'out of bounds', rather than to expend constant energy checking on normality. As stated earlier, this threshold, reactive nature of somatic markers is already an acknowledged part of the Somatic Marker Hypothesis (Damasio, 1994; Damasio, 2003).

Part of the argument for the constant monitoring of risk within RMM is also made through the use of Taylor's GSR data (Taylor, 1964). This interpretation of Taylor's work also partly motivated earlier theories such as Risk Homeostasis Theory (Wilde, 1976) and even RAT (Fuller, 2011), and has been questioned. Most importantly it has been pointed out that GSR is an extremely reactive measure, and responds to too many variables, not only risk (Fuller, 2005; Heino, 1996; McKenna, 1988; Summala, 2007). For example, one critique of Taylor (1964) made by Summala (2007) is that many of the road sections at which Taylor's participants showed increased GSR activity were also areas requiring significant motor control. Therefore it is possible that the GSR increases were simply caused by the physical activity of driving the vehicle. Fuller (2005) critiqued Taylor's (1964) findings in a similar way, saying that the changes in GSR Taylor observed could instead be taken as evidence for the constant monitoring of task difficulty, not risk.

Moving on, while RMM openly acknowledges the role of automatic actions and unconscious processes in creating a 'best feeling', it ultimately relies on the targeting and monitoring of a conscious feeling. Therefore, much like with the predictions of TDH and RAT, it should be expected that an individual's feelings can be seen to visibly change over a range of different driving situations. However, as already discussed in section 2.1.4 this constant monitoring of feelings has been challenged by some other models (Ljung Aust & Engström, 2011; Näätänen & Summala, 1974; Summala, 2005; Summala, 2007).

Another issue with RMM is that there is a lack of feedback loops in the model. This is because the only feedback shown in the model is onto the somatic markers, via sensory storage, from the outside influence of other road users, vehicles, and the road environment. It also seems to suggest that a driver's personality, motives, interaction patterns, and other factors affecting driving are totally set and stable and only arise from deep motivations.

Finally, Fuller (2011) states that RAT supersedes RMM by already handling the idea of target 'best feeling' through the more parsimonious use of a target range of feeling of risk. Fuller also states that the other 'best feelings' put forward by Vaa simply make up the dispositional motivations and proximal influences in setting a target risk range. For example, if a driver is seeking to gain the 'best feeling' of arousal, then this motivation will modify the target range of feeling of risk they are seeking.

2.3 The comfortable thresholds of the multiple comfort zone model

The multiple comfort zone model or safety margin model (Summala, 2005; Summala, 2007) is a hierarchical model of driver behaviour which could be described as a modern evolution of Näätänen & Summala's (1974) zero-risk theory and Summala's (1997) hierarchical and motivational model of behavioural adaptation. Much like TDH/RAT and the RMM, it also mentions the Somatic Marker Hypothesis (Damasio, 1994; Damasio, 2003), but only to point out that emotion and feelings have long played a role in zero-risk theory (Näätänen & Summala, 1974) via the subjective risk monitor (Summala, 2007). The Safety Margin Model also incorporates some parts of TDH and the RMM, while at the same time taking a somewhat different approach in terms of how driver decision making and behavioural adaptation is viewed. Also like TDH, it has been proposed as an attempt to create a model which produces testable hypotheses (Summala, 2005).

2.3.1 A hierarchical and motivational model

As an evolution of the earlier zero-risk theory (Näätänen & Summala, 1974), the multiple comfort zone model is a motivational model. It views driver's excitatory motives, personality, and driving goals as prevailing factors. These motives interact with the road system and push drivers towards changing their behaviour to satisfactorily meet their driving goals, for example, by increasing speed to arrive at a destination on time. One of these motives can also be a desire to take pleasure in driving, which is viewed as pushing drivers towards greater risk taking. These motives can also act as limiters on behaviour in terms of an individual's disposition towards compliance with the law (Summala, 2005; Summala, 2007). In terms of its hierarchical nature, it views driving as broken down between activities at the strategic, tactical, and operational levels (Michon, 1985; Summala, 1997). Within this hierarchy, the strategic level is the highest and refers to decisions about aspects of the driving task such as: the route to take, the vehicle to drive, or what time of day to leave. The tactical, or maneuvering, level is the next level down and refers to the general day to day handling of driving situations such as gap acceptance and the navigation of intersections and corners.

The lowest level is the operational level where the generally automatic processes of driving such as lane control, and gear and pedal operation occur.

2.3.2 Safety Margins

Given this motivational and hierarchical framework, the multiple comfort zone model concerns itself mainly with what keeps these motivations in check; a process which is essentially the same at each of the three levels. To do so, the multiple comfort zone model uses the control mechanism of safety margins. These are based on the idea of proxemics (Hall, 1966), in that individuals have certain areas of personal space around them which trigger emotive reactions if breached. The model states that drivers maintain a similar space around their vehicle. An proxemics approach to driving is an idea that dates back to work by Gibson & Crooks (1938) who proposed that drivers have a 'safety zone' which they use to detect threats and navigate the road environment. In essence, rather than one emotive control function for driving, such as the feeling of risk, driving is mainly controlled by the monitoring of various safety margins (Summala, 2005; Summala, 2007). The most prominent safety margins being those which are based on time, specifically time to collision and time to lane crossing. This makes the time available for decision making one of the key controllers of driver behaviour and it is somewhat comparable to the idea of the current task difficulty in TDH (Fuller, 2005) or the workload demand of a task (de Waard, 1996). So, if a driver is on a wide road, there is now more time available and, therefore their safety margins increase and their motives are free to perhaps push them towards higher speeds. On the other hand, if the situation changes to breach (or comes close to breaching) these safety margins then drivers begin to feel uncomfortable. This is the idea of a subjective risk monitor which triggers when these safety margins or thresholds are crossed and creates the experience of risk, a feeling which is usually absent from day to day driving. In this case, a feeling of risk acts as a warning and something to be avoided, rather than a variable to be targeted and maintained (Summala, 2005; Summala, 2007).

2.3.3 Comfort Zones

Much of the thinking around safety margins and the subjective risk monitor was already present in zero-risk theory (Näätänen & Summala, 1974). What the multiple comfort zone model adds is the idea that the act of staying within these safety margins constitutes being in a 'comfort zone'. Being within your safety margins does not produce one specific emotion or feeling but rather results in a general overall mood of comfort (Summala, 2005; Summala, 2007). The 'multiple' part of the comfort zone model comes from the idea that there are multiple candidates for margins, ranging from time to lane crossing to the comfort of the driver's seat, all of which constitute a comfort zone. This may seem similar to the idea of targeting and maintaining a 'best feeling' or 'feeling of risk' as suggested by RMM or RAT (Fuller, 2008; Fuller, 2011; Vaa, 2003; Vaa, 2007; Vaa, 2011), but Summala (2007) insists that this is not the case. Operating in a comfort zone does not arise by drivers targeting and monitoring 'comfort', but rather is an indirect side effect of the action of not crossing the thresholds of their safety margins (Summala, 2007). In other words, driving is seen as a mainly automatic control task bounded by well learnt safety margins. The automatic and mostly unconscious maintenance of these safety margins keeps individuals within a 'comfort zone' that is seen as not particularly arousing but is perhaps mildly pleasant (Summala, 2005; Summala, 2007). The breaching of these safety margins or a lack of goal progress, on the other hand, creates uncomfortable emotions and feelings which can act as warnings. This view of the comfort zone is very similar to the idea of mental workload discussed in section 2.3.2.4 and shown in Figure 2.5. This threshold account of the role of emotions and feelings in driving certainly matches well with the idea of somatic markers (Damasio, 1994; Damasio, 2003).

2.3.4 Satisficing not optimizing

A final important distinction in the multiple comfort zone model is that it clearly describes driver decision making as mainly operating via satisficing (Summala, 2007). That is to say that driver decision making, consciously or unconsciously, typically aims to have drivers do just enough to meet their goals rather than maximizing their gains and minimizing their losses. This fits well with established lines of thought in evolutionary and behavioural science (Simon, 1955), and is related to the concept of energy preservation mentioned in section 2.3.3.2.

2.3.5 Commentary on the multiple comfort zone model

The threshold account of feelings of risk and task difficulty promoted by the multiple comfort model is not supported by studies by Fuller, McHugh et al (2008) or by Kinnear, Stradling et al. (2008) who both found that ratings of feeling of risk were constantly present and increased systematically with speed. In addition, Fuller (2011) has commented that with the multiple comfort zone model, Summala's theorizing has become more inclusive, and that comfort zones are similar to the idea of targeting a feeling of risk or task difficulty. As mentioned above, Summala (2007) would disagree with this. However, Fuller (2011) also suggests that the multiple comfort zone model can already be accounted for within the framework of RAT; in that the motivational side of the model fits within setting a target range of task difficulty/feeling of risk. Fuller (2011) also suggests that the safety margins or comfort zones in terms of time to lane crossing, time to collision, and glare, are accounted for in the perceived task difficulty. Furthermore, Fuller (2011) states that the motive of compliance with enforcement is, as mentioned in section 2.1.2.1, already handled by TDH/RAT as an additional factor outside of the normal task difficulty/risk monitoring loop. Finally, Fuller (2011) suggests that the other 'comfort zones' or motives, such as the temperature inside the car, could also be modelled within RAT in a similar secondary fashion, although he specifies that they would be outside of normal safety motivations.

Common objections to zero-risk theory could also be applied to the multiple comfort zone model. One such objection is that if risk is not constantly monitored, then how does the subjective risk monitor know when risk is too high? (Fuller, 1984; McKenna, 1988; Rothengatter, 2002; Vaa, 2001). However, this objection could be explained as a misinterpretation of the model. It is the breaching of safety margins that activates the subjective risk monitor, doing away with a need to be constantly monitoring a feeling of risk and replacing it with monitoring the control task of driving (Summala, 2005; Summala, 2007).

Another common objection to zero-risk theory, and therefore the multiple comfort zone model, is that as a behavioural learning model it relies on too many contingencies being learnt in order to create all the safety margins needed (Fuller, 2005; Michon, 1985; Michon, 1989; Ranney, 1994). These objections however seem to ignore the highly predictable and forgiving nature of the driving environment and the years of experience that drivers have built up successfully navigating their environment before they even sit behind a wheel of a car. Finally, since the model is hierarchical, then Rothengatter's (2002) assertion that such hierarchical distinctions are artificial and do not reflect the reality of the complex control environment that makes up driving is also relevant.

2.4 Other contemporary models

The models discussed above are not the only post 2000 models aimed at describing driver behaviour. While the empirical chapters that follow will focus primarily on the models already described, the rest of this chapter provides summaries of some of the other models that have been proposed since 2000. The purpose of these summaries is not to provide a completely comprehensive review but rather to give some further indication of the ways that model development is trending. As such, only models that aimed to explain or describe the whole driving task or models which have particular impact on one or more of the main models discussed in this thesis are presented. These models were collected as part of an independent literature review and with the assistance of a table listing the models found during the Glendon (2011) analysis, mentioned in the introduction (Glendon, 2010).

2.4.1 Four facet model of driver behaviour

Groeger's (2000) four facet model of driver behaviour is a socio-cognitive, goal focused framework in which driver behaviour can be examined. It consists of four facets which are called: implied goal interruption, appraisal of future interruption, action planning, and (action) implementation.

The first of these facets, implied goal interruption, refers to the key assumption within the model, which is that driving is a complex multiple goal driven process and that progress towards these goals are constantly monitored, implicitly and explicitly, by drivers. This is done through the monitoring of the expectancies that arise from drivers goals and, therefore, this facet is said to come into play when a driver 'notices', either consciously or unconsciously, that their expectations for goal progress are not being met or may not be met in the near future. According to a factor analysis carried out by Groeger and his colleagues this facet is made up of an individual's readiness to respond, behavioural standards, scene evaluation ability, their tendency to provide cursory analysis of situations, and their ability for making spatial judgements.

The next facet, appraisal of future interruption, or simply appraisal, is conceptualised as when drivers determine what the outcome of the aforementioned goal interruption will be. According to a factor analysis, this facet includes the expectations of the drivers' own ability and their expectations of the abilities of other car users, as well as a range of personality factors such as behavioural responsibility, confidence, extraversion, stress proneness, and the value drivers place in being active or passive. Although Groeger doesn't mention it, it is worth noting that these first two facets could perhaps be seen as quite similar to the idea of situation awareness, which also is made up of steps, such as becoming aware of a problem and working out what will happen in the future (Endsley, 1995).

Action planning is the third facet and is relatively straight forward in representing the creation of a plan to deal with goal interruption. It should be noted that while this is referred to as 'planning' it does not necessarily imply that this is done in a conscious or deliberative manner, and indeed Groeger is careful to stress that all of the facets are capable of operating at both an implicit and explicit level. As such the action planning level can also simply represent the activation of automatic responses or heuristics. This facet represents a driver's general cognitive and physiological ability in terms of executive function. Factor analysis of this facet revealed three factors; general intelligence, reaction speed, and selection.

The final facet, implementation, refers to the physical and mental ability of the driver to implement their action plan. This also includes the plan to change nothing about their behaviour and maintain current performance if this is deemed the appropriate response. This level is constructed by four factors: motor control, eye-foot and eye-hand co-ordination, and the cognitive task of storing and retrieving digit spans.

The validity of the four facet model has been experimentally examined by Groeger who reports that it can account for 30–40% of the variance in driver behaviour, depending on whether self-assessments, expert assessments, or speed comparisons of a driver's behaviour are made. The model also includes hypothetical feedbacks between the fourth facet and the second and third, as well as feedbacks between the second and third facets with each other and the first level. Interestingly however, the model, when presented in diagram form seems to suggest that drivers can move straight from the first facet of identifying goal interruption right to the third facet of planning an action without first going through the second facet of working out the consequences of the detected goal interruption (Groeger, 2000). How this occurs is not made clear and indeed the text that accompanies the diagram of the model seems to imply that it operates in more of a linear stepwise manner, and indeed, it has been interpreted by some others in just such a fashion (e.g. Mesken, 2006).

Finally it should be noted that while Groeger does often refer to threat detection and hazard perception when discussing this model, he does also make clear that he believes that risk, in terms of accident risk, does not generally play a large role in driver behaviour. Rather, he suggests that most of the time 'threats' refer to challenges towards the immediate goals of drivers such as having a smooth comfortable ride or getting to a location on time.

2.4.2 The lateral acceleration model

The lateral acceleration model (Reymond, Kemeny, Droulez, & Berthoz, 2001) is an addition to the existing time to lane crossing model (TLC) which suggested that drivers maintain certain learnt, time based safety margins when navigating the road environment (Godthelp, Milgram, & Blaauw, 1984). The lateral acceleration model states that in addition to the visual information used to judge TLC safety margins, drivers are said to also have a learnt threshold based on the lateral acceleration they experience when navigating curves.

This was tested by Reymond et al (2001) through the use of a driving simulator that could be turned from static to dynamic in terms of its movement, thereby providing conditions in which feelings of lateral acceleration were absent or present. The result was somewhat mixed, with the upper limits of lateral acceleration in participants decreasing less steeply in the static condition but drivers generally maintained the same driving style when cornering across the two conditions.

Reymond et al (2001) suggested that this is because driver's motor control of cornering is so over learnt and automatic from on road situations where lateral acceleration is present, that they are able to maintain their usual cornering style even in conditions where this information is absent. This explanation does however somewhat undermine their argument for the added benefits provided by dynamic simulators in terms of providing accurate lateral acceleration information. While this model is obviously limited, the idea of a lateral acceleration threshold would easily fit within the multiple comfort zone model (Summala, 2005; Summala, 2007) which already uses TLC as a core performance threshold.

2.4.3 Conceptual model of seatbelt use

The conceptual model of seatbelt use is a regression model which takes a trait based approach to try to examine the determinants behind self-reported seatbelt use amongst young drivers in the US (Calisir & Lehto, 2002). The resulting model showed that while the participants in the study were able to sit down and make relatively accurate risk judgements about accident probabilities and consequences in the case of not wearing a seatbelt, that risk perception did not significantly predict self-reported seatbelt use. Rather, demographic factors such as age, gender, and GPA were the most significant predictors (combined r^2 of .16) with the perceived usefulness of the seatbelt also playing a small predictive role (r^2 .02–.03). The authors conclude that this finding means that drivers do not use conscious risk perceptions when making their decision to wear a seatbelt or not, but rather that seatbelt use is habitual. This model itself is obviously limited and descriptive but could be taken as support for broader models such as zero-risk theory (Näätänen & Summala, 1974; Summala, 1988) or the comfort zone model (Summala, 2005; Summala, 2007) which also state that risk perception plays very little role in daily driver behaviour. Although care should obviously be taken with regression studies which rely only on self-reported behaviour.

2.4.4 Motivational Model of Driving Anger and Aggression

The Motivational Model of Driving Anger and Aggression (Neighbors, Vietor, & Knee, 2002) is a personality model aimed at explaining, as the name suggests, driver anger and aggression. The model itself is an application of self determination theory (Deci & Ryan, 1987) to a driving situation. Self determination theory states that people are motivated to regulate their behaviour both in reaction to 'pressures' (external or internal) to produce certain behaviours and a tendency to react to events in a way that is 'ego-defensive'. To this existing framework the authors add the idea of preexisting tendencies for anger and aggression (traits), and then tested the model through the use of a questionnaire. The result was that ego defensiveness did predict self-reported driving anger, which then predicted self-reported driver aggression. Feeling pressured on the other hand had no significant impact. The authors take this as meaning that much driver aggression occurs due to the interpreting of the action of others as insulting or damaging to the ego of drivers. Ultimately however, this model suffers from the same problems as other self-report based models, and is, by design, not particularly useful for understanding driver behaviour as a whole.

2.4.5 The Driver-in-Control model (DiC)

The DiC model is a hierarchical model based on a cognitive systems perspective and criticizes earlier theories in terms of treating the driver as a separate component from the vehicle (Hollnagel et al., 2003). Instead it proposes that the driver and vehicle should be seen as a Joint Driver-Vehicle System. The model proposes a regulating loop where driver's intentions, objectives, actions, and behavioural outcomes are monitored. This is described as occurring at four distinct levels: the targeting level, where high level goals are set, the monitoring level, where current environmental traffic conditions are assessed, the regulating level, where goals for the immediate control of the vehicles are set, and the tracking loop where low level control of the vehicle goes on. The model also has feedbacks between the levels in terms of compensatory control actions between the last two levels and anticipatory control between the first three levels.

Ultimately, while the DiC is a useful systematic and cognitive description of goal driven processes in driving, it is openly described by its creators as a descriptive model and, therefore, could be criticized as not directly resulting in solid predictions that could be tested. However, it could be useful in modelling traffic behaviour and as a guideline for designers of driver assistance technology.

2.4.6 Causal Chain for the effect of road safety measures

This is a subjective utility maximisation, risk based model proposed by Elvik (2004) aimed at explaining the factors that lead to behavioural adaptation by drivers in the face of road safety measures. The model is a relatively straight forward causal chain with road safety measures first working to modify basic risk factors on the road. According to Elvik, drivers are continuously monitoring accident risk and, therefore, once a change in accident risk has occurred thanks to a new road safety measure, one of two things will happen. The first is 'antecedent behavioural adaptation', which is a pre-existing reaction or behavioural response to the change in the risk factors, which then goes on to change the safety margins the driver maintains through their behaviour. The second option is that there are changes to the 'structural safety margin's' of the road system. These changes in the structure of the road system, which change its objective safety margin, will then be behaviourally adapted to: if they are noticed by the driver, if the safety margin increase is large, if they primarily effect accident probability rather than injury probability, if the amount of utility gained by adapting is high, and if the damage that an accident may cause is low.

This model's use of accident risk as a central factor means that it can be criticized in the same way that earlier models, like RHT (1976), were. The primary criticism being that people are not very aware of accident risk, which is generally low, and that safety measures tend to only slightly alter this already low chance. This makes it very unlikely that people are able to monitor and react to these small changes. Furthermore, the subjective utility maximization view of risk perception taken by this model is generally considered to be quite rare in human decision making (Slovic et al., 2004; Summala, 2005; Summala, 2007).

2.4.7 Model of Accident Prevention

The Model of Accident Prevention (Lund & Aarø, 2004) was formulated in an attempt to move away from a perceived dominance of social psychology models, such as the theory of planned behaviour (Ajzen, 1985), in accident and health research. The Model of Accident Prevention states that there are three main types of measures that can prevent accidents: attitude modifications, behavioural modifications, or structural modifications. These three types of measure are therefore positioned at the core of the model. The model is, therefore, presented as an interaction between the person (made up of behaviour, attitudes, and beliefs) and the context/situation (made up of social norms, the culture and the physical environment). These sub aspects are shown as all interacting with each other, leading to the prevention of accidents and being influenced by the appropriate modifications (behavioural, attitudinal or structural). This means that the model itself is quite broad and descriptive in nature and, therefore, does not give much of an insight into the underlying mechanisms behind driver behaviour.

However, in order to validate the model, and provide weightings for the importance of the three modifications in preventing accidents, Lund & Aarø (2004) conducted a literature review on accident prevention measures. In this review they found that pure attitude modification interventions have little to no effect in preventing accidents and that behavioural and structural modification is much more effective. However, they also report that if attitude modifications are combined with behavioural or structural modifications then they seem to be able to enhance the accident prevention effect. This finding of the ineffectiveness of pure attitudinal accident prevention measures is not new, and in fact is partly what promoted the creation of the Model of Accident Prevention. However, such interventions are still common within the accident prevention field, so perhaps it is still a point that is worth making.

2.4.8 Psychosocial function of driving in young people

The Psychosocial function of driving is a social and motivational model aimed at describing the various lifestyle aspects that can influence young people's driving behaviour (Møller, 2004). The model was constructed through a focus group study with a group of 29 young drivers and resulted in Møller identifying four 'psychosocial functions' for driving. These are: visibility (a way to get attention), status (the expression of their self-identity), control (as in the ability to control and handle a vehicle), and finally mobility (the ability to get around and fulfill goals).

The psychosocial functions are then broken down into eleven categories such as what car brand the driver has or their risk perception. These psychosocial functions, which could also perhaps be called motivations, are then said to interact with three main lifestyle functions of driving: leisure use, driving with or for friends, and driving patterns in terms of self-expression.

This model is obviously limited in scope and mostly descriptive in nature. However, in a large scale questionnaire study Møller & Gregersen (2008) did find that the psychosocial function of driving was an indicator of self-reported risky driving activities. Interestingly, in this study the questions used to assess psychosocial function of driving were based on nine variables, not the four functions or eleven main variables reported in the earlier Møller (2004) paper.

2.4.9 The qualitative model of behaviour adaptation

The qualitative model of behaviour adaptation (Rudin-Brown & Parker, 2004) was originally called the quantitative model of behavioural adaptation (Brown & Noy, 2004) and presented at an ICTTP conference in 2000. This model is aimed exclusively at explaining behavioural adaptation to driver assistance systems and suggests that driving experience is mediated via the trust the driver has in the driver assistance system. This trust is affected by a driver's personality, particularly their locus of control and sensation seeking characteristics. The driver's personality and their trust in the system then create their mental representation of the driving task, which is executed at the strategic, tactical, and operational level, and then interacts with the road system. It could be argued that the aspects that make up this model are already covered within the major models discussed above: in terms of the motives and 'human factors' component of TDH/RAT (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, 2008; Fuller, 2011), the motives and personality components of the RMM (Vaa, 2003; Vaa, 2007; Vaa, 2011), and the 'extra motives' component of the multiple comfort zone model (Summala, 2005; Summala, 2007). However, the qualitative model of behaviour adaption is more specific, and this led Carsten (2009) to praise the model for generating testable predictions, some of which have already been relatively successfully tested (Rudin-Brown & Parker, 2004; Rudin-Brown & Parker, 2004).

2.4.10 Behavioural framework for aggression at intersections

This mathematical gap acceptance model exists purely to simulate drive behaviour at unsignalised intersections; specifically whether drivers will perform an 'aggressive manoeuvre' at an intersection or not (Kaysi & Abbany, 2007). The model uses driver characteristics such as gender and age, characteristics of their vehicles in terms of year and performance attributes, and attributes of the traffic flow, such as time spent waiting at the intersection, to predict the performance of aggressive manoeuvres. The base characteristics of the driver, their experience, and the current traffic conditions, are filtered through their skills, attitudes, perceptions, and preferences and then modified by any relevant situational constraints, such as the time of day or current sight distance at the intersection, before producing the choice to accept (or reject) a gap in the traffic.

The model itself was calculated through the use of quite simple binary probit models, with attitudes for example, simply being a binary disposition towards being aggressive or not. The model resulted in a prediction that being younger than 26, driving a sports car, and the average speed of the road being driven were the best predictors of aggressive manoeuvres at intersections. These predictions were somewhat validated by comparison with real world data.

2.4.11 The Safe driving behaviour framework

While not actually intended to replace any other models of driver behaviour, the Safe driving behaviour framework (Strecher et al., 2006) is still interesting as it combines several theories to create a reference point to review other literature on the psychological factors in driving. The models incorporated into the framework are TCI (Fuller, 2000; Fuller & Santos, 2002; Fuller, 2005; Fuller et al., 2008), RHT (Wilde, 1976), Deery's (1999) model of crash risk perception, the concept of reciprocal determinism from Social Learning Theory (Bandura, 1978), the theory of reasoned action (Fishbein & Ajzen, 1975), and the health belief model (Rosenstock, 1974).

The combination of all these models unsurprisingly results in what appears to be a quite a complex, multifaceted model of driver behaviour. But when examined more closely, the safe driving behaviour framework essentially turns around an idea of perceived accident risk being compared against a target level of risk acceptance, which then creates a behavioural intent. This intent is then moderated through the task difficulty of the current situation to produce behaviour. Other social or psychological factors such as sensation seeking or attitudes are shown as influences on these variables but it is this accident risk comparison that appears most important in the model. Therefore, the criticisms aimed at other such accident risk based models can easily be applied here (e.g. Fuller, 1984; Fuller, 2005; Michon, 1985; Michon, 1989; Näätänen & Summala, 1974; Ranney, 1994; Rothengatter, 2002). However, it is still interesting to see an attempt to combine several social and cognitive models together in this fashion.

2.4.12 Hierarchical model of operational anticipation windows in driving

Tanida & Pöppel (2006) provide a goal-directed model which attempts to provide a neuronal account of the driving task broken down into five hierarchical levels: the strategic, segmented tactical, manoeuvring, anticipative control, and sensorimotor and perceptual levels, with the last two levels being seen as outside of explicit control. These five levels are essentially an extension or finer detailed expansion of Michon's three level hierarchy which split driving into the strategic, tactical and operational levels (Michon, 1985; Michon, 1989).

The model states that anticipation of events and, therefore, goal processing is important for driving, yet this involves the processing of a lot of complex behaviour, a task which is limited by the ability of the brain to create windows in which the anticipation of events and outcomes can occur. These windows get progressively smaller in time frame as a driver moves down the proposed hierarchy from strategic control to the sensorimotor levels where the anticipatory windows are as small as 30 milliseconds. Apart from this attempt to introduce the concept of neuronal anticipatory time windows, and the five step hierarchy, this model is similar to other goal directed models in its basic operation. This suggests that drivers have goals at different levels, which then create anticipations, or in other words, expectations, which can be monitored, and then action can be taken if these expectancies are not met. Then, assuming that the driver has the resources, represented in the model by anticipatory time windows, to detect the loss in goal progress they will then change their behaviour in order to correct the situation. This time limited, goal directed, hierarchical conceptualization of driving is similar to the performance monitoring suggested by Summala in his multiple comfort zone model (Summala, 2005; Summala, 2007).

2.4.13 Situational analysis of behavioural requirements of driving tasks (SAFE)

SAFE (Fastenmeier & Gstalter, 2007) is built on Rasmussen's (Rasmussen, 1987) idea of information processing. The model states that drivers compare their perception of the current task environment with their expectations for performance and then make decisions based on stored heuristics. This results in a normative model of driving behaviour which can be used to carry out a task analysis. The model is therefore a descriptive or taxonomic model and cannot deal with, or predict, driver behaviour that deviates from normative rule following processes.

2.4.14 Driver celeration theory

Driver celeration theory (Af Wåhlberg, 2008) is a mathematical model aimed not at explaining driver behaviour as a whole but rather at predicting accident involvement. The core of the model is an assumption that all changes in speed indicate changes in risk, therefore driver celerations, which are the sum or average of all of a driver's accelerations and decelerations across a certain time, can be used to predict accident involvement. In other words, the model states that risky or dangerous behaviours tend to involve a lot of speed changes and, therefore, if you can look at an individual's celeration behaviour over time it should predict their accident involvement, specifically the accidents that they themselves cause. Ultimately, however, the whole model is just an exercise in curve-fitting and does not add anything to the psychological understanding of driver behaviour.

2.4.15 Calibration

Calibration (Kuiken & Twisk, 2001) is a motivational model based around the assumption that drivers are motivated to adapt to keep the mental load of the driving task to a minimum. This is done through the process of calibration, where drivers compare the perception of their own skills and capability with the demands and requirements they perceive arise from the driving task. This is very similar to the Task-Capability Interface model (Fuller, 2000) and task difficultly homeostasis (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008) discussed in section 2.1.1. The Calibration model is in the end descriptive but does suggest that part of the reason why young drivers are over represented in accidents is that their calibration is worse than more experienced drivers. This leads younger drivers to overestimate their own skills and underestimate the demands of the task. This in itself was praised by Rothengatter (2002) as an important idea that requires further research.

2.4.16 Åberg and Warners combined model and the Safety related driver behaviour model

Both Åberg & Warner's (2008) combined model and the Safety related driver behaviour model (Verschuur & Hurts, 2008) come from an attempt to combine two relatively popular models in traffic psychology. The first is the Theory of Planned Behaviour (Ajzen, 1985) and the second is Reason's (Reason, 1990) error taxonomy as assessed by the Driver Behaviour Questionnaire (DBQ).

In the case of Åberg & Warner's (2008) combined model, the power of these models to account for self-reported, and actual logged speeding was examined. The model was created through the use of a survey and states that the TPB variables of attitude, subjective norm, and perceived behavioural control, predict participants' perceived moral norm, which then predicts the DBQ variable of reported violations. Self-reported violations then predict self-reported speeding and to a lesser extent actual logged speeding. Attitude and perceived behavioural control also had small predictive impact on self-reported speeding, with moral norm also having a small predictive impact on actual logged speed. The only other DBQ variable that was significant was self-reported inattention, which was found to have a small predictive impact on self-reported speeding.

The Safety related driver behaviour model (Verschuur & Hurts, 2008) on, the other hand, used a much larger survey and was aimed mainly at predicting accident involvement. Much like the combined model, the only two DBQ factors that were found to be significant in the Safety behaviour model were self-reported violations and inattention. However, the predictive power of these variables was very weak.

To combine two such well used frameworks as the TPB and the DBQ is certainly an interesting approach. However the resulting models suffer from the same problems as both of its component measures in that they rely quite heavily on self-report and generally have small to very small predictive power.

2.4.17 Risk-adaption theory

Risk-adaption theory (Koornstra, 2009) is an application of what is called the 'psychophysical response and valence theory of choice behaviour' (Koornstra, 2007) to traffic behaviour. It also appears to be an expansion of an earlier model called the 'reference-frame theory of traffic risks' (Koornstra, 1990). The model itself is mathematical in nature as well as being quite dense and hard to tease apart. However, on close examination the model seems to suggest that risk behaviour in traffic is controlled by 'single-peaked' valences for fear conflicting with 'single-peaked' valences for arousal. So, in other words, the fear of an accident would conflict with the arousal of driving fast. The assumption seems to be that drivers have a preferred, ideal arousal level as well having a preferred ideal accident fear level. However, moving towards either of these levels effects the other, in that increasing arousal increases the fear of an accident away from the ideal range, and decreasing accident fear reduces arousal away from this point. The result is that when these two valences are combined, an 'indifference area' is created where there is not too much or two little of either variable.

The paper describing risk-adaption theory then goes on to state (Koornstra, 2009) that the model can account for three older models of driver behaviour: RHT (Wilde, 1976), zero-risk theory (Näätänen & Summala, 1974; Summala, 1988), and Threat avoidance theory (Fuller, 1984; Fuller, 1988; Fuller, 1990a; Fuller, 1990b; Fuller, 1992). It does so by setting one of its variables to zero. However the model itself does not necessarily support any of these interpretations, rather it just demonstrated that it could. Indeed the model seems to exist as a mathematical formulation in need of a driver and does not suggest how any of its variables should be set, or even really how they become set at an individual level. The closest it appears to come is suggesting that individuals are somehow sensitive to aggregate accident risk in the population. How this occurs is not made clear however. Ultimately, the idea that actions or situations have different valences which attract or repel individual decision making towards or away from them, is not new and is better expressed by other models, such as the Somatic Marker Hypothesis (Damasio, 1994; Damasio, 2003).

2.4.18 The situational control framework

A relatively recent model, the situation control framework (Ljung Aust & Engström, 2011) is aimed primarily at assisting designers of driver assistance and active safety systems with the design and evaluation of their products. The model takes a systematic and goal driven approach to driving, much like the DiC (Hollnagel et al., 2003), and combines it with a motivational account of driving similar to the multiple comfort zone model (Summala, 2005; Summala, 2007). By doing so, the model states that drivers seek goal states at various hierarchical levels of driving, including the goal of maintaining safety margins. The satisfactory movement towards these goals leads drivers to operate in a comfort zone and the failure to obtain or lack of progress towards these goals causes uncomfortable feelings. These uncomfortable feelings are then generally avoided, which restores the control based goals of the driver.

These safety or comfort zones are also proposed as guiding goal setting, with drivers tending to set goals which will place them within these zones. In particular, Ljung Aust & Engström (2011) define being in the comfort zone as feeling zero discomfort. The situational control framework, then goes on to suggest that when discomfort is felt, this will lead to learnt associations and to somatic markers (Damasio, 1994; Damasio, 2003) being created which can help with avoidance of similar situations in the future. The situational control framework, like the multiple comfort zone model (Summala, 2005; Summala, 2007), also makes the point of referring to driving behaviour as satisficing, rather than optimizing. All of this creates a conceptualization of a goal driven joint driver-vehicle system taking on sets of driver, vehicle, and environmental based 'trajectories' bounded by mostly automatically and unconsciously monitored safety margins, the crossing of which first produces feelings of discomfort and then eventually leads to a loss of control. The ability of drivers to maintain performance, unconsciously and consciously, within these safety margins is referred to as situational control.

Overall, the framework seems quite well thought out, and Ljung Aust and Engström (2011) provide a useful description to how it can be applied to evaluate active safety features. However, since this control framework is based heavily on the ideas of the multiple comfort zone model (Summala, 2005; Summala, 2007) most of the criticisms that apply to that model could also be made in reference to the situational control framework.

2.4.19 ITERATE and the Unified Model of Driver behaviour (UMD)

The IT for Error Remediation And Trapping Emergencies (ITERATE) project is an EU project aimed at creating and testing a Unified Model of Driver behaviour (UMD) (Barnard et al., 2010; Oppenheim, Shinar, Carsten et al., 2010; Oppenheim, Shinar, Enjalbert et al., 2010). In particular the UMD is designed to describe driver behaviour when interacting with active safety systems in emergency situations. The model aims to describe all forms of surface transport and appears to be designed in terms of being able to be used in the modelling of driver behaviour by computer software and for integration into intelligent agent systems.

The model itself is made up of five driver variables, mostly derived from a driver model put forward by Cacciabue & Carsten (2010). The five variables are: culture, attitude/personality (primarily sensation seeking), experience, driver state (with a special focus on fatigue) and task demand. These five factors then interact with each other to produce driver behaviour and performance, represented as error propensity and reaction time. Driver behaviour then interacts with the road environment, made up of the traffic, the road conditions and the visibility, via the mediating influence of the vehicle they happen to be operating, plus the result of their own, and their vehicles, interaction with any technological driver assistance systems available.

The UMD is relatively broad and simple, yet it has been used to create several general hypotheses (see Barnard et al, 2010 for details). These hypotheses are currently being evaluated by the labs that make up the ITERATE project, and the UMD is still under development.

CHAPTER 3 **THAT IS FAST ENOUGH**

A version of this chapter has been previously published as Lewis-Evans, B. & Rothengatter, T. (2009) Task difficulty, risk, effort and comfort in a simulated driving task – Implications for Risk Allostasis Theory. *Accident Analysis and Prevention, 41,* 1053-1063 and can be accessed online here: http://dx.doi.org/10.1016/j.aap.2009.06.011

Abstract

Risk Allostasis Theory states that drivers seek to maintain a feeling of risk within a preferred range (Fuller, 2008). Risk Allostasis Theory is the latest version of Task Difficulty Homeostasis theory, and is in part based on the findings of experiments where participants were asked to rate the task difficulty, feeling of risk and chance of collision of scenes shown in digitally altered video clips (Fuller, McHugh et al., 2008).

The focus of the current research was to expand upon the previous video based experiments using a driving simulator. This allowed participants to be in control of the vehicle rather than acting as passive observers, as well as providing additional speed cues. The results support previous findings that ratings of task difficulty and feeling of risk are related, and that they are also highly related to ratings of effort and moderately related to ratings of comfort and habit. However, the linearly increasing trend for task difficulty and feeling of risk described by the previous research was not observed: instead the findings of this experiment support a threshold effect where ratings of risk (feeling of and chance of loss of control/collision), difficulty, effort, and comfort, go through a period of stability and only start to increase once a certain threshold has been crossed. It is within the period of stability where subjective experience of risk and difficulty is low, or absent, that drivers generally prefer to operate.

3.1 Introduction

The underlying controlling factors of everyday driving behaviour have been debated extensively for many years (e.g. Michon, 1989; Ranney, 1994; Rothengatter, 2002). Models put forward have included attitude theories such as the Theory of Planned Behaviour (Ajzen, 1991), learning theories such as the threat avoidance model (Fuller, 1984), economic models such as Peltzman's (1975) driving intensity model and motivational models such as Risk Homeostasis Theory (Wilde, 1976; Wilde, 1982; Wilde, 1988), zero-risk theory (Näätänen & Summala, 1974; Summala, 1997) and the multiple comfort zone model (Summala, 2005; Summala, 2007). However, none of the proposed models have yet managed to achieve wide-spread acceptance amongst a majority of traffic researchers. The lack of a well-agreed understanding of the underlying controlling factors of everyday driving creates problems for road safety professionals. If effective interventions are to be put into place, then a good understanding of exactly what guides driver behaviour is important. It is also vital, given that these models could be used when designing interventions, that they are tested in order to determine their validity.

In 2000, Fuller proposed a new model; The Task-Capability Interface (TCI) model, and its accompanying Risk Allostasis Theory (RAT), states that a feeling of risk, as an indication of task difficulty, is the primary controller of driver behaviour (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller, McHugh et al., 2008; Fuller, 2008). The basic premise behind TCI is that driving is an interaction between the demands of the environment in which the behaviour is being produced, and the capability of the individual producing the behaviour. This interaction produces the difficulty of the task being performed which is then perceived by drivers, and if task difficulty becomes too great then loss of control occurs (Fuller, 2000; Fuller & Santos, 2002; Fuller, 2005; Fuller et al., 2008; Fuller, McHugh et al., 2008). In this way TCI is more a description of the driving task rather than a model which predicts everyday driver behaviour.

It is instead RAT that takes on the aspect of a predictive model. RAT states that individuals have a preferred range of perceived feeling of risk in which they operate and that they will alter their behaviour to maintain the feeling of risk within this preferred range (Fuller, 2008). An individual's preferred level of feeling of risk is determined by their current and long term motivations, along with how capable they currently perceive they are. This means that this range of preferred feeling of risk is not set and may alter as an individual's motivations and perceptions of their capability change (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008). That preferred feeling of risk is a range, and that it is flexible differentiates RAT from Risk Homeostasis Theory, where target level of risk was seen as less flexible and more of a discrete target (Wilde, 1976).

However RAT, like Risk Homeostasis Theory, does still rely on the constant monitoring of a variable, in this case feeling of risk, which in turn is an indication of task difficulty, and comparing it to a preferred level. RAT in itself is a replacement for Task-Difficulty Homeostasis (TDH) theory in which a preferred range of task difficulty was monitored (Fuller & Santos, 2002; Fuller, 2005; Fuller et al., 2008; Fuller, McHugh et al., 2008; Fuller, 2008). When the model was still called Task-Difficulty Homeostasis the monitoring of difficulty was at one point related to the monitoring of mental workload (Fuller, 2005). Furthermore, it was originally predicted that feelings of risk would act in a threshold manner, acting as a warning to drivers that they were near the edge of their preferred range of task difficulty (Fuller, McHugh et al., 2008). However, since that time TDH has developed into RAT and feelings of risk have become a constantly monitored variable. In particular feeling of risk is not seen as a variable that is only salient after a certain threshold has been crossed, as suggested by zero-risk theory (Näätänen & Summala, 1974; Summala, 1997), but rather is continuously salient in its influence on driver decision making. However, while feelings of risk are continuously salient, drivers may not be aware of their influence on their decision making. This is seen in the following statement:

"... the effects of risk feelings on decision making are not binary (one moment they are irrelevant, the next they become salient): task difficulty and feelings of risk are continuously present variables which inform driver decisions (whether consciously or not). However, only when some threshold point is reached may risk feelings become particularly salient in driver consciousness" Fuller et al. (2008, p. 31).

In combination with this constant monitoring of feeling of risk is a threshold type relationship thought to warn individuals when they are operating outside of their preferred range of feeling of risk. It is also perhaps the point which feelings of risk may begin to consciously effect decision making of drivers. This risk threshold also seems to be around the same time at which individuals report feeling at risk of being involved in a crash (Fuller, McHugh et al., 2008).

That feelings of risk are being constantly monitored and compared to a preferred range opens RAT to many of the same criticisms that had previously been aimed at Risk Homeostasis Theory (Evans, 1986; McKenna, 1990; Summala, 1988; Summala, 1997). In psychology, a feeling is a subjective and conscious experience of an emotion, with emotions being seen as objective physiological and mental states (Damasio, 1994; Damasio, 2003; VandenBos, 2006). That is to say, feeling implies conscious awareness at some level. If this is the case, the most important objection to RAT is that most of the time drivers report feeling no risk during day-to-day driving and it is only when a performance related safety margin is crossed that drivers become aware of any feelings they could label as risk (Summala, 1988; Summala, 1997). In the past these objections have tended to relate to the monitoring of crash or statistical risk. But objections that it would be stressful and demanding mentally to be constantly directing attention towards a subjective variable in order to continuously compare it to a preferred level or range of experience of that variable, are still relevant, even when the variable is "feeling of" rather than "statistical" risk.

Similarly, if mental workload is examined it is true that people do tend to adjust their behaviour in order to operate at an optimum level of workload (Fuller, 2005). However, it seems that it is the absence of under or over load that indicates that an individual is operating at optimal mental workload. This is demonstrated in Figure 3.1 where a range of measurement tools and their ability to detect mental workload is shown. As can be seen in the figure both objective physiological and subjective assessments of workload are unable to detect operation in the optimal A2 area. Rather operation in this area has to be inferred by the finding that an individual is not operating in any of the under or over load areas which can be detected (de Waard, 1996).

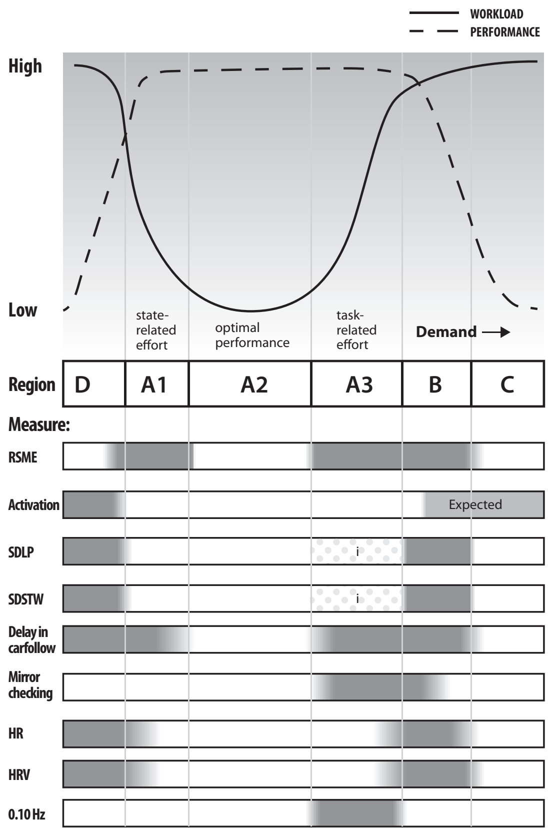

Figure 3.1. The relation of workload to performance in 6 regions and the sensitivity of different measures to driver mental workload. Shading indicates the measure is sensitive to workload in this region (from de Waard, 1996), pg 101).

In this way mental workload is similar to a threshold type relationship with under and over load thresholds and optimally functioning individuals feeling no load at all, or a stable low load, creating a U-shaped curve (de Waard, 1996).

Fuller (2007; 2008) attempts to address these concerns around the constant monitoring of a feeling of risk, with reference to Damasio's Somatic-Marker Hypothesis (Damasio, 1994; Damasio, 2003). The Somatic-Marker Hypothesis claims that through past experience, specific stimuli become marked by associated emotions, which are underlying body states. Damasio refers to this as a somatic marker and suggests that when the marked stimulus is encountered then this marker is also triggered. These markers can also be in some cases present from birth (Damasio, 1994). Activation of the somatic marker could produce greater attentional capture for these stimuli, resulting in feeling. In addition, as these emotions are seen as changes in the body state of the individual, they are also speculated to be able to bias an individual into behaving in a specific way due to the resulting changes in the internal physiology and associated psychology of the individual. In this last way the body states associated with emotions are said to be able to shape behaviour without conscious awareness (Damasio, 1994; Damasio, 2003). Fuller, therefore, has suggested that it is through this process that feeling of risk is monitored (Fuller, 2007). However, Damasio's theory makes a clear distinction between emotions, which are body states and do not need consciousness, and feelings, which are the experiences of emotions (Damasio, 1994; Damasio, 2003). It is the emotions, which are underlying body states, constantly present within the Somatic-Marker Hypothesis. Fuller, however, only uses the term 'feeling', which seems inappropriate, as he seems to be paradoxically suggesting that feeling of risk is constantly monitored, constantly salient and yet not felt.

Placing issues of terminology aside, it is not clear exactly how the Somatic-Marker Hypothesis fits with the contention made by RAT that individuals select a range of feeling of risk at which to operate and maintain operation in this area (Fuller, 2008). Rather than a range, the Somatic-Marker Hypothesis seems to lead to the suggestion that there are set learnt stimuli which, when encountered, trigger an emotion and can then lead to a feeling of experienced risk (or bias behaviours through resulting body changes), assuming that this feeling has been learnt to be associated with the relevant emotion (Damasio, 1994; Damasio, 2003). It is at this point action will be taken to avoid this feeling. Either that or motivational aspects will cause this feeling to be tolerated. This is a learnt threshold avoidance relationship more along the lines of that suggested by zero-risk theory (Näätänen & Summala, 1974; Summala, 1997) or threat avoidance theory (Fuller, 1984), rather than a constant monitoring and maintaining of a preferred level of feeling of risk in an allostatic fashion as suggested by RAT (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008; Fuller, 2008). Finally, and perhaps of most relevance to this paper, Fuller (2007) acknowledges that the application of Damasio's Somatic-Marker Hypothesis within RAT is speculative and does not currently have direct experimental support.

Rather, the primary experimental support for RAT is a study carried out by Fuller, McHugh et al. (2008), which has been subsequently replicated by Kinnear et al. (2008). This experiment examined the relationship between individuals' subjective ratings of task difficulty, feeling of risk, their assessment of when loss of control would occur and speed. In order to examine the relationships between, participants were presented with digital video footage of three roads; a residential road, a dual carriageway and a rural road, being driven at several different speeds. The differences in speed were achieved by digitally altering the video and, therefore, the footage included no other moving vehicles and no information from in-car speed instrumentation.

Participants were presented with the speeds starting with the slowest and then increasing in 5 mph increments. After each increment they were then asked to indicate how much risk they thought they would feel driving this road at the speed shown, as well as how difficult they thought it would be, and how many times they thought they would lose control of the vehicle or be in a collision.

It was initially hypothesized by Fuller, McHugh et al. (2008) that task difficulty would have a systematically increasing relationship with speed and that feeling of risk and ratings of loss of control would operate more on a threshold fashion, as predicted by zero-risk theory (Näätänen & Summala, 1974). However, the results of the experiment showed that both task difficulty and feelings of risk were highly linearly related to speed ($r^2 = .98$), and that only ratings of potential loss of control showed a threshold relationship. It was also found that ratings of task difficulty and feeling of risk were highly correlated with each other ($r = .81$, $p < .001$). This led to the conclusion that a feeling of risk provides continuous feedback to drivers allowing them to maintain the difficulty of the driving within preferred levels. However, the presentation of speeds in steadily increasing 5 mph increments raises the possibility that an order effect is responsible for the strong linear relationships found between task difficulty, feeling of risk, and speed. This means that the systematically increasing relationship of task difficulty and feeling of risk with speed reported could be, at least in part, an artifact produced by the methodology used.

A replication by Kinnear et al. (2008) produced similar results but no threshold effect was found for ratings of loss of control. It is possible that this is because the question used by Kinnear et al. asked about the loss of control of a hypothetically identical other driver rather than of the participants' own driving ability. Previous research has suggested that people assess their own ability as higher, and crash risk as lower, than that of others, even their peers (Harré & Sibley, 2007; McKenna, Stanier, & Lewis, 1991; McKenna, 1993). Therefore it is possible that even though the wording Kinnear et al. (2008) used specified a driver that was just like the participant, the participants may have rated these hypothetical identical others in a more negative fashion than when asked to rate their own crash risk. Kinnear et al. (2008) also presented the speeds in an ascending fashion, again raising the possibility of an order effect. Fuller (personal communication, September 2, 2008) however, has claimed that different speed orders were tested in his original study and produced similarly linear increasing results. This experiment will seek to address both methodological issues by presenting speeds in random order within each trial, and by including two questions on crash risk which follow wordings similar to those used by both Fuller, McHugh et al. (2008) and Kinnear et al. (2008).

This experiment seeks to expand on Fuller, McHugh et al.'s (2008) findings, by using a driving simulator to examine three vital components. The first is the predicted systematically increasing relationship between speed, ratings of task difficulty, and feeling of risk (Fuller, McHugh et al., 2008). That individuals are sensitive to changes in the difficulty of the task they are performing (in this case increases in speed) is important in order for them to be able to constantly monitor the related comparator variable of feeling of risk. This is necessary in order for them to be able to select a certain level/range of this variable at which to function. That is to say, if a certain target range of feeling of risk is preferred (higher than zero) there must be, assuming no other distractions, a detectable difference in feeling of risk between differing levels of speed in order for drivers to be able to choose/maintain the speed they prefer to operate at. In line with the previously raised objections to constant monitoring of risk (McKenna, 1988; Näätänen & Summala, 1974; Wagenaar, 1992) and the original predictions of Fuller, McHugh et al. (2008) it is hypothesized that instead a threshold effect will be apparent.

The second component is the strong relationship between the subjective ratings reported. In this experiment, additional ratings of effort and comfort will be added and their relationship to subjective risk and task difficulty examined. Effort was selected as a measure of mental workload, a comparator initially suggested by Fuller and Santos (2002) when RAT was still known as Task-Difficulty Homeostasis. Ratings of comfort have been indicated by Summala (2005) as an important part of his multiple comfort zone model where they are suggested to indicate operation outside of or near the edge of threshold-like safety margins. It is hypothesized that ratings of effort and comfort will also be related to ratings of risk and task difficulty. A rating of how typical the speed experienced is to the participant will also be gained in order to see the effect of previous experience. It is expected that through this scale that drivers will indicate a clear preference for travelling at speeds which they rate as typically experienced.

The relationship between participants' subjective ratings and a chosen preferred or target speed will also be examined. The use of the driving simulator allows for the introduction of a free speed condition where participants can choose their own speed rather than being always restricted to preset speeds. The subjective ratings given at this speed will be compared to ratings for the fixed speeds.

It is predicted that in line with a threshold model of feeling of risk, task difficulty and effort, that ratings at this chosen speed will be lower or the same as the ratings given to speeds before this point and that only speeds higher than this preferred speed show a systematic increase with speed. In other words, participants will not prefer a certain level of feeling of risk along an increasing continuum but instead rate their preferred speed as having no, or a low and stable, feeling of risk, task difficulty, and effort.

3.2 Method

3.2.1 Participants

There were 47 participants recruited from the undergraduate population at the University of Groningen; 25 male and 22 female. Recruitment was carried out through the psychology department's computerised recruitment pool and two course credits were given for participation in the research. The males had a mean age of 21.2 (SD = 2.0), and had held their drivers' licence for an average of 2.8 years (SD = 1.4). Females had a mean age of 20.3 years (SD = 1.2), and had held their drivers' licence for 2.1 years (SD = 1.1) on average.

3.2.2 Materials

Two sections of road were created in the driving simulator. One road simulated a residential street and the other, a section of dual carriageway. The roads contained no other traffic or adverse weather conditions. In addition, speed limit signs were absent from the roads. The use of a residential road and a dual carriageway were chosen as these were two of the road types used in the previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008). The final road type used in the previous studies, a rural road, was not used in this case due to time restrictions. This was deemed acceptable since the previous studies found very similar results across all three road types (Fuller, McHugh et al., 2008; Kinnear et al., 2008).

The experiment was carried out using the University of Groningen's STSoftware driving simulator, which consists of a fixed-base car mock-up with controls linked to a dedicated graphics controller, and allows participants a 210° view of the road environment. A cardboard cutout was placed over the speed instrumentation in order to obscure it.

Nine set speeds, plus a free speed condition, were assigned to each road. The set speed conditions functioned in a manner similar to cruise control and restricted speed to a set value. However, unlike conventional cruise control, participants were unable to set the speed or disable it. In the free speed condition, the participants were able to drive the simulated vehicle normally and select their own travelling speed. The set speeds for each road were set in 10 kmph increments and presented to participants in randomized order. The speed for the residential road ranged between 20 and 100 kmph, and for the dual carriageway the range was 80 to 160 kmph.

3.2.3 Procedure

Participants were asked to fill out a demographic questionnaire that collected information about their age and driving experience. Participants were then tested individually on each road section under various speed conditions. Twenty-three of the participants encountered the residential road first and the other 24 were presented with the dual carriageway first. The participants then had to complete both an observation and driving task. This was again counter balanced between participants. Both the road and task orders were counterbalanced between males and females.

Before starting with the driving or observation tasks, a practice track was presented to the participants to allow them to become familiar with the simulator. If participants felt sick or uneasy with the simulator at this point they were removed from the experiment.

3.2.3.1 Observation task

Participants experience all nine different speed conditions for each road. All the nine speed conditions were presented for one road before moving on to the next. The order in which the speed increments were presented was determined by random number generation. After each speed condition the participants filled in a questionnaire (in Dutch) on which ratings of predicted task difficulty, feeling of risk, effort, and comfort were gained using 7-point Likert scales. The rating scales used were similar to those used previously by Fuller, McHugh et al. (2008). Below is an example of the bipolar scale used for task difficulty during the observation task:

How difficult would you find it to drive this section of road at this speed?

1 2 3 4 5 6 7

Extremely Easy Extremely Difficult

In terms of the ratings for risk and effort, a unipolar scale was used where a rating of 1 indicated the absence of the variable being assessed. For example a rating of 1 for feeling of risk corresponded to "no risk". In addition participants were asked to indicate if they would never, seldom, sometimes, nearly always or always typically drive at the speed experienced on the road type shown. In terms of ratings of comfort, a rating of 7 corresponded to extremely comfortable, and a rating of 1 with extremely uncomfortable. For later analysis and presentation this scale was reversed to match the other scales, so in the following results section of this paper comfort decreases as the subjective rating given increases, much as subjective impressions of task difficulty increase as the rating given increases.

In addition, participants were also asked to give an indication of how many times they thought they would lose control of the vehicle or have an accident if they drove the road shown, at the speed shown, every day for 2 months (i.e. 60 times). This was a question worded in a similar fashion as that used by Fuller, McHugh et al. (2008). A similar question asked for a rating of how many times 60 drivers like the participants, would crash if they drove the road shown, at the speed shown. This was worded in the similar fashion as that used by Kinnear et al. (2008). With both questions, the participants were able to freely indicate an appropriate number, including an indication that they or an identical other would not crash at all. Once all the relevant speed conditions for a road section were presented, participants were also asked to give a preferred speed for the road shown and a maximum speed at which they thought they could drive and maintain control of the vehicle. In order to control for order effects, 23 of the participants were given the questionnaire presented in the normal order and 24 in reverse order.

3.2.3.2 Driving task

This task was similar to the observation task except that the participants had the ability to control the steering of the vehicle. Also, a free speed choice condition was presented to the participants during this task, once for each road type, and the speed at which participants drove during this condition was recorded. After each drive, participants were again asked to fill in a similar questionnaire to the one used for the observation task. The only difference between the questionnaire used here and that of the observation task, was that the questions were worded to ask what was experienced rather than asking participants to give an indication of what they thought they would experience. For example, the question assessing task difficulty was worded as follows: "How difficult did you find it to drive this section of road at this speed?" Other than this change in wording the same rating scales were used and the same variables assessed. In addition, speed information was collected at a rate of 10 Hz during the free speed condition. Average speed and standard deviation of speed were then calculated for each participant individually and then averaged across all subjects.

3.2.4 Analysis

The collected subjective ratings were examined by creating two datasets. The first contained the averaged subjective ratings given at each speed category for all participants, for each road, and for both the observation and driving task. Ratings given by the participants for the free speed condition during the driving task were not included in this dataset.

A second dataset was created using the data gathered in the driving task in order to examine the ratings given by participants during the fixed speed conditions relative to the ratings they gave during the free speed condition. The dataset was created by first calculating the average speed each participant drove during the free speed condition. Once this speed was known, then the ratings from the three set speed conditions above and below this speed were collected and arranged around the ratings given for the free speed condition so that it sat in the center. For example if one participant drove at 58 kmph on average on the residential road, then the ratings they gave on that task were set as the zero or center point, and then the ratings for the 30,40, 50, 60, 70, and 80 kmph fixed speed conditions arrayed on either side. So their order of ratings would read: 30, 40, 50, free speed (58 kmph), 60, 70, 80. Another participant may have driven at 63 kmph on average, and therefore their order of ratings would read 40, 50, 60, free speed (63 kmph), 70, 80, 100. This was done for both road types. Once this was done for each participant, the ratings where averaged and the relative dataset created.

3.3 Results

MANOVA, correlation and regression analysis was carried out on both the averaged and relative datasets using SPSS 14.0 for windows. MANOVA analysis with a difference contrast for speed for the averaged dataset, showed main effects of road type ($F = 8.41$, $p < .01$), task type ($F = 32.59$, $p < .001$), and speed ($F = 71.39$, $p < .001$). Interaction effects were also found between road and speed ($F = 13.81$, $p < .001$), task type and speed ($F = 7.58$, $p < .001$), and road, task type and speed ($F = 2.84$, $p < .05$). Further analysis for each subjective variable by road type and task revealed significant main effects of road type only on ratings of comfort ($F = 9.88$, $p < .01$), ratings of loss of control for the drivers themselves ($F = 7.21$, $p <.01$) and ratings of typical speed ($F = 47.35$, $p < .001$). In all these cases the residential road produced higher ratings than the dual carriageway. Main effects of task type were found for ratings of task difficulty ($F = 44.29$, $p < .001$), feelings of risk ($F = 42.79$, $p < .001$), effort ($F = 65.51$, $p < .001$), comfort ($F = 55.85$, $p < .001$), loss of control for self ($F = 16.37$, $p < .001$) and for others ($F = 14.11$, $p < .001$), but not for ratings of how typical the speed was ($F = 1.32$, $p = .256$). Where these significant differences were found the observation task produced higher ratings than the driving task. Despite the differences observed between the tasks and roads, the shape of the trends shown between the observation task and the driving task are quite similar. MANOVA analysis of the relative dataset with a difference contrast for speed, failed to find a main effect of road type ($F < 1$, NS) but a main effect of speed was observed ($F = 45.85$, $p < .001$).

3.3.1 Relationship of ratings of task difficulty, and risk to speed

Ratings of task difficulty, feeling of risk, and risk of collision/loss of control do not linearly increase with increases in speed. Rather, as shown in Figure 3.2 it appears that participant indications of

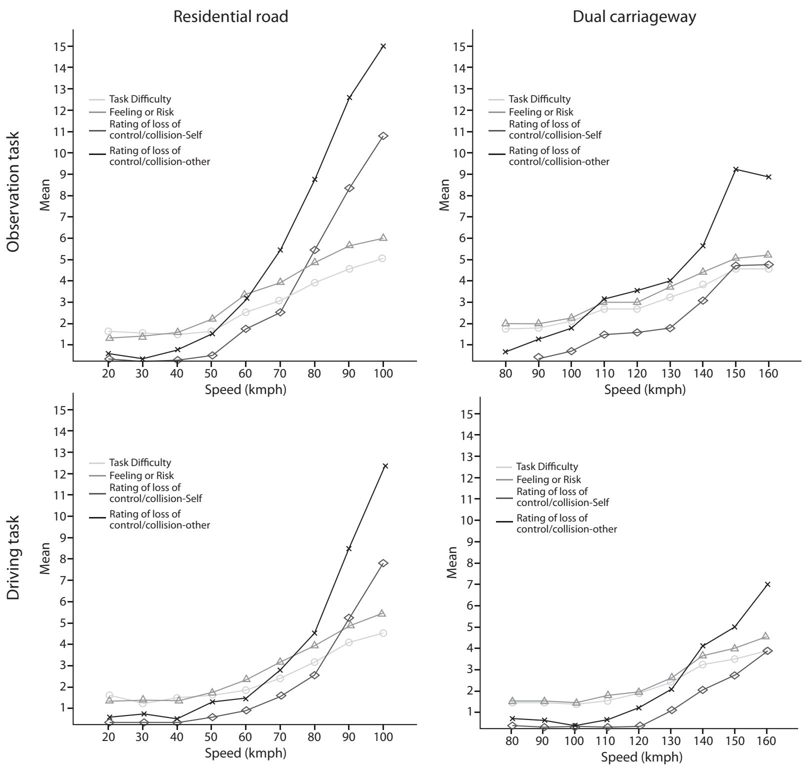

Figure 3.2. Average ratings of task difficulty, feeling of risk and loss of control in relation to increasing speed across both road and task types.

task difficulty and risk start low or absent and only significantly increase once a certain speed has been reached. The only exception to this is the trend for crash risk on the observation task on the dual carriageway, which appears more clearly exponential in nature. In terms of the rating of loss of control of the vehicle/collision, it is also clear that participants began rating this as higher than zero earlier when assessing an identical other rather than themselves.

Table 3.1. Regression analysis for task difficulty, feeling of risk and loss of control with speed across both road and task types

Residential Road – Observation Task						
	20 to 40 km/h			50 to 90 km/h		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.00	-.05	-.57	.39***	.62	13.22
Feeling of Risk	.03	.16	1.91	.41***	.64	14.02
Loss of Control – Self	.00	-.06	-.66	.15***	.38	6.84
Loss of Control – Other	.00	-.00	-.03	.19***	.43	7.87
Residential Road – Driving Task						
Task Difficulty	.00	-.05	-.33	.48***	.69	15.95
Feeling of Risk	.00	.06	.70	.51***	.71	17.00
Loss of Control – Self	.00	-.06	-.73	.10***	.32	5.61
Loss of Control – Other	.00	-.02	-.21	.16***	.40	7.29
Dual Carriageway – Observation Task						
	80 to 100 km/h			110 to 160 km/h		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.02	.15	1.73	.21***	.45	8.51
Feeling of Risk	.01	.10	1.13	.22***	.47	8.80
Loss of Control – Self	.05**	.23	2.78	.08***	.27	4.73
Loss of Control – Other	.04**	.22	2.66	.08***	.29	4.95
Dual Carriageway – Driving Task						
Task Difficulty	.00	.00	.00	.32***	.56	11.37
Feeling of Risk	.00	-.01	-.14	.34***	.58	12.05
Loss of Control – Self	.01	-.11	-1.27	.10***	.31	5.44
Loss of Control – Other	.01	-.10	-1.16	.17***	.42	7.57

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

Regression analysis of the rating of task difficulty, and risk show no significant relationship between the reported values and speed in the first three speed conditions on the residential road, under both the observation and driving tasks. Similarly, for the dual carriageway, the ratings for the driving task and the ratings of task difficulty and feeling of risk for the first three speed conditions during the observation task, fail to show any significant increasing or decreasing trend and are flat in nature. Ratings of both self and other assessed risk of loss of control do show significant ($p < .001$) r^2 values ($t = 2.78$, $r^2 = .05$ and $t = 2.65$, $r^2 = .05$ respectively) during these first three speed conditions during the observation task for the dual carriageway. After the first three speed conditions the trend in ratings of risk and task difficulty for both roads and across both conditions, begins to show statistically significant increases ($p < .001$), with r^2 values ranging from .08 to .51 as shown in Table 3.1.

3.3.2 Relationship of ratings of effort, comfort and typical speed to speed

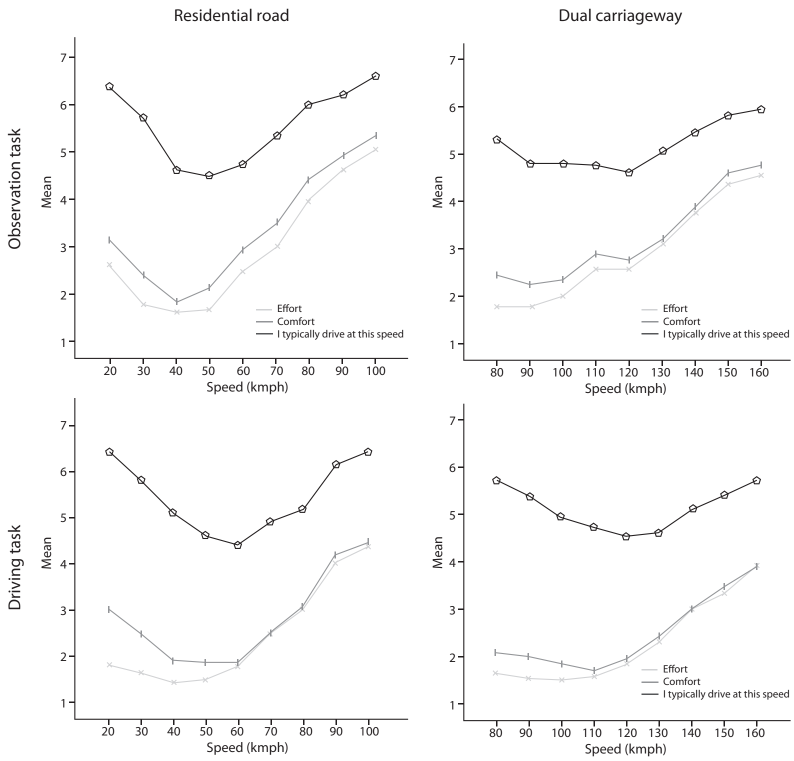

Figure 3.3. Average ratings of effort, comfort and "I typically drive at this speed" in relation to increasing speed across both road and task types.

Ratings of effort, comfort, and indications of typical speed for the residential road showed a U-shaped relationship with speed starting off initially high and then trending downwards until beginning to again trend upwards as shown in Figure 3.3. This is true for both the observation and driving task. Although, for the driving task the U-shape is less marked, especially for ratings of effort where the downward trends for effort were not statistically significant ($p > .05$).

The relationship is not as clear for the dual carriageway in terms of ratings of effort and comfort which during the observation task appeared to have a somewhat linear increasing relationship with speed. However, indications of typical speed still show a somewhat U-shaped curve for both the observation task and the driving task on the dual carriageway. Ratings of

Table 3.2. Regression analysis for effort, comfort and "I typically drive at this speed" with speed across both road and task types

Residential Road – Observation Task						
	20 to 40 km/h			50 to 90 km/h		
	r^2	Beta	t	r^2	Beta	t
Effort	.05**	-.23	-2.76	.38***	.61	12.92
Comfort	.08***	-.29	-3.54	.34***	.58	11.88
Typically Drive	.32***	-.57	-8.07	.44***	.66	14.76
Residential Road – Driving Task						
Effort	.01	-.12	-1.45	.43***	.66	14.65
Comfort	.07***	-.26	-3.14	.36***	.60	12.50
Typically Drive	.21***	-.46	-6.15	.40***	.63	13.55
Dual Carriageway – Observation Task						
	80 to 100 km/h			110 to 160 km/h		
	r^2	Beta	t	r^2	Beta	t
Effort	.00	.07	.78	.20***	.45	8.48
Comfort	.00	-.03	-.32	.18***	.42	7.78
Typically Drive	.04*	-.21	-2.53	.19***	.45	8.30
Dual Carriageway – Driving Task						
Effort	.00	-.06	-.68	.30***	.54	10.86
Comfort	.00	-.07	-.79	.26***	.51	9.81
Typically Drive	.09***	-.30	-3.64	.15***	.39	7.08

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

comfort on the driving task for the dual carriageway also seem to show a slight decrease to start with, although it is not as clear as the trend on the residential road. In terms of ratings of effort for the driving task, it appears to start stable and then only increase once a certain speed has passed. The shapes of the trends are consistent with the results of the regression analysis shown in Table 3.2.

3.3.3 Relationship between chosen free speed and subjective ratings

Figure 3.4 shows the subjective ratings given by participants relative to the rating they gave when they were able to pick their own speed during the driving task. The zero point on the x-axis represents the free speed condition and each increment above or below is a speed increment faster or slower. These points differed across participants, so in order for them to be assessed the procedure described in Section 3.2.3 was used to create the relative data seen here. The subjective rating scales for task difficulty, risk, effort, and comfort stayed low until the chosen speed was reached and then began to markedly increase after this point. Although in the case of ratings of loss of control for an identical other, this value began to increase before ratings of loss of control for the participants themselves. The exceptions to this were ratings of feeling of risk for the residential road, where there was a slight significant linear increase initially ($r^2 = .07$, $p < .01$), then a dip at the free speed point and then the ratings start increasing again, although considerably more sharply ($r^2 = .25$, $p < .001$). Ratings of comfort for the residential road also do not follow the general pattern, with more of a U-shaped curve being apparent. Meaning that as the preferred speed was approached participants rated the speed as being more comfortable, and after it was exceeded as increasingly uncomfortable. Indications of how typical the experienced speed was showed a clear V-shaped curve with ratings decreasing as the free speed choice condition is approached and increasing afterward.

The results of regression analysis on the first three speed points and the last three speed points are consistent with the trends shown in Fig. 3.4 and are given in Table 3.3.

3.3.4 Relationship between chosen free speed, maximum speed and preferred speed

When asked to indicate a speed at which they preferred to drive for each of the roads, the majority of individuals (N = 43 for the dual carriageway and N = 44 for the residential road) chose a speed lower than the speed they said was the maximum they would be able to drive before losing control of the vehicle. On average the ratings of preferred speeds were 112 kmph (SD = 17.82) on the dual carriageway. The average maximum speed before losing

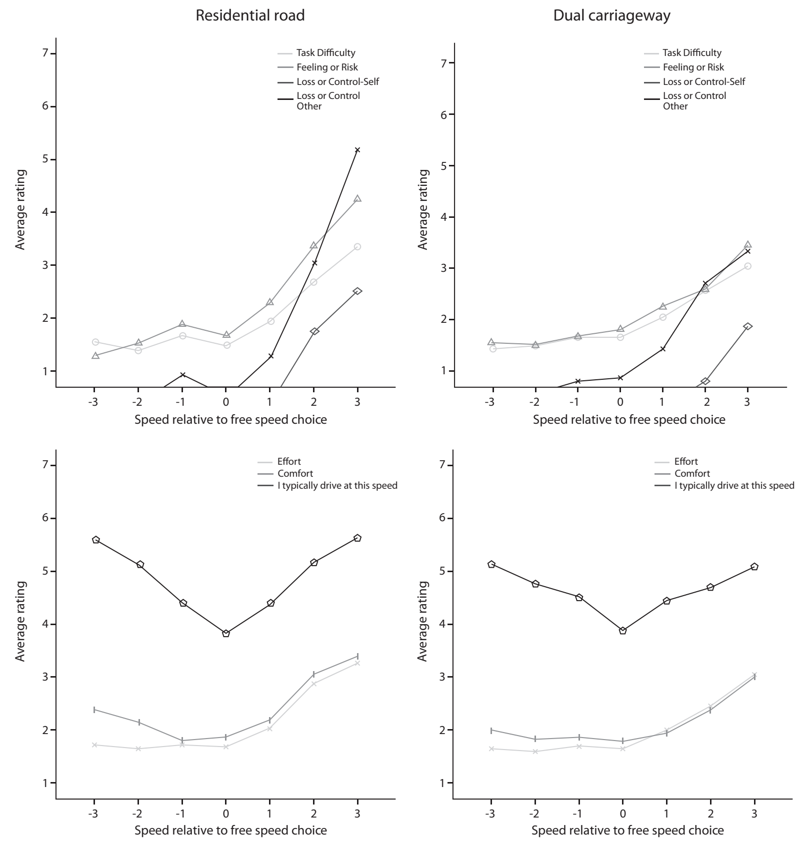

Figure 3.4. Relative ratings of task Difficulty, risk, loss of control, effort, comfort, and "I typically drive at this speed" across both road types. A relative speed of 0 corresponds to the average rating participants gave for the free speed condition. Each increment above or below this point (-3, – 2, – 1, 1, 2, 3) corresponds to a fixed speed condition above or below the average preferred speed of the participants.

control was rated for the same road at 141 kmph (SD = 27.43). In terms of the residential road, the preferred speed averaged 49 kmph (SD = 11.21). The maximum speed on this road averaged 73 kmph (SD = 16.86).

In comparison to the actual speed participants drove at during the driving task, on the residential road; 43% of participants drove at a speed lower than both their preferred and maximum speeds, 38% drove at a speed higher than their preferred speed but lower than their maximum speed, and 13% drove at a speed faster than both previously rated speeds. The remaining participants had missing data for their self-reported maximum and/or preferred speeds. The average speed driven by participants on the residential road was

Table 3.3. Regression analysis for relative scores of task difficulty, risk, loss of control, effort, comfort and habit with speed across both road types.

Residential Road						
	-3 to – 1			1 to 3		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.00	.05	.60	.22***	.46	6.09
Feeling of Risk	.07**	.26	3.09	.25***	.50	6.66
Loss of Control – Self	.00	-.01	-.09	.15***	.39	4.96
Loss of Control – Other	.03	-.16	-1.90	.13***	.35	4.40
Effort	.00	.06	.64	.07**	.26	3.06
Comfort	.00	.10	1.15	.09***	.29	3.50
Typically Drive	.19***	-.43	-5.58	.28***	.53	7.26
Dual Carriageway						
	-3 to – 1			1 to 3		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.01	.09	1.05	.09***	.30	3.53
Feeling of Risk	.00	.05	.61	.10***	.31	3.78
Loss of Control – Self	.00	.02	.24	.10***	.31	3.78
Loss of Control – Other	.00	-.03	-0.38	.11***	.33	3.95
Effort	.01	.08	.91	.06**	.25	2.88
Comfort	.04*	.20	2.32	.04*	.20	2.32
Typically Drive	.07**	-.27	-3.16	.10***	.32	3.89

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

58 kmph (SD = 11.66). On the dual carriageway 53% of participants drove at a speed higher than their indicated preferred speed but lower than their maximum speed, 23% drove at a speed lower than both of these values, and 19% drove at a speed faster than both these values. The remaining two participants had missing data. On average the speed chosen to drive for the dual carriageway was 117 kmph (SD = 19.04).

3.3.5 Correlations between task difficulty, risk, effort, comfort and habit

Using a Pearson's correlation, task difficulty, feeling of risk, and effort were found to be strongly related ($r = .81 – .91$, $p < .01$) with each other across both road types and task conditions, and to be moderately to markedly correlated with ratings of comfort and ratings of loss of control ($r = .44 – .77$, $p < .01$). Ratings of how typical the drive was, were moderately correlated with comfort ($r = .47 – .59$, $p < .05$) across both roads and tasks but only had a low correlation to moderate correlation with the other subjective measures ($r = .29 – .59$, $p < .01$). Similar correlations were found between the variables if the ratings were examined relative to the participants free speed choice. Although the correlations tended to be slightly lower than those reported for the averaged results.

3.4 Discussion

The findings of this experiment do not support some of the predictions put forward by Fuller, McHugh et al. (2008). The first is that ratings of task difficulty and feeling of risk should systematically increase with increases in speed. This relationship was found to occur in a very strong linear fashion across all speeds examined by Fuller, McHugh et al. (2008) and Kinnear et al. (2008). However, in the case of this study it appears that before any increasingly relationship is observed the ratings of task difficulty and feeling of risk initially go through a period of stability in which there is no clear increasing or decreasing trend. It is only once a certain speed has been reached, around 50 kmph on average for the residential road and around 110 kmph on average for the dual carriageway, that ratings of these variables begin to increase. Furthermore even once ratings of task difficulty and feeling of risk variables do start to increase with speed, they do not do so as strongly as previously found (Fuller, McHugh et al., 2008; Kinnear et al., 2008) and are only moderately, not highly, correlated with increasing speed. This relationship is similar to the threshold trend found for ratings of crash risk in both this study and the previous observation experiments (Fuller, McHugh et al., 2008; Kinnear et al., 2008). It should also be noted that the average rating for task difficulty and feeling of risk during this period falls between 1 and 2 on the scale used. Given that a rating of 1 on the scale of feeling of risk corresponds to "no risk", this indicates that many of the participants indicated they would not experience, or were not experiencing, any feeling of risk across a range of speeds. This is in contrast to the findings of Fuller, McHugh et al. (2008) whose results suggested the constant presence of some experienced level of feeling of risk which linearly increased with speed. Due to the nature of the difficulty scale used, a similar conclusion is not possible given that a rating of 1 corresponded to "very easy" rather than indicating an absence of difficulty.

Similarly when the relationship of ratings of task difficulty and feeling of risk relative to participants free speed choice are examined, a threshold relationship is again apparent. With the exception of ratings of feeling of risk for the residential road, ratings of feeling of risk and task difficulty are stable with no significant trend with speed until after the free speed condition has past. Again, the average of the ratings given, including those given for the condition where participants were able to drive at their own chosen speed, only moves above 2 after the free speed condition is past. This indicates that many participants did not report any feeling of risk when driving at their preferred speed and also did not experience any feeling of risk during the three fixed speed conditions that would fall before the speed they selected to drive. If participants are aiming for a range of feeling of risk, why then did they drive at the speed chosen when their ratings of this value do not seem to significantly differ from the ratings they gave at earlier, lower speeds? One exception to the threshold relationship found was in the ratings of feeling of risk for the residential road. In this case there is a slight significant increase of ratings with speed as the free speed condition is approached. However, at the point of chosen free speed the ratings dip before starting to increase at a significantly increased rate. This again indicates a preference amongst participants during free driving for feeling of risk to be low or absent.

A similar threshold relationship for ratings of task difficulty and feeling of risk was apparent for ratings of effort, with average ratings of effort only crossing above 2 once a certain speed was passed, or in the case of the relative data set, only once the preferred speed had been passed. Again this indicates that participants generally preferred to drive at a speed at which they indicated ratings of effort were low and stable, or absent.

The threshold relationship for effort ties in well with existing research on human performance and the optimal range of workload under which individuals generally prefer to operate (de Waard, 1996; Recarte & Nunes, 2002). Performance, physiological and subjective assessments of workload are not able to detect operation in this optimal area; rather, the confirmation that an individual is operating optimally comes from the fact that they are not found to be, or do not report that they are, at any of the over, or unload, areas that are able to be detected. When operating at this optimal level drivers are experiencing no, or very minimal and stable, mental load (de Waard, 1996; Recarte & Nunes, 2002). Similarly, ratings of comfort showed threshold effects, either staying stable and then increasing, or showing more of a U-shape where participants rated the driver as more and more comfortable until a certain point and then as increasingly uncomfortable once this point was passed. This is what would be expected according to Summala's multiple comfort zone model (2005).

It should also be noted that participants in this study did not only prefer a speed at which subjective ratings of the variables assessed were absent or low and stable but that they picked a driving speed just before their ratings of the assessed variables started to markedly increase. This could suggest that, as is the case in zero-risk theory (Näätänen & Summala, 1974), and as originally suggested by Fuller, McHugh et al. (2008), that the perception of these variables acts as a warning to participants, causing them to avoid these feelings when driving unless otherwise motivated not to.

The results in this experiment for the relationship between ratings of task difficulty, feeling of risk, and speed are quite different from the strong linear trends reported by Fuller, McHugh et al. (2008) and Kinnear et al. (2008). This could be because, when compared with watching a video on a single screen, the simulated driving task provides more cues for the drivers to make decisions. The simulator allows for presentation of sound and peripheral visual information that may improve speed judgment. It could also be that the use of a simulator during the driving task allowed participants to use more accurate data of their own performance, in terms of lane keeping, to make their judgments. However, the fact that the trends in subjective ratings were quite similar between the observation task, where lane keeping was kept perfectly by the simulation software, and the driving task indicates that this may not be the case.

While the simulator may provide a more ecologically valid environment, the driving task during the fixed speed conditions is somewhat unusual. During the fixed speed conditions, participants were unable to choose their own speed, thereby making the task essentially simply a tracking task with the speed demand being set externally. Driving however, is generally seen to be a self-paced task. Therefore, the validity of the task presented to participants in this experiment could be called into question. There are times, however, during everyday driving where speed will be more or less set and the task reduced to that of simply lane control, such as when driving with cruise control or in a stream of traffic. In addition, during the free speed condition participants were able to have free control over their driving.

Another explanation for the difference in findings between this and previous studies, in terms of the absence of the strong linear increasing trend, could be the order of presentation of the speeds to the participants. The two previous studies presented the speeds in an ascending order starting from lowest to highest, whereas, in this experiment participants were presented with the speeds in a random order for each road and for each condition. It is possible, therefore, that the findings of the previous studies were influenced by an order effect. However, Kinnear et al. (2008) reported a study by Lynn (2006) that showed that order of presentation had minimal impact on the data, and Fuller (personal communication, September 2, 2008) claimed that other orders were attempted in his original study and the same increasing linear trends were produced. Still, to eliminate any alternative explanation for the effects found, randomisation of speed presentation is to be preferred.

It is also possible that the rating scales used in this experiment were not sensitive enough to detect small changes in the variables assessed, especially at the lower speeds. However the scales used here were similar to those used by both Fuller, McHugh et al. (2008) and Kinnear et al. (2008), which managed to produce strong linear increasing trends with speed. Further research could however explore the use of a broader scale.

With the exception of the observation task for the dual carriageway, this study found the same threshold relationship for ratings of loss of control that was reported by Fuller, McHugh et al. (2008). Participants also generally rated the chance of others losing control of their vehicle as higher than zero before they begin rating their own chances higher than zero. This is likely due to a positive self-assessment bias, with participants viewing their own chances of being involved in a crash as lower than that of others (Harré & Sibley, 2007; McKenna et al., 1991; McKenna, 1993).

As predicted, high correlations between ratings of feeling of risk, task difficulty, and effort were reported. The high correlation between feeling of risk and task difficulty is in line with the previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008). This strong correspondence between subjective ratings of risk, task difficulty and effort is not surprising. Risk is more than just the severity of a consequence for an action: it is also the chance that that consequence will occur (Nordgren et al., 2007). Task difficulty, as defined by Fuller (2000) is the demands of the environment being compared against the capability of the individual to meet those demands. Therefore, task difficulty could easily be seen as a chance of failure, one of the vital components of risk. For example, when using a driving simulator, the consequences of failure are very low, however, as shown in this experiment, participants are willing to indicate that they experience risk. In fact, when driving in a simulator participants report they are not concerned with the consequences of accidents but rather are concerned with avoiding accidents (Glendon, Hoyes, Haigney, & Taylor, 1996). This means that participants are reacting to the chance of failure or the difficulty of the task, rather than the consequence when assessing risk. This indicates a strong intrinsic link between the concepts of risk and task difficulty, both objectively and in the subjective assessments of participants. Similarly effort, in terms of mental and physical workload, can be seen as an indicator of task difficulty (de Waard, 2002; Fuller, 2005). As the demands of the environment increase, more effort is required to match those demands and vice versa. Also, as an individual uses more effort their capacity decreases, therefore, their ability to match the demands of the environment decreases, increasing task difficulty (Fuller, 2000; Fuller & Santos, 2002; Fuller, 2005). Similarly, it is unsurprising that tasks that feel difficult/risky/effortful are often uncomfortable, signal a chance of failure/loss of control and are typically outside of what is usually experienced by an individual.

Finally, when asked to state a speed at which they prefer to drive as well as a maximum speed at which they would be able to retain control of the vehicle, the majority of participants chose a preferred speed lower than their stated maximum. This suggests that, as found in previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008) people do not believe that they drive at the limit of their personal performance in terms of maintaining control of a vehicle. This is supported by the fact that given the actual opportunity to choose their speed of travel within the simulator, the majority of participants chose a speed that was at least lower than their stated preferred maximum speed.

There are several potential weaknesses with this study. Firstly, the simulated roads used were probably less environmentally complex than the videos used in the previous studies. This is due to the photo realistic nature of video when compared to the more limited settings available in the simulator. The relative lack of complexity means that perhaps some important cues may have been absent from the simulated environment. However, the use of a driving simulator does allow for tighter experimental control over the stimuli presented to participants. This may help to reduce potential cofounding effects. The absence of other traffic from both this study and the previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008) also reduces the ecological validity.

Another problem is related to the very nature of asking for subjective ratings of the variables involved. It is possible that in doing so, the variables increased in salience and, therefore, participants may be paying more attention to these factors than they would while driving their vehicle normally, when they have not been prompted to consider such factors has risk, difficulty, effort or comfort. This does, however, add more weight to the suggestion that these feelings are not present until a certain threshold has been reached, as even with attention drawn to these variables there still appears to be a threshold relationship in the data.

The participants in this experiment were also younger and less experienced on average than those used in previous studies. This may have affected their ratings of the various variables involved. It could be argued that inexperienced drivers are not good at perceiving risk and may, therefore, not be able to constantly monitor this factor and rate it in the linear increasing fashion found by the previous studies. However, the study by Kinnear et al. (2008) included three levels of experience: learner, inexperienced and experienced drivers, and all the three groups produced similarly linearly increasing ratings of risk and task difficulty.

Ultimately the findings of this current experiment seem to support a threshold model for perception of task difficulty, feeling of risk, crash risk, effort, and comfort. These ratings are generally indicated by participants to be both low and stable, or absent, until a certain speed after which they begain to increase. In terms of feeling of risk, these findings are in line with the expectations of zero-risk theory (Näätänen & Summala, 1974), risk avoidance theory (Fuller, 1984), the multiple comfort zone model (Summala, 2005) and earlier predictions of the Task-Difficulty Homeostasis theory (Fuller, McHugh et al., 2008) where the experience of risk acts as a warning to drivers and only becomes salient once certain conditions have been met.

The findings of this study suggest that when designing road safety interventions, practitioners should take into account the threshold relationship in the perception of risk, task difficulty, effort, and comfort. Causing a driver's threshold to be crossed may be useful in creating safer behaviour amongst drivers. The challenge however will be to cross driver's subjective thresholds without actually increasing the real objective danger to the driver and other road users. In addition, since thresholds likely differ between individuals, care should be taken when designing interventions which aim to affect a whole population. Furthermore, the strong relationship between subjective ratings of risk, task difficulty and mental workload means that road safety practitioners should be aware that any intervention which alters one of these variables is likely to impact on the others.

CHAPTER 4 **THAT IS CLOSE ENOUGH**

A version of this chapter has been previously published as Lewis-Evans, B., De Waard, D., & Brookhuis, K.A. (2010). That's close enough – A threshold effect of time headway on the experience of risk, task difficulty, effort, and comfort. *Accident Analysis and Prevention*, 42, 1926–1933 and can be accessed online here: http://dx.doi.org/10.1016/j.aap.2010.05.014

Abstract

Subjective impressions of task difficulty, risk, effort, and comfort are key variables of several theories of driver behaviour. A point of difference between many of these theories is not only the importance of these variables, but also whether they are continuously present and monitored or only experienced by individuals at certain critical points in the driving task. Both a threshold relationship and evidence of constant monitoring of risk and task difficulty have been found for speed choice. In light of these conflicting findings this study seeks to examine a different part of the driving task, the choice of time headway.

Participants (N = 40, aged 19 to 30) drove in a simulator behind a vehicle travelling at 50 km/h at set time headways ranging from 0.5 seconds to 4.0 seconds. After each drive, ratings of task difficulty, risk, comfort, and effort were collected. In addition, participants were asked to drive at the time headway they preferred. In order to assess familiarity, participants also drove on both the left and right hand side of the road and the role of driving experience was also examined.

The results show support for a threshold awareness of task difficulty, risk, effort, and comfort in relation to time headway. Participants' ratings of these variables tended to be low, or nil at large time headways, but then around the 2.0 second mark, began to noticeably increase. Feelings of task difficulty, risk, and effort were also found to be highly correlated with each other. No effect of driving experience or side of the road was found.

4.1 Introduction

An understanding of driver decision making is an important goal of traffic psychology, and several models have been put forward to do so. But no model has of yet received wide spread acceptance and use in the field. However, variables such as task difficulty, risk, effort, and comfort have all at varying times been suggested as vital components of the decision making process in drivers.

Risk, in particular, has been the main focus of many models. One of the most well known is Risk Homeostasis Theory (Wilde, 1976), which proposed that there is a preferred target level of risk of being involved in an accident that drivers seek to maintain. Other models, such as zero-risk theory (Näätänen & Summala, 1974), the Driving Intensity model (Peltzman, 1975) and Threat Avoidance theory (Fuller, 1984) have also suggested that an awareness of the risk of being in an accident is a central factor in driver decision making.

Other models have focused not on the risk of being in an accident, but on drivers' general feelings of risk – which may or may not be related to their perception of accident risk. These include models such as the Risk Allostasis Theory (Fuller, 2008), and the Monitor Model (Vaa et al., 2000; Vaa, 2003; Vaa, 2007). In the case of the Monitor Model, a feeling of risk is only one of a possible number of feelings thought to drive decision making. However, within the Monitor Model the ability to monitor a feeling of risk is thought to be of great importance due to the assumed evolutionary value of being able to do so and, thus, seems to stand out amongst the other possible best feelings suggested (Vaa, 2003; Vaa, 2007). That risk is assumed to be important in the Monitor Model, relies on the work of Daimasio and his Somatic Marker Hypothesis (Damasio, 1994; Damasio, 2003). The Somatic Marker Hypothesis suggests that certain body states, emotions, result from mostly learnt environmental triggers. These body states then can bias action towards particular outcomes even if the individual is unaware of them. Since the relationship between body states and action is thought to have arisen due to the process of evolution, it is thought that body states that signal risk have a large impact due to their assumed survival value.

Risk Allostasis Theory (Fuller, 2008) also refers to the Somatic Marker Hypothesis and states that individuals have a feeling of risk they prefer to maintain and that they take appropriate actions to do so. Risk Allostasis Theory arose out of Task Difficulty Homeostasis theory (de Waard, 2002) which theorised that individuals seek to maintain a certain preferred level of Task Difficulty, perhaps indicated by the current level of mental workload or effort (Fuller, 2005). As such, in Risk Allostasis Theory, feeling of risk is also thought to be an indicator of task difficulty, due to the strong correlation between these variables (Fuller, McHugh et al., 2008; Kinnear et al., 2008).

Apart from task difficulty, risk, and effort, a feeling of comfort has been put forward by the multiple comfort zone model (Summala, 2005) as a potential primary variable in driver decision making. Within this model, uncomfortable feelings are thought to indicate when drivers are approaching, or exceeding, certain learnt safety margins.

One important point of difference between the theories discussed above is how they view their variables of interest, whether that is risk of an accident or feeling of risk, in terms of driver awareness of these variables. For example, is the variable of interest constantly present and monitored as suggested by Risk Homeostasis Theory (Wilde, 1976), Risk Allostasis Theory (Fuller, 2008) or the Monitor Model (Vaa, 2007)? Or, are drivers only experiencing and acting on these variables once certain thresholds have been crossed, as suggested by zero-risk theory (Näätänen & Summala, 1974), risk avoidance theory (Fuller, 1984), or the multiple comfort zone model (Summala, 2005).

The relationship between ratings of task difficulty, feeling of risk, and assessment of crash risk in relation to speed, was investigated by Fuller, McHugh et al. (2008). In order to do so, participants were required to rate videos of three different roads being driven at a range of speeds. The speeds were produced by digitally altering one piece of film footage for each road and were presented to participants, starting with the slowest speed and then in increasing 5 mile per hour increments after that. It was expected that ratings of task difficulty would increase systematically with speed, in line with predictions made by Task Difficulty Homeostasis. Ratings of feeling of risk and crash risk, on the other hand, were predicted to show a threshold relationship in that they would only start to increase once a certain speed was observed (Fuller, McHugh et al., 2008). As expected, a strong linearly increasing relationship between speed and ratings of task difficulty was found but, surprisingly, this was also the case for ratings of feeling of risk. However, ratings of crash risk did show a threshold type trend. It was also found that ratings of feeling of risk and task difficulty were strongly correlated with each other ($r = 0.81$), a finding that Fuller, McHugh et al. (2008) took to mean that feeling of risk could act as an indicator of task difficulty.

The findings of Fuller, McHugh et al. (2008) therefore seem to support a constant perception and monitoring view of variables such as task difficulty and feeling of risk. However, a recent investigation of the Fuller, McHugh et al. study using a driving simulator instead of video presentation produced a different picture (Lewis-Evans & Rothengatter, 2009). Participants in this study were required to sit in a fixed base driving simulator and either simply watch a road being driven, or had control over the steering of the vehicle while it was driven at a set speed. Like the earlier Fuller, McHugh et al (2008) study, participants were required to give ratings of feeling of risk, crash risk, and task difficulty after each trial. In addition, ratings of comfort, effort, and how typical the speed travelled was, were collected as well. Unlike the Fuller, McHugh et al (2008) study, the speeds the participants experienced in the simulator were presented in random order, and also the participants had an opportunity to drive each of the two roads used at whatever speed they preferred. The results of the driving simulator study confirmed the previous finding that ratings of task difficulty and feeling of risk are strongly correlated with each other, and in addition are strongly correlated with ratings of effort. However, the strong, linear, increasing trend of ratings of task difficulty and feeling of risk with speed was not apparent. Rather, a threshold trend was found, with ratings of feelings of risk, crash risk, task difficulty, and effort staying low, or nil, until a certain speed was reached, and only after this speed did they begin to increase. Ratings of how typical the speed was and of comfort, on the other hand, tended to have more of a U-shaped relationship with speed.

The difference between the results gained by the studies discussed above, means that it is important that more research in this area is carried out. Also, there has been some criticism that studies aimed at testing models of driver behaviour have focused too much on speed as an independent variable (Carsten, 2009). While driving is typically seen as a self-paced task, and a driver's choice of speed is one important way in which they can affect the task, there are other behaviours which drivers can generally freely perform. Selecting and maintaining appropriate time headways to lead vehicles is one such behaviour.

If models of driver behaviour aim to describe the whole of driver decision making then they should be able to explain a driver's choice of time headway, a variable that in many cases is able to be freely varied by drivers. The decision of how close to follow a lead vehicle is made quite often in traffic, especially in built up areas and on motorways, and it is clear that drivers do not always select their time headway appropriately. In New Zealand, for example, rear end crashes are one of the most common crash types (Ministry of Transport, 2008). In 2007, ten percent of all injury crashes in New Zealand were coded as "Rear end", the 3rd most common type of injury crash after "Loss of control while cornering" (22.3%) and "Lost control on a straight" (10.5%). Thankfully, rear end crashes do not often result in fatalities (only 1.6% of all fatal crashes in 2007 in New Zealand), but they are nevertheless still a problem due to their high frequency, if only for their material and economic costs. This situation is likely to be similar in other motorised western countries such as in the USA, where rear end collisions make up approximately 29% of all crashes (National Highway Traffic Safety Administration, 2003). This study therefore seeks to examine the relationship between time headway and ratings of risk, task difficulty, effort, and comfort.

It was predicted, that in line with previous studies, a high correlation between ratings of effort, task difficulty, and risk would be apparent. It was also predicted that a threshold relationship between time headway and ratings of task difficulty, risk, and effort will be found, along with a U-shaped curve for ratings of comfort and whether the time headway driven was typical or not. This is because the constant monitoring of a subjective variable such as a feeling, and comparing it to a set subjective state, seems excessively stressful and demanding. Instead, it is more reasonable to suggest that certain learnt behaviours or environmental situations cause a feeling to be felt and then acted upon (Summala, 1997). Feelings, after all, are said to arise from attention directed towards the emotional body state, which is generally made up of learnt reactions to certain environmental stimuli (Damasio, 1994; Damasio, 2003). In other words, they are not constantly present but rather occur only once certain conditions have been met.

Given that past experience may therefore be important in setting thresholds, it was also decided to examine the effect of familiarity and driving experience. In order to do this all participants were required to complete the driving task on both the familiar right hand and the unfamiliar left hand side of the road. Simply changing the side of the road driven was chosen as a manipulation of familiarity because it is unfamiliar to drive on the other side of the road but, as long as no turning maneuvers are involved, it is not particularly difficult or risky to do so. In addition, both inexperienced and experienced drivers were recruited. It was expected that the threshold point for experienced and inexperienced drivers may differ and that driving on the unfamiliar side of the road may also shift or remove the threshold effect.

4.2 Method

4.2.1 Participants

Participants were recruited through posters placed around the University of Groningen and were paid 15 Euros for taking part. This resulted in 40 participants in total, 20 male and 20 female. The participants were recruited and categorised as experienced or inexperienced based on the number of kilometers they had driven in their lifetimes. Experienced drivers had to have driven at least 10,000 kilometers and inexperienced driven less than 10,000 kilometers. The experienced group contained 23 participants (12 male, 11 female) who had driven between 10,000 and 350,000 kilometers in their lifetimes. They had held their licence for an average of 6.5 years (SD = 5.9) and were on average 25.4 (SD = 6.0) years old. The inexperienced group contained 17 participants (8 male, 9 female) who had driven between 300 to 9,000 kilometers in their lifetimes. They had held their licence for an average of 1.9 years (SD = 1.1) and were on average 21.5 years old (SD = 2.0).

4.2.2 Materials

The University of Groningen fixed based driving simulator was used in the study. The simulator runs STSoftware software and allows participants a 210-degree view of the road environment. A cardboard cutout was placed over the instrument panel to prevent speed information being available to the participants. Participants drove on a residential street, created according to Dutch road design guidelines, which took approximately 3 minutes to drive. The street had on-coming traffic at a rate of one vehicle approximately every 12.5 seconds. Depending on the condition, the on-coming traffic was placed to always be in the opposite lane to that driven by the participants; so in the left lane when the participants were driving in the right lane and the right lane when the participants drove on the left. This was done to prevent any overtaking. Information on the time headway between the participants' vehicle and the lead vehicle was collected at a rate of 10 Hz.

The simulator was programmed with eight different time head-ways between the participants' car and a lead vehicle. This allowed for the speed and time headway of the participant's car to be set by the simulator, similar to driving a vehicle with adaptive cruise control. The time headway ranged from 0.5 to 4.0 seconds, in 0.5 second increments, and the speed of travel for both the participant and lead vehicle was locked to 50 km/h. In all trials the participants retained lateral control of the vehicle. At the start of the drive the participants' vehicle began 10 metres behind the lead vehicle. When the relevant program was started both vehicles would begin to accelerate and the required time headway would be set and maintained for the rest of the drive. In addition to the eight set time headways, participants were also given the opportunity to drive at a time headway of their own choosing behind the lead vehicle. In this case the lead vehicles speed was locked to 50 km/h and participants were instructed to follow the lead vehicle as closely as they felt comfortable.

4.2.3 Procedure

Participants first filled out a demographic questionnaire containing questions about their age and driving experience. Then they were placed in the simulator and allowed to practice driving, for around 5 minutes on a practice track, in order for them to become comfortable.

Participants were then randomly assigned to one of two groups, counterbalanced across genders and experience level. The first group of participants had to drive all the different time headways, in random order, including the free choice condition, first on the right hand side of the road, and then on the left. The second group carried out the same tasks but drove on the left hand side first and the right hand side second. In all the fixed time headway conditions participants were simply instructed to drive as they would normally while staying behind the lead vehicle. In the case of the free choice time headway condition participants were asked to follow as close to the vehicle in front as possible while still feeling comfortable.

After each drive, during which one following distance condition was experienced, the participants filled in a one page questionnaire (in Dutch). The questionnaire asked for ratings of experienced risk, task difficulty, effort, and comfort on 7-point Likert scales as shown below:

How difficult did you find it to follow the lead vehicle at this distance?

1 2 3 4 5 6 7

Not Difficult Very Difficult

How much risk did you experience following the lead vehicle at this distance?

1 2 3 4 5 6 7

No Risk Maximum Risk

How much effort did it take to follow the lead vehicle at this distance?

1 2 3 4 5 6 7

No Effort Maximum Effort

How comfortable did you feel following the lead vehicle at this distance?

1 2 3 4 5 6 7

Very Comfortable Very Uncomfortable

Participants were also asked to answer two questions about crash risk. One asked participants to give an indication of how many times they thought they would have an accident or lose control of the vehicle if they had to follow a car at the distance shown every day for two months (i.e. 60 times). The second asked the same question, but was phrased as how many times a driver just like the participant would have an accident or lose control. These questions were used to examine the difference between assessing crash risk for the participants themselves versus their perception of crash risk for a hypothetical identical other. The two questions about crash risk were open and participants were free to give any number, including indicating that they didn't think that they or the other driver would have any crash.

The questionnaire also contained one final question asking the participants to indicate if they would typically follow a vehicle at the time headway they just experienced. This was done using a 1-7 point scale with 1 corresponding with "never" and 7 with "always". This scale was reversed for later data analysis.

4.2.4 Analysis

In order to carry out the analyses two datasets were created. One dataset, referred to as the averaged dataset, simply contained all the averaged ratings given by the participants for each of the fixed time headway conditions, on both the left and right hand side of the road.

The second dataset, referred to as the relative dataset, was created to examine the free choice condition. First, the average time headway chosen for each of the individual participants was calculated for both the left and right hand side drives. Then, using the average following distance for each individual, the ratings from the three set time headways above and below the free choice time headway were collected and placed around the ratings given during the free choice condition. So, if on average the participant had driven with a time headway of 2.3 seconds then the ratings they gave would be assigned as the zero point, and then the fixed distance ratings for 1.0, 1.5, 2.0, 2.5, 3.0 and 3.5 seconds would be arranged on either side of it. Another participant may have driven at 1.75 seconds and in that case the ratings for 0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 would also be collected. This was done for each participant and then averaged over all participants to create a dataset where all values were relative to the ratings given during the free following condition. Due to how the data was arranged, it was possible that fewer than 3 fixed time headways fell on either side of the time headway driven by the participant. For example, if the participant drove at a time headway of 1.2 seconds from the lead vehicle, then only the 0.5 and 1.0 second fixed time headways were available below the time headway selected by the driver. In the case of a missing value it was replaced by the average of the remaining data points for that individual participant in order to allow statistical analysis to be carried out.

MANOVA analysis were run for both datasets with the within subjects factors of time headway and side of the road. A difference contrast was used for time headway and all the subjective ratings were included as measures within the MANOVA. Gender and driving experience were included in the analyses as between subject factors. In order to examine the trends of each subjective variable in relation to time headway, individual regression analysis was performed for each subjective variable in both datasets. In the averaged dataset, a regression was first run for the ratings given for the time headways between 4.0 and 2.5 seconds, and then another regression was run on each of the subjective variables for headways between 2.0 and 0.5 seconds. A similar split was performed for the relative dataset, in that regressions were run for each variable for the time headway intervals leading up to their preferred time headway rating, and then again for the time headway intervals leading away from their preferred time headway. Due to the MANOVA analysis revealing a significant effect of side of the road, the regression analysis for both datasets was also run separately for data gathered on the right and left hand sides of the road. Pearson's correlations, again split by side of the road, were run for both datasets to examine the relationship between the subjective ratings.

A MANOVA was also run to examine the difference in average free following distance chosen by the participants. The MANOVA included side of the road as the within subjects factor, as well as gender and driving experience as between subjects factors. Pearson's correlations were also run to examine the relationship between individuals chosen time headway and their subjective ratings of task difficulty, feeling of risk, effort, comfort, crash risk and how typical the following distance was. All analyses were undertaken using SPSS 16.0 for Windows.

4.3 Results

A MANOVA analysis, with a difference contrast for time headway, was run for both the averaged and relative datasets. For the subjective ratings in the averaged dataset, there were main effects for time headway ($F = 5.47$, $p < .001$), in that the subjective ratings increased as time headway decreased. A significant main effect of side of the road was also found ($F = 3.29$, $p < .05$), as well as a significant interaction effect between side and time headway ($F = 1.38$, $p < .05$). There was no effect of driving experience ($F = .99$, $p = .46$) or gender ($F = 1.53$, $p = .20$) on the ratings however. Post-hoc tests using a Bonferroni adjustment, revealed that there was a significant effect for ratings of feelings of risk, in that ratings of feelings of risk when driving on the right hand side of the road were higher than those given when driving on the left hand side (Mean difference = .21, $p < .01$).

In the case of the relative dataset, MANOVA analysis with a difference contrast for time headway, found that there were also significant main effects for time headway ($F = 5.51$, $p < .001$) and side of the road ($F = 7.0$, $p < .05$), as well as an interaction between side and time headway ($F = 1.60$, $p <.01$). As with the averaged dataset there was no effect of experience ($F = .60$, $p = .77$) or gender ($F = 1.37$, $p = .25$). Post-hoc tests using a Bonferroni adjustment, revealed once again that ratings of feeling of risk were significantly higher when driving on the right hand side of the road (Mean difference = .22, $p < .05$)

4.3.1 Relationship between subjective ratings and time headway in the averaged dataset

In the case of the averaged dataset, none of the subjective variables recorded were found to increase in a simple linear fashion as time headway decreased. Rather, as shown in Figure 4.1, ratings of risk (feeling of risk and crash risk), task difficulty, effort, and comfort, all tend to be flat and stable until a certain time headway was reached. This time headway is around 2.0 seconds for both the left and right hand sides of the road and it is only after this point that the ratings of these variables begin to significantly increase. There is one exception to this, which is in the ratings of feeling of risk for the right hand side of the road. In this case there is a very small significant trend ($t = 2.24$, $r^2 = .03$, $p < .05$) before the 2.0 second mark, which then increases considerably once 2.0 seconds is exceeded ($t = 8.73$, $r^2 = .33$, $p < .001$). However, it should be noted that if the trend for ratings of risk on the right hand side of the road is examined between 4.0 and 2.5 seconds, rather than between 4.0 and 2.0 seconds, then the small significant trend is no longer apparent. Figure 4.1 also clearly shows that the ratings of crash risk participants gave for other drivers increase much more rapidly than ratings of crash risk for the participants themselves.

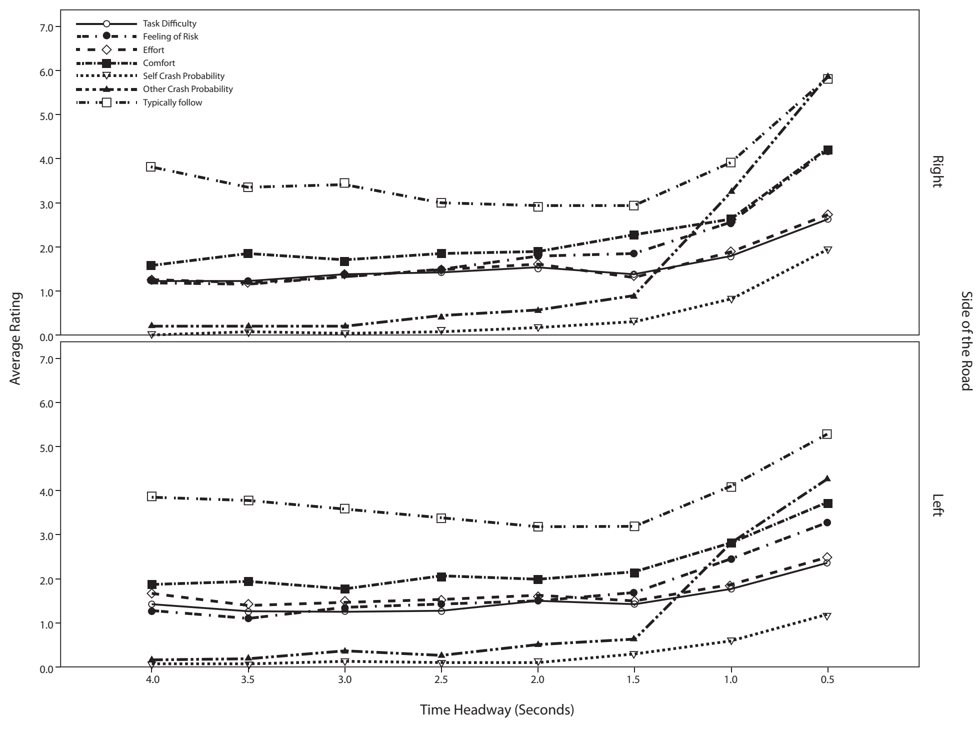

Figure 4.1. Average ratings of task difficulty, feeling of risk, effort, comfort, crash risk (self and other), and "I typically follow at this distance" in relation to decreasing time headway in seconds and by side of the road driven.

Furthermore, it is only once this 2.0 second mark has been crossed that ratings of task difficulty, feeling of risk, and effort rise above an average rating of 2. As a rating of 1 for task difficulty, feeling of risk and effort indicates the absence of these variables, this suggests that many of the participants were not yet willing to indicate that they were feeling or experiencing any difficulty, risk, or effort until after the 2.0 second mark. The trend for ratings of whether the time headway experienced was typical or not appears to be slightly U-shaped, in that participants indicated that the time headway became more and more typical, until around 2.0–2.5 seconds. Then after 2.5 seconds the participants begin to indicate that the time headway became more and more atypical. This trend is apparent on both sides of the road.

Table 4.1. Regression analysis of the averaged dataset for ratings of task difficulty, risk, loss of control, effort, comfort and typical follow with time headway for both sides of the road.

Right hand side of the road						
	4.0 to 2.5 seconds			2.0 to 0.5 seconds		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.02	.15	1.84	.15***	.39	5.28
Feeling of Risk	.03*	.18	2.24	.33***	.57	8.73
Effort	.02	.14	1.75	.16***	.40	5.50
Comfort	.00	.05	.64	.23***	.48	6.88
Self Crash Probability	.02	.14	1.76	.11***	.33	4.37
Other Crash Probability	.02	.12	1.54	.09***	.29	3.85
Typically follow	.03*	-.17	-2.20	.37***	.61	9.56
Left hand side of the road						
	4.0 to 2.5 seconds			2.0 to 0.5 seconds		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.01	-.09	-1.141	.10***	.31	4.15
Feeling of Risk	.02	.12	1.572	.26***	.51	7.4
Effort	.00	-.06	-.71	.10***	.31	4.16
Comfort	.00	.04	.489	.16***	.40	5.55
Self Crash Probability	.01	.11	1.44	.13***	.36	4.79
Other Crash Probability	.01	.10	1.279	.06***	.24	3.09
Typically follow	.01	-12	-1.50	.23***	.48	6.92

* $p < 0.05$ *** $p < 0.001$

As shown in Table 4.1, the results of a regression analysis of the first four time headways for each subjective variable, and the last four are consistent with the trends discussed above. The r^2 values for the left hand side during the 2.0 to 0.5 second period appear to be slightly lower than those for the right hand side, but other than that the general trend is similar.

4.3.2 Relationship between subjective ratings and time headway in the relative dataset

As shown in Figure 4.2 the relative dataset initially appears to show somewhat similar threshold trends to that of the averaged dataset in terms of ratings of feeling of risk, crash risk, and comfort. However, the trend for ratings of effort and task difficulty are different in that they appear to stay flat and stable across all the time headway increments, apart from a peak in the middle at the free choice condition.

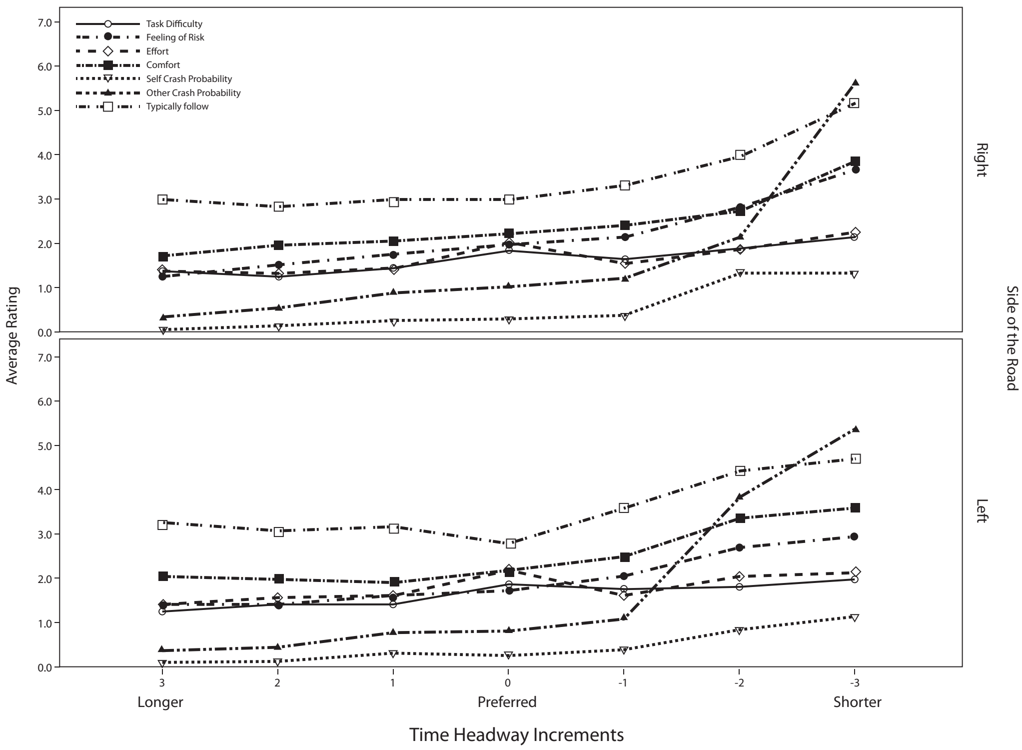

Figure 4.2. Relative ratings of task difficulty, feelings of risk, effort, comfort, crash risk (self and other), and "I typically follow at this distance" in relation to decreasing time headway in seconds and by side of the road driven. A value of zero on the x-axis corresponds to the average rating given by participants during the free following condition. Each increment above or below the zero point (3, 2, 1, -1, -2, -3) represents a fixed time headway condition below or above the average time headway selected by the participants in the free following condition.

As with the averaged dataset, the trend of the feeling of risk variable when driving on the right side of the road, significantly increases slightly before the free time headway condition ($t = 2.7$, $r^2 = .06$, $p < .05$) and then increases rapidly after this point ($t = 6.33$, $r^2 = .20$, $p < .001$). Furthermore, the ratings for self crash risk and other crash risk when driving on the right also shows a significant increase during the period before the free time headway is reached ($t = 2.00$ & 2.34, $r^2 = .03$ & $.04$, $p < .05$). Also, the trend for the typically drive variable appears to have lost its U-shape when examined for the right hand side drive. Once again the results of a regression analysis, shown in Table 4.2, are consistent with the trends discussed above.

Table 4.2. Regression analysis of the relative dataset for ratings of task difficulty, risk, loss of control, effort, comfort and typical follow with time headway for both sides of the road.

Right hand side of the road						
	1 to 3			-1 to -3		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.00	.05	.51	.02	.14	1.81
Feeling of Risk	.06**	.24	2.7	.20***	.45	6.33
Effort	.00	.02	.21	.00	.04	0.51
Comfort	.01	.11	1.20	.15***	.38	5.22
Self Crash Probability	.03*	.18	2.00	.05**	.23	2.98
Other Crash Probability	.04*	.21	2.34	.10***	.32	4.17
Typically follow	.00	.01	.10	.21***	.46	6.54
Left hand side of the road						
	1 to 3			-1 to -3		
	r^2	Beta	t	r^2	Beta	t
Task Difficulty	.01	.11	1.16	.01	.07	.85
Feeling of Risk	.01	.10	1.124	.19***	.44	6.12
Effort	.01	0.12	1.30	.00	.03	.34
Comfort	.00	0.03	.35	.19***	.43	6.01
Self Crash Probability	.03	0.16	1.80	.11***	.33	4.38
Other Crash Probability	.03	0.16	1.79	.08***	.29	3.78
Typically follow	.00	0.03	.32	.25***	.50	7.23

* $p < 0.05$ ** $p < 0.01$ *** $p < 0.001$

4.3.3 Correlations between ratings of task difficulty, risk, comfort and typical time headway

Using a Pearson's correlation, ratings of task difficulty, feeling of risk, and effort were found to be moderately to strongly correlated with each other ($r = .59$ to $.78$, $p < .001$). Ratings of task difficulty, feeling of risk and effort were moderately correlated with ratings of comfort ($r = .41$ to $.65$, $p < .001$). Ratings of feeling of risk were also moderately correlated with participants' ratings of self crash risk ($r = .51$ to $.62$, $p <. 001$) but only had modest correlations with ratings of crash risk for another driver ($r = .14$ to $.28$, $p < .05$). Ratings of effort and task difficulty, on the other hand, were only modestly related to ratings of crash risk, both for the participants themselves and for others ($r = .14$ to $.29$ $p < .05$), except in the case of ratings of task difficulty in the relative dataset for indications of others crash risk when driving on the left, which showed no significant correlation ($r = .10$). Finally, ratings of how typical the following distances were, modestly to moderately correlated with all the other variables ($r = .29$ to $.66$, $p < .01$), with the strongest correlations being with ratings of feeling of risk. Apart from the exception mentioned above for task difficulty, the correlations were relatively consistent across both datasets, and no matter which side of the road the participants drove on.

4.3.4 Free following time headway

During the free following condition, participants on average drove at a time headway of 1.78 seconds ($SD = .89$) behind the lead vehicle on the right hand side of the road, and 1.67 seconds ($SD = .88$) on the left. MANOVA revealed that there was no significant difference in time headway by side of the road ($F = .86$, $p = .36$), driver experience ($F = 1.03$, $p = .32$), or gender ($F = 1.84$, $p = .18$). Pearson's correlations were also calculated between the chosen time headway and the subjective ratings given after driving at that distance. It was found that, on both sides of the road, ratings of feeling of risk ($r = -.43$ to $-.49$, $p < .01$) and crash risk for other drivers ($r = -.37$ to $-.38$, $p < .05$) were significantly negatively correlated with the time headway. No other variable was significantly correlated with the free choice of time headway.

4.4 Discussion

As predicted, there was a strong relationship between ratings of task difficulty, feeling of risk, and effort. This is consistent with previous findings (Fuller, McHugh et al., 2008; Kinnear et al., 2008; Lewis-Evans & Rothengatter, 2009), and is not surprising, as risk, difficulty, and effort often occur together naturalistically. Risk is formally defined as the likelihood of an occurrence multiplied by the outcome of that occurrence (Nordgren et al., 2007), and task difficulty is the interaction between the capability of an individual and the demands of the environment. It could, therefore, be argued that task difficulty is simply the first part of the risk equation, the likelihood of the occurrence. Also, task difficulty and effort are intrinsically linked, as capability can be seen as related to the amount of effort available, and the demands of the environment set the amount of effort required for performance (Fuller, 2005). Given that the correlation appears robust across studies, it may be that ratings of feeling of risk, task difficulty, and effort are labels for the same underlying construct. Further research to see if these variables can be separated would be interesting. It does seem, however, that once the threshold had been crossed, the ratings of feeling of risk were more sensitive to decreases in time headway than the ratings of task difficulty and effort.

Also as predicted, the threshold relationship previously described by Lewis-Evans and Rothengatter (2009) for task difficulty, feeling of risk, crash risk, effort, and comfort with speed, was also apparent here for time headway, at least in the averaged dataset. Ratings of task difficulty, feeling of risk, crash risk, effort, and comfort generally stayed low and stable until a certain following distance was reached, around 2.0 seconds, and after this point began to significantly increase. In the case of the relative dataset, however, the trend is not as clear as previously found for speed, where the speed choice made by participants acted as a clear threshold point (Lewis-Evans & Rothengatter, 2009). This relationship is still apparent for ratings of feeling of risk, comfort, and crash risk but ratings of effort and task difficulty in the relative dataset appear to stay flat over the time headways examined. This could be because the instruction given to the participants, to travel as close as possible while still feeling comfortable, was inappropriate. Given that the participants' chosen time headway was on average around 1.67 to 1.78 seconds, it may be that participants obeyed the "follow as close as possible" part of the instruction more so than the instruction to remain comfortable. The resulting relatively close following distance leads to quite a few missing values in the relative dataset as there were not always 3 fixed time headways available to fill the -1 to -3 positions in the relative dataset. This may have affected the trend lines. Perhaps an instruction for the participants to simply follow as they would normally would have been more appropriate.

The fact that a threshold relationship is apparent in this data is particularly interesting given the unusual nature of the task required of the participants. In essence, all the participants had to do was maintain lateral control, on an identical road, several different times. The speed of the vehicle, and its time headway to the lead vehicle were all set and maintained by the simulator, with the exception of the free following condition. It could therefore be argued from an objective position, that in this experiment, following the lead vehicle at a headway of 0.5 seconds is no more effortful, difficult or risky than following at 4.0 seconds. That the participants did indicate that it felt risky, difficult, effortful, and uncomfortable to be close to the lead vehicle, despite the lack of real objective difference in these variables, is suggestive of an effect of previous experience and learnt thresholds being responsible for these feelings. It may be that, as suggested by threat Avoidance theory (Fuller, 1984), zero-risk theory (Näätänen & Summala, 1974), and the multiple comfort zone model (Summala, 2005), that participants have a certain, learnt, headway at which they prefer to follow vehicles. Once this learnt, preferred headway is crossed, uncomfortable feelings that can be labelled as difficulty, risk, or effort, begin to be experienced. The multiple comfort zone model, in particular, takes an approach which is similar to that laid out by Gibson and Crooks (1938) in their Field of Safe Travel model. The multiple comfort zone model suggests that just like individuals have learnt personal spaces around them during everyday life that make them feel uncomfortable if they are breached, they also create a zone of safe travel or safety margin around themselves when driving. When this safety margin is exceeded it indicates to the driver that something is not as usually experienced (Summala, 2005). These safety margins may not actually be related to the objective risk or safety of the situation, however, and are instead learnt based on previous experience.

The typical following distance ratings for the averaged dataset also support an idea of learnt thresholds. Ratings of how typical the time headway experienced was, followed a U-shaped trend, with the bottom of the U being around the same point at which ratings of task difficulty, risk, effort, and discomfort begin to increase. This is in line with a similar result for indications of typical speed of travel found previously (Lewis-Evans & Rothengatter, 2009).

With the possibility of learnt thresholds in mind, this study attempted to test the role of familiarity in determining the threshold point. As such, drivers were required to complete the following distance task on both the familiar (for Dutch drivers) right hand side of the road, as well as the unfamiliar left hand side. It was thought that driving on the unfamiliar side of the road may have shifted or removed the threshold effect, and perhaps increased ratings of difficulty, risk, effort, and discomfort. However, there was very little difference in the results produced by driving on the left hand side of the road, with the general trend for both sides being similar. The only significant increase in ratings was in fact found for ratings of feeling of risk for drivers travelling on the right hand side of the road, and this effect was small. The lack of an effect caused by road type could be because drivers were aware of what was causing any potential feelings of unfamiliarity, and were able to dismiss them as not relevant to the time headway task. Perhaps if a task involving manoeuvres traditionally seen as difficult when driving on an unfamiliar side of the road (such as navigating intersections or roundabouts) had been used there would have been a more marked impact. However, this would then confound the variable of simple unfamiliarity with the increased difficulty and risk of such manoeuvres.

In addition, there was no significant impact of driver experience on the ratings given. This may indicate that drivers learn or establish these thresholds early and that once a threshold has been crossed the reaction is similar no matter how experienced the individual is. In their examination of the relationship between speed, ratings of risk, and task difficulty, Kinnear et al. (2008) also found no effect of driving experience on ratings of these variables.

There are several potential weaknesses with this study. To begin with, it is possible that by asking participants to rate the variables assessed that they become more salient to the participants. This would bias the results towards reporting those variables more readily and perhaps shift participants' threshold point of awareness. However, the finding that even with attention directed towards these variables, participants still often rated them as absent during the larger time headways, does give additional support to the idea that these variables are not usually experienced.

It is also possible that the rating scales used in this experiment were not sensitive enough to pick up underlying changes in the variables assessed. This could also be impacted by the relatively large changes in following distance experienced by the participants. It is possible that steps of 0.5 seconds may have been too large to see the actual threshold point of the participants.

Furthermore, the task that the participants performed could justifiably be labelled as unusual. Driving is usually described as a self-paced task where drivers are free to choose their own speed and time headway, amongst other things. In this experiment, however, drivers were for most of the time locked into the same speed and the control of time headway was completely out of their hands. There are times during driving, however, when the task is not particularly self paced such as when in a stream of traffic. Also the task used in this experiment could be seen as similar to driving with adaptive cruise control, which allows for control of both time headway and speed to be handed over to the vehicle.

4.5 Conclusion

This experiment offers further evidence for driver behaviour models that provide a threshold account for the experience of task difficulty, risk, effort, and comfort while driving. Furthermore, that a threshold relationship is apparent for both following distance and speed, is in part validation of threshold models to embrace the entire driving task. It also appears from the results of this experiment, that experience and learning may play some role in setting the thresholds used by drivers. Ultimately this means that road safety practitioners cannot rely on drivers to always be consciously aware of changes in the driving task brought about by interventions. Rather, if practitioners want to cause drivers to consciously change their behaviour in reaction to the experience of task difficulty, risk, effort, or comfort, then whatever road safety intervention is being implemented must cause the drivers threshold for the perception of these variables to be crossed. This could be particularly challenging given that there is likely considerable variation between, and perhaps within, individuals' thresholds for the perception of these variables.

CHAPTER 5 **MAINTAIN THAT SPEED**

A version of this chapter has been previously published as Lewis-Evans, B., De Waard, D., & Brookhuis, K.A. (2011). Speed maintenance under cognitive load – Implications for theories of driver behaviour. *Accident Analysis and Prevention, 43,* 1497-1507 and can be accessed online here: http://dx.doi.org/10.1016/j.aap.2011.02.030

Abstract

No model of driver behaviour has yet managed to achieve widespread acceptance and use in the field of traffic psychology, partly due to the difficulty in testing many of the theories. However, one class of theories, the motivational theories, can be usefully split into two groups, and the differences between them can then be examined. One group posits the constant monitoring and targeting of a certain subjective variable, often risk, as the controlling factor in driving. The other group however states that subjective variables such as risk are only relevant once a certain threshold has been passed.

In this study we aimed to examine this difference by manipulating both speed of travel and the amount of cognitive load participants were under. Participants were asked to initially drive at their preferred speed for 1 minute in a driving simulator. Participants' speed was then automatically increased or decreased by 10, 20, 30 km/h or left unchanged. Participants were then required to maintain the new speed for 1 minute. After this 1 minute, the speed was again automatically changed and had to be maintained for one more minute, but this time participants also carried out a secondary mental arithmetic task. Finally, participants were asked to again drive for another 1 minute at their preferred speed. This procedure was repeated seven times, once for each speed manipulation; -30, -20, -10, +0, +10, +20 and +30 km/h. After each 1 minute interval, verbal ratings of task difficulty, effort, feeling of risk, and the typicality of the speed, were collected

The results show a threshold effect in ratings of task difficulty, effort and feeling of risk, with no significant difference given between the ratings during the baseline period and the experimentally decreased speed periods until after participant's preferred speed of travel had been exceeded. Furthermore, even when under cognitive load the threshold relationship was still apparent, if somewhat diminished. Finally, it appears that when under cognitive load drivers have difficulty maintaining a travelling speed which is lower than the speed at which they would prefer to drive. However, driving at a speed in excess of their preferred speed appears to be easier to maintain, at least in the short term.

5.1 Introduction

Motivational theories of driver behaviour can be roughly split into two groups. The first group is made up of those theories which state that drivers are constantly aware of, monitor, and seek to maintain a set level or range of a variable, such as risk. Whereas the second group of theories, claims that variables such as a perception or feeling of risk are only relevant, and only experienced, at certain times during driving, i.e. when a certain threshold is exceeded (Michon, 1989; Ranney, 1994; Rothengatter, 2002).

The classic example of the monitoring type of motivational model is Risk Homeostasis Theory (RHT) which was first put forward by Wilde (1976). RHT states that individuals have a target level of risk which they seek to maintain. This target level of risk is created through a motivational cost/benefit trade off, where the benefits and costs of risky behaviours are weighed against the benefits and costs of safer behaviours. RHT also states that unless these costs and benefits are altered, target risk will stay the same, and drivers will act in a fashion that means they are constantly monitoring and always attempting to return to this target level of risk. This process, called risk compensation by Wilde (1988), led to an extreme claim that road safety engineering measures, such as widening roads, would have no effect on safety; individuals would just use up the safety gained by widening the road, by speeding for example, in order to maintain their preferred level of risk. This extreme risk compensation has been discounted to a large extent, however, as it seems clear that many non-motivational road safety measures, such as the general improvement in car safety designs over time, have managed to have a positive impact on road safety (e.g. McKenna, 1990; OECD, 1990).

While complete risk compensation may not occur, negative behavioural adaptation, where drivers act in a fashion that reduces the safety which could otherwise be gained through an intervention, is a well accepted phenomenon (OECD, 1990). It should be noted, however, that behavioural adaptation is essentially just a way of saying that people change their behaviour in reaction to changes in the environment. This is hardly revolutionary. Behavioural adaptation can also act in a positive fashion to increase safety, for example, people drive slower on narrower roads (Godley, Triggs, & Fildes, 2004; Lewis-Evans & Charlton, 2006). Given the acceptance of behavioural adaptation, most modern theories of driver behaviour have concentrated not on trying to show if this phenomenon occurs, but why it does.

Other examples of theories that fit within the first monitoring and target maintaining group, include Risk Allostasis Theory (RAT)(Fuller, McHugh et al., 2008), and the Monitor Model (Vaa et al., 2000). RAT differs from RHT in that it specifies that individuals maintain a target range of a feeling of risk, rather than a single target level of crash risk put forward by RHT. Also RAT states that this target range is a lot more flexible and open to change than the target level of risk within RHT, which was seen as quite fixed and stable (Fuller & Santos, 2002; Fuller, 2005; Fuller et al., 2008; Wilde, 1988). Within the theoretical underpinnings of RAT, Fuller is quite clear that "the effects of risk on decision making are not binary" and that "task difficulty and feelings of risk are continuously present variables which inform driver decisions" (Fuller et al., 2008, p. 31).

The Monitor Model differs from the previous two examples of monitoring theories in that it suggests that multiple subjective variables are monitored and maintained, leading to an overall target best feeling (Vaa et al., 2000; Vaa, 2003; Vaa, 2007). Although, within the framework of the Monitor Model the monitoring of feelings of risk is given high importance due to the assumed evolutionary value of being able to reliably detect risk (Vaa, 2003; Vaa, 2007).

Interestingly, both the Monitoring Model and RAT reference the Somatic Marker Hypothesis of Damasio as supporting their view of risk, or some other feeling, as being constantly monitored (Damasio, 1994; Damasio, 2003; Fuller, 2007; Fuller, 2008; Vaa, 2003; Vaa, 2007). However, the Somatic Marker Hypothesis does not seem to support this interpretation. Rather, it specifically classifies feelings, such as the feeling of risk central to RAT, as conscious perceptions of an internal body state. These feelings are therefore not seen as continuously present, and similarly the underlying internal body states, or emotions, are reactions to certain learnt or innate stimuli and also not continuously present for monitoring (Damasio, 1994; Damasio, 2003). It would seem therefore, in conflict with the statements of Fuller et al. (2008; 2008), that the Somatic Marker Hypothesis does view the effect of risk on decision making as binary, in that it is either there or not. To be clear what is available in most cases, for constant monitoring, according to Damasio (1994; 2003) is the body itself. It is changes in the general body state caused by certain stimuli that can be detected, or that can influence behaviour unconsciously. These changes therefore only occur when certain thresholds have been crossed, i.e. if stimuli present or not, or present in a certain required quantity (Damasio, 1994, 2003).

This leads on to the threshold class of theories. The classic example of this is zero-risk theory (Näätänen & Summala, 1974; Summala, 1988). Zero-risk theory claims that risk is only perceived occasionally. Specifically, zero-risk theory states that drivers only experience risk once certain safety margins have been exceeded. Only once this threshold is crossed, and risk is experienced, do drivers take action to reduce this risk back to zero if possible, unless they are otherwise motivated not to do so. It is worth pointing out here that while zero-risk theory does contain a component called the "Subjective Risk Monitor" this component is only triggered during the relatively rare situations when a driver's safety margins have been exceeded. This means that there is an aspect of the monitoring of risk in zero-risk theory, but this only occurs once a threshold has been crossed, and not continuously as claimed by monitoring models such as RAT (Fuller et al., 2008; Fuller, McHugh et al., 2008; Näätänen & Summala, 1974; Summala, 1988).

Other examples of threshold models are threat avoidance theory (Fuller, 1984) and the multiple comfort zone model (Summala, 2005). Threat avoidance theory (Fuller, 1984) is a behavioural model which suggests that people learn to associate risk with certain situations and only respond to risk when those situations arise. It also suggests that since the road environment is quite forgiving, associations between objectively risky driving and subjective impressions of risk are not often made and, therefore, not often experienced, and in fact this disconnect acts to encourage objectively risky behaviour.

The multiple comfort zone model (Summala, 2005) can be viewed as an evolution of the earlier zero-risk theory. It states that the maintenance of performance based safety margins are the primary controlling factors behind driver behaviour, but adds that there may be additional feelings, along with or instead of risk, which arise when these margins are exceeded. This creates an uncomfortable or unpleasant feeling that drivers will seek to remove. Ultimately the most important factor that separates the threshold models from the monitoring models is that in threshold models the relevant variable, often risk, acts as a warning and as a sensation that should be removed. In monitoring models, however, this subjective variable is constantly present and constantly guiding driver behaviour.

Unfortunately experiments aimed at testing specific models of driver behaviour have been relatively rare due to the difficulties of coming up with valid, testable hypotheses that would effectively falsify the individual theories. However, it may be possible to at least examine the difference between the constant monitoring of subjective variables versus threshold perception of subjective variables and then perhaps the number of competing theories could be somewhat narrowed down.

Some previous experiments have found support for the constant monitoring of feeling of risk and task difficulty in reaction to speed changes while driving (Fuller, McHugh et al., 2008; Kinnear et al., 2008), but others have challenged this and instead found evidence for threshold perception of these variables (Lewis-Evans & Rothengatter, 2009; Lewis-Evans, de Waard, & Brookhuis, 2010). What these studies do agree on is that there seems to be a strong relationship between how people perceive and rate a feeling of risk, and how they perceive and rate task difficulty.

In this paper we seek to add to the previous experiments (Fuller, McHugh et al., 2008; Kinnear et al., 2008; Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010) in two ways. Firstly, we again examine the relationship between speed and subjective ratings of task difficulty, feeling of risk, and effort. If accounts of constant monitoring are accurate, then ratings of task difficulty, risk and required effort should systematically increase with speed, as was found in the experiment of Fuller, McHugh et al. (2008). This would mean that ratings at speeds lower and higher than individuals preferred speed should be different from ratings drivers give when driving at their preferred speed. Conversely if a threshold account holds, then ratings of task difficulty, feeling of risk and effort should initially be low, stable, and no different from the ratings given during a baseline period where drivers are allowed to drive at the speed they prefer. Then once the speed at which drivers prefer to drive has been surpassed, ratings of task difficulty, feeling of risk, and effort, will increase. Idealised predicted differences between theoretical accounts, using ratings of task difficulty as an example, are shown in Figure 5.1.

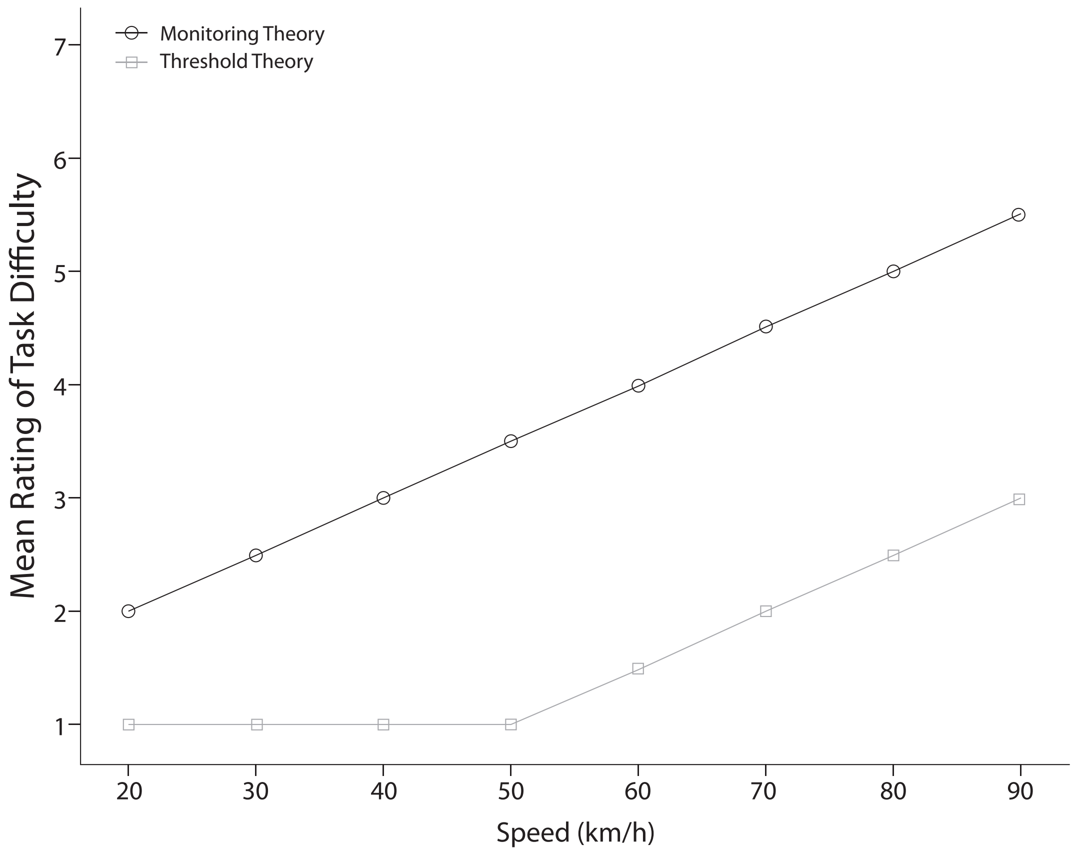

Figure 5.1. Idealised predictions of the relationship between ratings of task difficulty and speed based on monitoring and threshold theories.

Secondly, we seek to further explore the relationship between individuals' reported perceptions of risk and their ratings of task difficulty. These two variables have previously been found to be strongly related to each other (Fuller, McHugh et al., 2008; Kinnear et al., 2008), and also to ratings of effort (Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010). This is not surprising given that risk, difficulty, and effort are often linked naturalistically. In fact it is very difficult to think of any way of increasing the difficulty of driving without also increasing the risk. In this experiment the difficulty of the task being performed has been increased through the addition of a secondary task.

The hypotheses related to the addition of the secondary task are twofold. Firstly, it was expected that the addition of a secondary task would increase ratings of effort, task difficulty, and feeling of risk. So in other words, if Figure 5.1 is examined, a rating of 1 would increase to a rating of 2 for example. The second hypotheses is that if a threshold type relationship, such as the one shown in Figure 5.1 was found, then it is possible that the presence of the threshold would be removed, or perhaps shifted to an earlier speed. This is based on the idea that simply the extra loading nature of the secondary task would cause the threshold to either be crossed right away, resulting in a monitoring type reaction as shown in Figure 5.1, or that it would be crossed earlier, for example at 40 km/h rather than 60 km/h in Figure 5.1.

5.2 Method

5.2.1 Participants

Participants were recruited from students enrolled in the English Bachelors in Psychology at the University of Groningen and given course credit for participation. To comply with the University's ethical requirements, they provided informed consent before being admitted to the experiment. In order to take part, participants had to have had at least one year driving experience on a valid drivers' licence. A total of 56 participants were recruited in this way, 22 male and 34 female. However, one of the male participants consistently drove at speeds in excess of 130 km/h during the experiment and was a clear outlier. As such, he was removed from the experiment. In addition, two female participants experienced feelings of nausea when using the simulator and did not complete the experiment. This left 21 males and 32 females in the final dataset. The females on average were 20.4 years old (SD = 1.2) and had held a drivers' licence for an average of 2.7 years (SD = .9). The males were 21.9 years old on average (SD = 2.9) and had held a drivers' licence for an average of 3.6 years (SD = 2.6).

5.2.2 Materials

The experiment was carried out using the University of Groningen driving simulator. The simulator is on a fixed base, running software by STSoftware and uses three LCD screens to give participants a 210-degree view of the road environment. In order to hide the speed information, and force participants to rely on their own perception of speed, a cardboard cutout was placed over the instrument panel. A winding rural road was created in the simulator with lane widths of 3.0 m in both the right and left hand lanes. The road also had the same surface properties and road marking for the entire drive and never altered in elevation. There was no traffic in the simulation and information about participants' speed was collected at a rate of 10 Hz. The secondary task chosen, was the Paced Auditory Serial Addition Test (PASAT, Gronwall & Sampson, 1974) created using E-Prime software and run on a Windows XP laptop with an USB powered external speaker system.

5.2.3 Procedure

The experiment required many different steps and trials, and is somewhat complex. Therefore the procedure is summarised in Table 5.1 below.

Participants provided consent to participate and then filled in a short questionnaire which collected information on their age, gender, and how long they had held their drivers' licence. Participants then completed a practice drive in the simulator for 5 minutes during which no data was recorded on their driving performance. If participants were uncomfortable with the simulator they could continue to drive after this initial 5 minutes, however none of the participants took this opportunity. If at this point, or at any other time during the experiment, the participants started to feel nauseous or unwell they were asked to stop and did not progress in the study.

After the practice drive, the PASAT task was explained to the participants and they were given a chance to practice it for 3 minutes, without driving. During the PASAT task, participants heard a string of numbers from 1 to 9 being read out, with 1.8 seconds between each number. Participants then had to verbally respond by adding the number they just heard to the number that they had heard preceding it. For example if they first heard the number 1, and then next heard the number 4, they were required to call out "5" (1 + 4), and then if the next number they heard was 3 then they had to reply "7" (4 + 3) and so on. The participants were told to answer verbally as quickly as possible, and that their accuracy was being assessed, although no data was recorded during the PASAT practice session. Outside of the practice session,

Table 5.1. Summary of the procedure, detailing when speed, subjective and PASAT data were collected. The Practice Drive and PASAT practice only occurred once per participant, then each participant completed the trial blocks 7 times, once for each speed category (-30,-20,-10, +0,+10,+20+30 km/h).

Stage & Condition	Data Recorded			
	Duration	Speed	PASAT	Subjective
Pre-trial				
1. Practice drive	5 minutes	NO	N/A	NO
2. PASAT practice	3 minutes	N/A	NO	N/A
Trial blocks - Repeated 7 times (-30,-20,-10,0,+10,+20+30 km/h) in random order for each participant				
1. Baseline condition	Duration	Speed	PASAT	Subjective
1.1 Participants instructed to start the vehicle and drive at the speed they find most comfortable.	Variable	NO	N/A	NO
1.2 Participants notify the experimenter that they have reached the speed they find most comfortable. Then they continue driving at this speed for 1 minute.	1 minute	YES	N/A	NO
1.3 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 1.2). During this time participants are free to vary their speed.	Variable	NO	N/A	YES
2. No load condition	Duration	Speed	PASAT	Subjective
2.1 Using the average speed driven during step 1.2 of the Baseline condition as a reference point the control of speed is taken away from the participant, and given to the simulator and increases or decreases by 10, 20, or 30 km/h or remains unchanged. Participants must continue to control steering at this point but have no way of altering the speed.	Variable	NO	N/A	NO
2.2 Participants notify the experimenter that they could take control of speed back, and maintain the speed they are currently travelling at (the speed set in step 2.1)	Variable	NO	N/A	NO
2.3 Speed control is given back to the participants, returning them once again to full control. Participants notify the experimenter when they believe they are travelling at the new speed that was set for them in step 2.1	Variable	NO	N/A	NO
2.4 Participants are asked to maintain their current speed for 1 minute	1 minute	YES	N/A	NO
2.5 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 2.4). During this time participants are free to vary their speed.	Variable	NO	N/A	YES

3. Load condition	Duration	Speed	PASAT	Subjective
3.1 Using the average speed driven during step 1.2 of the Baseline condition as a reference point the control of speed is taken away from the participant, and given to the simulator and increases or decreases by 10, 20, or 30 km/h or remains unchanged. Participants must continue to control steering at this point but have no way of altering the speed.	Variable	NO	N/A	NO
3.2 Participants then the experimenter that they could take control of speed back, and maintain the speed they are currently travelling at (the speed set in step 3.1)	Variable	NO	N/A	NO
3.3 Speed control is given back to the participants, returning them once again to full control. Participants notify the experimenter when they believe they are travelling at the new speed that was set for them in step 3.1	Variable	NO	N/A	NO
3.4 Participants are asked to maintain their current speed for 1 minute and to simultaneously carry out the PASAT task to the best of their ability while maintaining control of the vehicle.	1 minute	YES	YES	NO
3.5 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 3.4). During this time participants are free to vary their speed.	Variable	NO	N/A	YES
4. Return to baseline condition	Duration	Speed	PASAT	Subjective
4.1 Participants instructed to drive at the speed they find most comfortable.	Variable	NO	N/A	NO
4.2 Participants notify the experimenter that they have reached the speed they find most comfortable. Then they continue driving at this speed for 1 minute.	1 minute	YES	N/A	NO
4.3 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 4.2). During this time participants are free to vary their speed.	Variable	NO	N/A	YES
4.4 Participants are asked to stop the vehicle, and then the simulation is reset to the start in order to run a new block.	Variable	NO	N/A	NO
3.5 Participants instructed to continue to drive in a fashion that maintains their control of the vehicle and take their time and to verbally answer 4 subjective questions about the last minute of driving (period 3.4). During this time participants are free to vary their speed.	Variable	NO	N/A	YES

the correct and incorrect answers were recorded by the experimenter but no feedback was given to the participants as to the accuracy of their answers. During the experiment, while driving, participants were instructed to perform the PASAT task to the best of their ability, while still maintaining control of the vehicle and the vehicle's speed.

After practicing the PASAT task, the first trial block was started. The first condition was always a baseline (condition 1 in Table 5.1): in the baseline condition participants were instructed to start the vehicle and drive at a speed that they found most comfortable. They could take however long they wished to do so, and once they had reached a comfortable driving speed they then notified the experimenter. Only then, after being notified, was information on their driving speed recorded by the simulator for 1 minute, to establish a baseline average speed. During this 1 minute, participants were simply instructed to continue to drive at whatever speed they found comfortable. After 1 minute was up the participants continued to drive but had to give four verbal ratings to the following questions, asked in the order presented below by the experimenter:

How difficult did you find it to drive this section of road at this speed?

1 2 3 4 5 6 7

Extremely Easy Extremely Difficult

How much risk did you experience driving this section of road at this speed?

1 2 3 4 5 6 7

Maximum Risk No Risk

How much effort did it take to drive this section of road at this speed?

1 2 3 4 5 6 7

No Effort Maximum Effort

Would you typically, in these conditions, drive at this speed

1 2 3 4 5 6 7

Always Never

It was stressed to the participants that they should take their time to answer the above questions, and that remaining in control of the vehicle was the most important factor. Ratings of feeling of risk were later reversed for data analyses.

The next step was the no load condition (condition 2 in Table 5.1): the participants were informed, while still driving, that control of their speed would be taken away from them and given to the simulator, much like cruise control being engaged. Only speed control was taken away however, and participants had to continue to steer. Using the average speed collected in the baseline condition, the speed of the vehicle was then increased or decreased by 10, 20, or 30 km/h or was set to the previous average speed. So if the participant had driven 52 km/h on average during the baseline condition, then, in the plus 30 km/h trial the new speed would be set to 82 km/h. After the new speed was set, participants were then asked to tell the experimenter when they thought they could take control of the speed back and continue to drive at the new speed they were currently travelling at. As with every step where the participants were asked to notify the experimenter, participants could take as much time as they liked to carry out this step. Once the participants indicated that they could take control, then the experimenter switched speed control from the simulator back to manual. Since participants could not see exactly the speed at which they were travelling from the speedometer, they had to rely on their own perception, which meant when speed was transferred back to the participants it would sometimes increase or decrease. Therefore, participants were instructed to say when they thought they were driving at the speed they had just observed. Once the participants did indicate they were travelling at the appropriate speed, they were asked to attempt to maintain their speed of travel. Again, participants had no feedback from the speedometer and had to rely on their own perception of speed to make this judgment. Speed data were then recorded for the next minute, after which participants again had to give verbal ratings as described in the baseline condition. While giving these ratings participants could vary their speed freely.

The next condition was the load condition (condition 3 in Table 5.1): this condition was nearly completely identical to the no load condition, including using the same average speed data from the baseline condition (condition 1 in Table 5.1). The only change is that participants were required to complete the PASAT task as well as maintaining their speed during the 1 minute period before subjective impressions were collected.

The final condition in each trial was the return to baseline (condition 4 in Table 5.1) which was simply a repeat of the baseline condition. Once the return to baseline condition was completed in a trial, participants were asked to stop the vehicle and the simulation was reset so that another trial could begin. Each participant completed 7 blocks of trials, each containing the 4 conditions described above. Each block represented one speed manipulation, and the blocks were presented in a randomly generated order for every participant. This means that each participant experienced driving at 10, 20, and 30 km/h faster and slower than their baseline periods, as well as one condition where the target speed set was the same as the average speed they drove during the baseline period. Furthermore, the load and no load conditions were counter balanced across the participants. This means that 26 participants (11 males, 15 females) carried out the task as described in Table 5.1, and 27 participants (10 males, 17 females) carried out the load condition (condition 3 in Table 5.1) of each trial before the no load condition (condition 2 in Table 5.1). On average the whole experiment took around one and a half hours to complete.

5.2.4 Analysis

The ratings of task difficulty, effort, feeling of risk, and typical driving speed were collected and averaged across all participants for each speed category (+/- 0, 10, 20, 30 km/h) and condition (baseline, no load, load, return to baseline). For the analysis of the ratings of feeling of risk, the scores were reversed to bring them in line with the other ratings used. Analyses were also carried out for the objective data on the speeds travelled by the participants. The independent variables in this experiment, therefore, are the speed conditions (+/- 0, 10, 20, 30 km/h) and the four trial conditions; baseline, no load, load, and return to baseline. The dependent variables are the actual speed driven and the subjective ratings of task difficulty, feeling of risk, effort, and the typical driving speed question. Accuracy on the PASAT task was the final dependent variable assessed. The programs used for analysis were SPSS 16 for Windows and IBM SPSS 18 for Macintosh.

5.3 Results

5.3.1 Ratings of task difficulty, risk, effort and typical driving speed

A separate, repeated measures MANOVA analysis was run for each of the subjective variables, to compare them between the four different conditions with a polynomial contrast, baseline, no load, load and return to baseline, at each of the seven speeds. There were significant differences across the four conditions for all speeds (-30, -20, -10, 0, +10, +20, +30) in ratings of task difficulty ($F(3) = 31.72$ to 192.91, $p < .001$, $\eta_p^2 = .39$ to $.80$), effort ($F(3) = 25.09$ to 136.66, $p < .001$, $\eta_p^2 = .39$ to $.74$), feeling of risk ($F(3) = 15.71$ to 187.85, $p < .001$, $\eta_p^2 = .39$ to $.74$), and typical driving speed ($F(3) = 22.31$ to 91.47, $p < .001$, $\eta_p^2 = .24$ to $.79$). A breakdown into comparisons of particular interest, and relevant post hoc tests with a Bonferroni correction, are presented in the following sections.

5.3.1.1 Baseline condition and return to baseline condition

The post hoc tests with a Bonferroni correction failed to find any significant difference ($p = 1.00$) in ratings of task difficulty (MD = -.16 to .16, SE = .10 to .15), effort (MD = -.22 to. 08, SE = .11 to .18), feeling of risk (MD = -.10 to. 16, SE = .10 to .17), and typical driving speed (MD = -.36 to .28, SE = .13 to .20), between the baseline and return to baseline data. This held true for every speed condition, and is shown in Figure 5.2.

It is also clear from Figure 5.2 that ratings of all the subjective variables stayed essentially flat across all the speed conditions during the baseline and return to baseline trials. The flat, non significant, natures of these trends are supported by regression analysis shown in Table 5.2.

5.3.1.2 Baseline condition and no load condition

Post hoc tests with a Bonferroni correction showed that for the first three speed conditions (-30 to -10 km/h) there was no significant difference between the ratings for task difficulty given during the baseline and no load conditions (MD = -.06 to .40, SE = .15 to .21 $p > .05$). The same was found to be true during the first four speed conditions (-30 to +0 km/h) for ratings of effort (MD = -.42 to -.08, SE = .16 to .20, $p > .08$) and feeling of risk (MD = -.28 to .36, SE = .13 to .17, $p > .18$). As can be seen in Figure 5.3, however, from the 4th speed condition for task difficulty (MD = .54 to 2.88, SE = .16 to .22), and the 5th speed condition for effort (MD = 1.14 to 2.46, SE = .19 to .25) and feeling of risk (MD = 1.44 to 2.90, SE = .20 to .23) the ratings given during the no load conditions were significantly higher than those given during the baseline periods ($p < .01$).

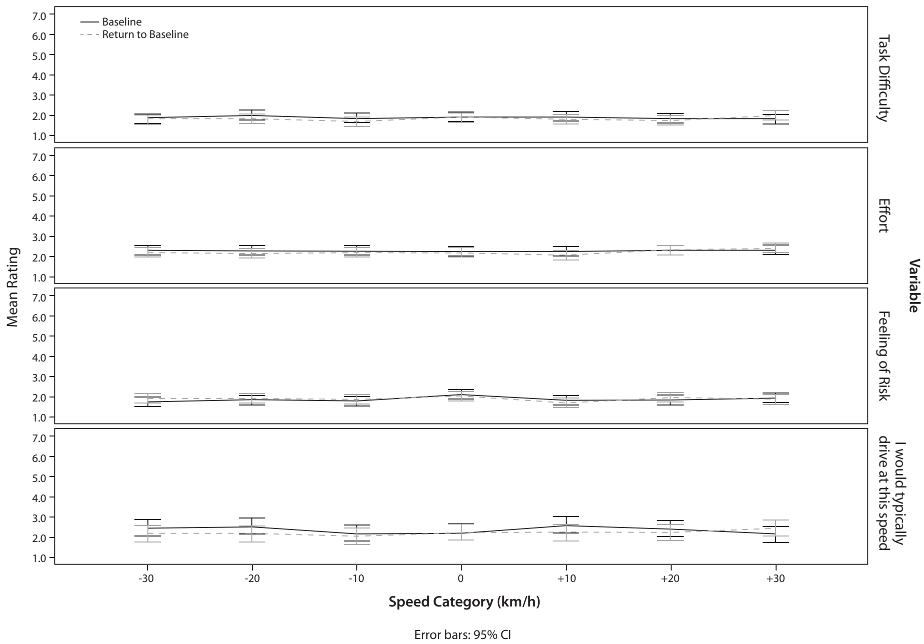

Figure 5.2. Average ratings of task difficulty, effort, feeling of risk, and I would typically drive at this speed across all speed categories (-30 to +30 km/h) for the baseline and return to baseline conditions. Speed category '0' is the preferred speed.

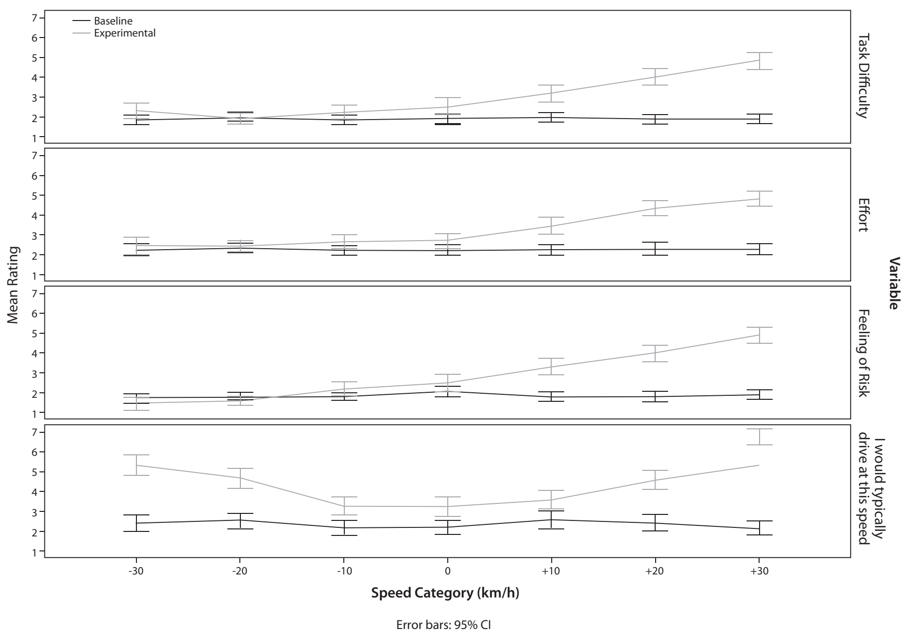

Figure 5.3. Average ratings of task difficulty, effort, feeling of risk, and I would typically drive at this speed across all speed categories (-30 to +30 km/h) for the baseline and no load conditions. Speed category '0' is the preferred speed.

Table 5.2. Regression analysis of the ratings of task difficulty, effort, feeling of risk, and typical driving speed for the baseline and return to baseline conditions.

	Speed Categories – Baseline							
	-30 to -10 km/h				0 to 30 km/h			
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	.00	-.04	.97	.00	-.03	-.42	.67
Effort	.00	.00	-.03	.98	.00	.02	.35	.73
Feeling of Risk	.00	.04	.43	.67	.00	-.06	-.80	.42
Typical Driving Speed	.01	-.07	-0.85	.39	.00	-.02	-.34	.74
	Speed Categories – Return to Baseline							
	-30 to -10 km/h				0 to 30 km/h			
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	-.05	-.66	.51	.00	.06	.87	.38
Effort	.00	.01	.10	.92	.01	.09	1.26	.21
Feeling of Risk	.00	-.03	-.35	.73	.00	-.02	-.34	.74
Typical Driving Speed	.00	-.04	-.51	.61	.00	.04	.58	.56

Conversely ratings of whether the participants would typically drive at the speed they were experiencing were significantly higher ($p < .01$) during the no load condition than those given during the baseline condition for all speed categories (MD = .98 to 3.12, SE = .20 to .31). As seen in Figure 5.3, ratings of typicality of speed appear to follow a somewhat U-shaped curve, with the bottom of the U being at the no speed change category. This means that participants indicated that speeds were more and more typical as they approached no speed change, and then less so as they moved away from it. The trends described above are supported by the results of the regression analysis for the no load condition, as shown in Table 5.3. There is no significant trend for ratings of task difficulty and effort between the -30 and -10 km/h speed categories ($r^2 = .00$, $p > .45$) and then there is an increasing trend from the preferred speed category onwards ($r^2 = .26$ and .25, $p < .001$).

Table 5.3. Regression analysis of the ratings of task difficulty, effort, feeling of risk, and typical driving speed for the no load condition.

Speed Categories – No Load								
	-30 to -10 km/h				0 to 30 km/h			
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	-.01	-.16	.87	.26	.51	8.48	< .001
Effort	.00	.06	.76	.45	.25	.50	8.39	< .001
Feeling of Risk	.07	.26	3.32	< .001	.26	.51	8.49	< .001
Typical Driving Speed	.19	-.44	-6.06	< .001	.20	.45	7.19	< .001

Ratings for feeling of risk are different, as they show a slight significant increasing trend before the participants' preferred speed is exceeded ($r^2 = .07$, $p < .001$) which then changes to a larger increase afterwards ($r^2 = .26$, $p < .001$). The regression results for typically driven speed are consistent with the U-shaped description given above.

5.3.1.3 No load condition and load condition

As can be seen in Figure 5.4, the general trend of ratings of task difficulty, effort, feeling of risk, and typical driving speed, appear to be relatively the same between the no load and load conditions. However, it does seem that, at least in the case of ratings of task difficulty and effort, that the curve for the load task has been shifted upwards.

The results of the post hoc tests with a Bonferroni correction confirm that ratings of ratings of task difficulty (MD= .68 to 1.96, SE = .20 to .28) and effort (MD= .78 to 1.88, SE = .21 to .27) were significantly higher than in the no load condition ($p < .01$) for each speed category during the load condition. Ratings of feeling of risk were also significantly higher (MD= 1.26 to 1.74, SE = .23 to .29, $p < .001$) during the load condition for the first 4 speed categories (-30 to +0 km/h). However for the next two speed categories (+10 to +20 km/h) there was no significant difference (MD= .64, SE = .25, $p > 0.09$) between ratings of feeling of risk given during the load and no load conditions. A significant difference in ratings of feeling of risk is detectable for the final, +30 km/h condition, however (MD= .58, SE = .21, $p < .05$). Ratings of whether the participants would typically drive at the speed experienced, only significantly ($p < .05$) differed during the -30 km/h (MD=-.82, SE = .28) and no change speed categories (MD= .86, SE = .30), otherwise there was no significant difference ($p > .09$) in the ratings given during the no load and load conditions (MD=-.52 to .74, SE = .24 to .31).

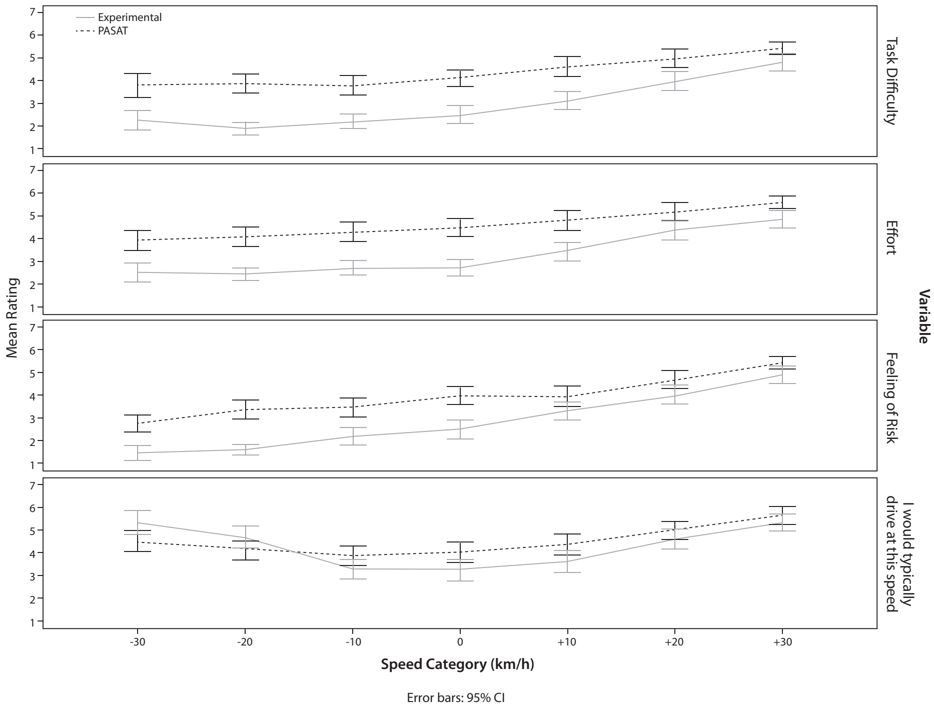

Figure 5.4. Average ratings of task difficulty, effort, feeling of risk, and I would typically drive at this speed across all speed categories (-30 to +30 km/h) for the no load and load conditions. Speed category '0' is the preferred speed.

However, the U-shape for ratings of typical driving speed appears less acute during the load condition. The trends for the load condition are generally confirmed by the results of a regression analysis as shown in Table 5.4. It can be seen that the trends are similar to those in the no load condition (see Table 5.3) but shallower.

Table 5.4. Regression analysis of the ratings of task difficulty, effort, feeling of risk, and typical driving speed for the load condition.

Speed Categories – Load								
	-30 to -10 km/h				0 to 30 km/h			
	r^2	Beta	t	p	r^2	Beta	t	p
Task Difficulty	.00	.00	-.05	.96	.11	.33	5.10	< .001
Effort	.01	.1	1.21	.23	.08	.28	4.22	< .001
Feeling of Risk	.04	.20	2.51	< .05	.15	.39	6.00	< .001
Typical Driving Speed	.03	-.16	-2.03	< .05	.14	.37	5.72	< .001

5.3.2 Correlations between task difficulty, effort and feeling of risk

Across all conditions, task difficulty and effort are highly correlated with each other ($r = .69$ to $.85$, $p < .01$). With the lowest correlations during the baseline and return to baseline periods ($r = .69$ and $r = .71$ respectively, $p < .01$), and the highest, during the no load and load conditions ($r = .85$ and $r = .83$ respectively, $p < .01$). Ratings of feeling of risk are moderately correlated with task difficulty and effort for the baseline ($r = .60$ and $r = .56$, $p < .01$) and return to baseline conditions ($r = .65$ and $r = .62$, $p < .01$). The no load condition ($r = .81$ and $r = .75$, $p < .01$) produced the highest correlations between task difficulty, effort and feeling of risk, with the load task also producing moderately high correlations ($r = .69$ and $r = .70$, $p < .01$).

5.3.3 PASAT accuracy

Accuracy at the PASAT task across all participants ranged from an average of 67.24% (SD = 18.85) for the +30 km/h condition to 71.30% (SD = 14.21) for the -10 km/h condition, resulting in an average performance across all speed categories of 69.09% (SD = 12.81). Repeated measures MANOVA analysis found no significant differences between speed conditions ($F(6) = 1.27$, $p > .27$).

5.3.4 Speed differences between the baseline and return to baseline conditions

Repeated measures MANOVA with a polynomial contrast for condition, showed a clear effect on mean speed by condition for the -30, -20, -10, +10, +20 and +30 km/h speed trials ($F(1) = 5.62$–19.72, $p < 0.05$, $\eta_p^2 = .11$ to $.30$) but no significant effect during the no speed change category ($F(1) = .61$, $p < .44$, $\eta_p^2 = .01$). This can be seen in Figure 5 where the -30, -20, -10 km/h trials resulted in significantly lower speeds during the Return to Baseline condition, and the +10, +20 and +30 km/h categories resulted in significantly higher speeds. This was confirmed through the use of a post hoc test with a Bonferroni correction, which again showed significantly different speeds ($p < .001$ to $p < .05$) for the -30, -20, -10, +10, +20 and +30 km/h conditions.

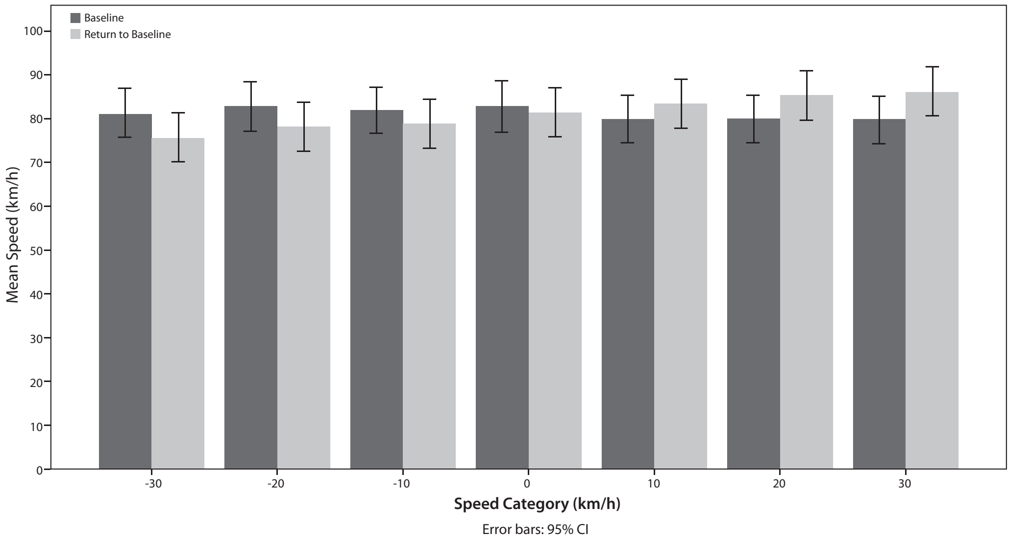

Figure 5.5. Average speed travelled (km/h) during each speed category (-30 to +30 km/h) for the baseline and return to baseline conditions. Speed category '0' is the preferred speed.

5.3.5 Speed differences between the no load and load conditions

The average speed during each speed category for the no load and load conditions are shown in Figure 5.6. While the speeds are generally similar it does appear that in the load condition participants drove faster than during the no load condition during the -30 and -20 km/h speed categories, and slower during the +30 km/h condition. The use of a repeated measures MANOVA, with a polynomial contrast for condition, confirms this with a significant main effect of speed during the -30 ($F(1) = 6.26$, $p < .05$, $\eta_p^2 = .13$), -20 km/h ($F(1) = 4.51$, $p < .05$, $\eta_p^2 = .10$) and +30 km/h ($F(1) = 4.91$, $p < .05$, $\eta_p^2 = .10$) speed categories. There was no significant difference between the average speed driven during the no load and load conditions for any of the other speed categories ($F(1) = .02$ to 2.4, $p > .13$). A post hoc test with a Bonferroni correction, confirms these findings, with a significant effect of load for the -30, -20 and +30 km/h conditions ($p < .05$) (Figure 5.6).

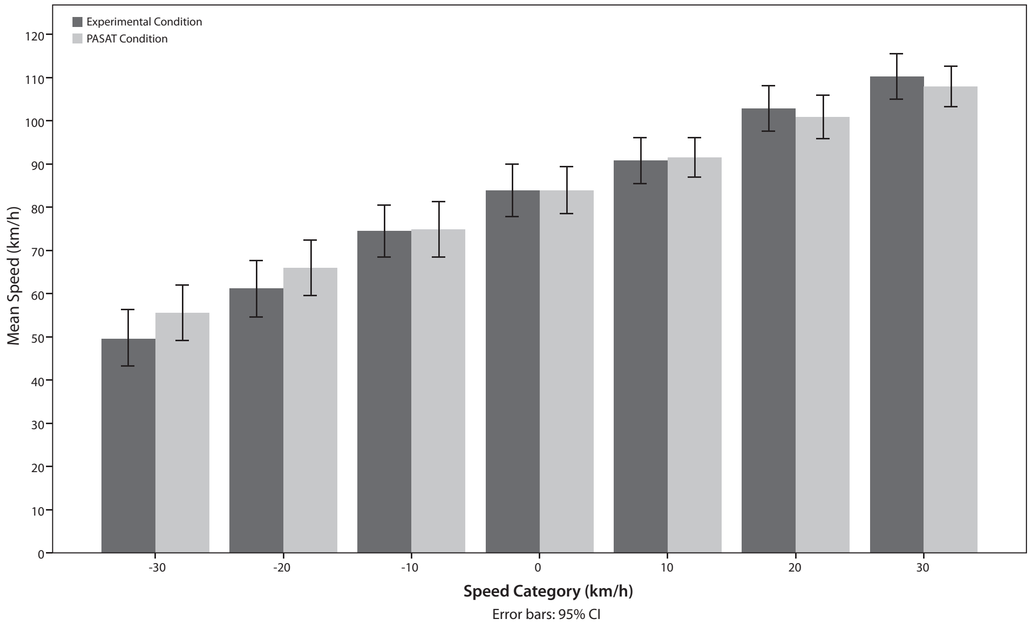

Figure 5.6. Average speed travelled (km/h) during each speed category (-30 to +30 km/h) for the no load and load conditions. Speed category '0' is the preferred speed.

5.4 Discussion

The results of this study seem to add further support to theories of driver behaviour that posit a threshold relationship between variables such as task difficulty, effort, feeling of risk, and driving behaviour. In particular, in the no load data there does appear to be a clear threshold effect, particularly for task difficulty and effort, where these variables start out rated as low and stable and then increase once a certain speed has been exceeded. For ratings of effort, this threshold point occurred when participants were first forced to go faster than they would usually freely choose. In the case of task difficulty, however, it could be said to occur slightly earlier, during the no speed change trial.

This threshold type relationship appears to be slightly different when considering ratings of risk, however. In the no load and load conditions it would seem that ratings of risk increase slightly before the no speed change category, and then increase at a much more rapid rate after this apparent threshold point has been crossed. This is still a threshold type effect but there also appears to be some constant monitoring of change in feeling of risk. However, care should be taken with this assumption. It is possible that by the nature of the experiment, where participants were initially asked to drive how they preferred, rate the risk, difficulty, and effort, and then explicitly saw an artificial increase or decrease in their speed, and were then again asked to provide ratings for that new speed, that this could have introduced bias into their answers. Explicitly seeing the speed changes may have induced more rational comparative thinking when asked for ratings of risk than is likely to exist in normal driving.

The participants' average ratings of task difficulty, effort, and feeling of risk were found to be highly correlated with each other, although the correlations did differ somewhat between the conditions. This is in line with previous research and is likely due to the naturalistic linkage between these variables during most tasks (Fuller et al., 2008; Fuller, McHugh et al., 2008; Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010).

The additional difficulty of performing the PASAT task is clearly demonstrated by the higher ratings of task difficulty, effort, and feeling of risk given by the participants during the load condition. In particular, the average ratings for task difficulty and effort during the minus 30 km/h trial are higher even than those given during the plus 10 km/h trial in the no load condition. However the threshold trend in the subjective ratings is still apparent in the load condition data, with an increasing trend in ratings of task difficulty, effort, and feeling of risk after the no speed change category has been exceeded. This highlights the importance of actual travelled speed, and particularly the usually travelled speed, rather than subjective impressions of task difficulty, effort, and feeling of risk in triggering this threshold effect.

There is one variable in the paper that could be described as constantly changing, and thus open to constant monitoring, and that is the rating of the typicality of the speed being experienced by the participants. In the no load condition data, and to a lesser extent in the load condition data, ratings of how typical the speed experienced was, trends down towards where the threshold point for the other variables occurs and then trends upward after this point has been exceeded. This indicative nature of how typical the experience is, has also been found in previous studies of both speed (Lewis-Evans & Rothengatter, 2009) and close following behaviour (Lewis-Evans et al., 2010) where again, the ratings of this variable pointed to where the threshold point for ratings of task difficulty, effort, and feeling of risk would occur. This suggests that choosing a speed of travel could be based more on past experience and driving in a habitual, automatic fashion, rather than on aiming for a particular level of a subjective variable.

Further support for a tendency to move towards a habitual speed is in the recorded speed results for the no load and load conditions. During these tasks the participants had to target and maintain a new speed initially set for them by the simulator. In most cases, they were able to do so, with or without the PASAT task. However, during the -30 and -20 speed categories in the load condition, the participants drove significantly faster than they did during the no load condition. This means that despite indicating that the task was more difficult, more effortful, and felt more risky than the in no load condition, the participants actually drove faster in this condition and therefore technically increased the objective difficulty and risk of the situation. This is in contrast to conventional thinking that when under load, action should be taken to objectively decrease load. The increase may be because the extra mental workload created by the PASAT task reduces a participant's ability to consciously control or monitor their speed, which leads to speed maintenance being handled more by lower level automated processes which work to increase the speed back towards a habitually learnt speed. However, increasing their speed does bring them back towards the speed they would choose to drive if freely able to. If this speed control is indeed somewhat habitual, and automatic, it is likely that it takes very little cognitive effort to drive at your preferred speed (Rasmussen & Jensen, 1974), therefore, it could be claimed that by driving faster the participants are in fact reducing the effort needed to perform the task. There was only one significant drop in speed during the high speed categories while under the load condition, which occurred for the +30 km/h category. This suggests that people may be better at maintaining speeds in excess of what they prefer to drive when under secondary task load than they are at maintaining speeds which are lower than they would typically drive, at least for the short periods of time examined in this experiment. The above findings are consistent with the accounts of threshold theories, as they suggest that driving, including speed choice, is often controlled by habitual, over learnt and often unconscious automated skills (Fuller, 1984; Näätänen & Summala, 1974; Summala, 2005).

A potential issue with the speed findings is that in this experiment participants did not have access to their exact speed through a speedometer. This is a threat to the ecological validity of the experiment and may mean that the results found here would not occur in real situations where drivers could check the speedometer at any time. However, Recarte and Nunes (2002) found a similar effect where their participants increased their travelling speed when given additional mental tasks, but only if the participants were driving at a slower speed than they would typically choose, otherwise no change in driving speed was found. The increase occurred irrespective of whether the participants had access to a speedometer or not. Additionally, research on driver gaze patterns has found that drivers do not spend much time looking at their instruments. For example Harbluk et al. (2007) found that their subjects only devoted around 1.5% of their time gazing at their instruments, and that this significantly reduces to around .6% of their time when placed under cognitive load. This means that at other times drivers are likely to be relying on their own perception of the speed from the environment around them, much as they had to in this experiment. The finding that drivers are worse at maintaining lower speeds when under mental load also lends support to the claim that some proportion of speeding may be carried out unintentionally (Fuller et al., 2008; Fuller, McHugh et al., 2008). It may be the case that automatic, habitual, speed preferences have build up from a history of repeated intentional speeding, or it may be that particular elements of road design suggest an inappropriate speed to drivers when they are distracted, and is acted on by automatic processes despite the presence of contrary legal speed limits, temporary or permanent. This distinction could be investigated through further study.

Finally, if ratings of all the subjective variables are compared between the after and baseline periods then there is no difference in the ratings given. However, in terms of the speed driven, the participants drove significantly slower in the return to baseline conditions when they had previously been made to drive slower than they preferred in the no load and load conditions, and drove significantly faster if they had been made to drive faster in the no load and load conditions. This finding points to a speed adaptation effect, where driving at the faster or slower speed has altered the participants' visual perception of speed (Schmidt & Tiffin, 1969). This finding does not particularly add to the discussion around the two groups of driver behaviour models, but it is surprising that the apparent speed adaptation occurred so quickly, given that participants were only driving at increased or decreased speed for a few minutes.

There are a few potential problems with this study which are worth noting. The first is the artificial nature of the speed maintenance task. Speed choice is typically seen as being freely manipulated by drivers. Forcing drivers to pay attention and maintain a speed, rather than vary it naturally, may in itself have increased the difficulty of the driving task and inflated the subsequent subjective ratings. Similarly just by making the participants aware that they had to provide ratings of task difficulty, effort, feelings of risk, and how typical the speed experienced was, may have made these variables more salient than they would usually be in day to day driving. Again, this would be expected to have perhaps inflated their ratings of the subjective variables. Conversely, it is possible that the Likert scale the participants used to provide subjective impressions of task difficulty, effort, feeling of risk, and typical driving speed, was not sensitive enough to pick up small changes in these variables and, therefore, suppressed the ratings and changed the nature of the trends shown, especially at the speeds below the participants' preferred speed. The changes in speeds used in this experiment were quite large however, and the scales used were consistent with those appearing in previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008; Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010). Perhaps future research should investigate the use of a continuous scale, although these scales do carry the possibility of over exaggeration of values by participants.

Another potential problem is that the distance covered by the individual participants was not constant across all speed categories. For example, during the minus 30 conditions, participants would have covered on average around 4.38 km across the four 1 minute periods in which data was collected. In the plus 30 condition this would have increased to an average of approximately 6.40 km travelled. This is further complicated because, as can be seen from Table 1 in Section 2, the participant's own free choice of speed during the baseline condition was used as a reference point for setting speeds for the no load and load condition in each block of trials. This means that driving speed could vary across participants, and across trials within participants. Therefore, the distance covered could also vary. All of this means the ratings given for the higher speeds are confounded by the participants also having travelled more distance and, therefore, encountered more turns and twists of the road network, and vice versa for the slower speeds. Furthermore, as shown in Table 1, participants could also take however long they wanted to notify the experimenter that they are either at a comfortable speed, in the baseline or return to baseline condition, or that they can take control of the speed back in the load and no load conditions. During this time the participants continued to drive and, therefore, progress down the road. While participants were not asked about this time and no data was recorded, it could have also impacted on their subjective ratings, likely increasing them due to the increased difficulty of the task in terms of deciding when to give control back. Given this, it is promising that we still find a threshold relationship. Also, it is hoped that the random order of speed trials helped to minimise any bias this introduced.

The finding that performance in the PASAT task was constant across all speed categories is another potential problem. It would be expected that as the difficulty of the main driving task increased then the accuracy of the secondary PASAT task should decrease with the increased external load caused by faster speeds due to there being only a limited amount of cognitive resources available at any one time (de Waard, 1996). This did not occur. One possible explanation is that the PASAT task was not difficult enough, although on average participants did only have an accuracy of around 70% which suggests it was challenging for them, although consistently so. In future studies it may, therefore, be better to use a shorter time interval between presentations of the numbers, or perhaps modify the PASAT task so that, for example, participants are required to add the number they just heard to the number they heard two presentations ago. It is also possible that PASAT is not sensitive enough to changes in cognitive load brought about by changes in speed. It should also be said that simply by including a secondary task such as the PASAT lowers the ecological validity of the experiment. The PASAT task is not a realistic task that drivers will be typically carrying out while driving. Therefore, perhaps for future studies a more naturalistic secondary task should be chosen. However the PASAT task does have the advantage of creating a high level of load and is continuous, as well as easy to administer verbally, which is why it was selected for this experiment.

Finally, the participants who took part in this experiment were all of one age group. Specifically, they were young psychology students at the University of Groningen. As such, this limits the generalisability of the findings. Future research would be aided by examining a wider age group, and also individuals of varying experience. However, previous research in this area found no differences in ratings of task difficulty and feeling of risk between learner, inexperienced and experienced drivers (Kinnear et al., 2008; Lewis-Evans et al., 2010).

5.5 Conclusion

This paper, while not conclusive, does present further evidence for a threshold relationship in the perception of task difficulty, effort, and feeling of risk. It does not fully support an idea that the perception of these variables is necessarily nil before this threshold point is crossed. But rather, that they only seem to alter in a clear and systematic fashion after a threshold point has been exceeded.

This paper also highlights the habitual control of speed with ratings of the typicality of the speed experienced being the most sensitive of all the subjective measures. Furthermore, it seems that drivers who are under cognitive load are not as good at maintaining speeds lower than they would typically drive as they are at maintaining speeds higher than normal, at least for short periods. The result of this could be that, when distracted, drivers could speed up unconsciously and break speed limits without intending to. If some significant proportion of speeding is indeed unintentional then the countermeasures aimed at preventing it will have to be different from those which could target intentional speeding. The paper also appears to show that speed adaptation can occur after only short periods of increased or decreased speed.

CHAPTER 6 **DID YOU SEE THAT?**

A version of this chapter has been previously published as Lewis-Evans, B., De Waard, D., Jolij, J. & Brookhuis, K.A. What you may not see might slow you down anyway: Masked images and driving, *PLoS One* and can be accessed online here: http://dx.plos.org/10.1371/journal.pone.0029857

Abstract

Many theories of driver behaviour suggest that unconscious or implicit emotions play a functional role in the shaping and control of behaviour. This has not been experimentally tested however. Therefore, in this study the effects of emotive masked images on driver behaviour were examined. While driving a simulator, participants were repeatedly exposed to negative or neutral emotionally laden target images that were sandwich masked by emotionally neutral images. These images were encountered across two different trials, each of which consisted of 3-4 minutes of driving on a rural road. The results indicate an effect of the negative target images primarily in reducing the extent of familiarisation occurring between the first and second experimental drives. This is evident in a reduced decrease in heart rate and a reduced increase in high band heart rate variability and actual travelling speed from the first to second drives if the negative target image was presented in the second drive. In addition to these findings there was no clear effect of the target image on subjective ratings of effort or feelings of risk. There was, however, an effect of gender, with the majority of the effects found in the study being limited to the larger female dataset. These findings suggest that unconscious or implicit emotional stimuli may well influence driver behaviour without explicit awareness.

6.1 Introduction

Many recent models that seek to explain driver behaviour have come to incorporate functional views on the role of emotions in driving. These theories include Task Difficulty Homeostasis theory (TDH) (Fuller, 2005; Fuller et al., 2008), Risk Allostasis Theory (RAT) (Fuller, 2011), the multiple comfort zone model (Summala, 2005) the Risk Monitor Model (RMM) (Vaa, 2003; Vaa, 2007; Vaa, 2011), feeling of risk homeostasis (Kinnear, 2009) and the situational control framework (Ljung Aust & Engström, 2011). The way that emotions are said to affect driving differs somewhat between the models; for example, in the multiple comfort zone model (Summala, 2005; Summala, 2007) they operate in a threshold manner with emotions being produced by breaches in safety margins. This is in contrast to the account given by RAT (Fuller, 2011) or RMM (Vaa, 2003; Vaa, 2007; Vaa, 2011) where levels of preferred emotions or feelings are set and constantly monitored. However, as mentioned above, all the models view emotions in a functional fashion, suggesting that they play an important role in biasing or influencing driver decision making, sometimes even without entering into explicit conscious awareness. So for example, uncomfortable emotions such as those related to the risk arising from a narrow road, would signal to the driver to be cautious and to reduce their speed.

RMM in particular, takes a strong functionalist stance, suggesting that risk and the detection of risk via emotions and feelings is a vital evolutionary adaptation for survival (Vaa, 2003; Vaa, 2007; Vaa, 2011).

Most of the above models approach the issue of emotion via reference to the Somatic Marker Hypothesis (Damasio, 1994; Damasio, 2003). The Somatic Marker Hypothesis states that emotions, defined as unconscious physiological states, and feelings, which represent the later conscious awareness of these emotions, have a significant impact on human decision making. In particular, unconscious emotional physiological states are presumed to arise in reaction to certain learnt or innate stimuli and 'mark' such stimuli or situations in ways that bias decision making towards or away from them. The presence of these emotional physiological states can typically be detected via psychophysiological measurements.

The main experimental evidence for the Somatic Marker Hypothesis comes from a study carried out using the Iowa Gambling Task that compared neurologically 'normal' people with patients who had impaired emotional systems due to ventromedial prefrontal damage (Bechara, Damasio, Tranel, & Damasio, 1997). The Iowa Gambling Task involved participants losing or gaining fake US currency by drawing from four decks of cards. Two of the decks had high gains but also high losses, making them poor choices in the long run, and the other two had smaller pay outs but also smaller losses, making them a better long term choice. What was found is that even before the 'normal' participants could report that they consciously knew which decks were the best they were producing detectable changes in skin conductance when choosing a card from a poor choice deck. This was taken as a sign of somatic, or body, markers being formed, which predated conscious awareness and eventually helped the participants to decide which deck was the best decision. The skin conductance response was missing in the impaired individuals and they continued to select cards from the poor decks. This particular interpretation of the Iowa Gambling task has been challenged however, with some researchers suggesting the results obtained, at least in terms of the deck choice performance, could better be explained via problems with working memory, attention, or rehearsal learning in the impaired individuals (Fellows & Farah, 2005; Manes et al., 2002).

Outside of the Somatic Marker Hypothesis, the majority of the above driver behaviour models also owe some of their structure, in terms of how they refer to emotions, to the work of Taylor (1964). Taylor claimed to show that skin conductance reacted during a drive at areas of high accident occurrence. Furthermore, Taylor claimed that over time, skin conductance levels were kept relatively stable and suggested that this meant that drivers were targeting or trying to maintain a set level of anxiety or risk while driving. This same targeting view is taken by TDH (Fuller, 2005; Fuller et al., 2008), RAT (Fuller, 2011) and RMM (Vaa, 2003;

Vaa, 2007; Vaa, 2011) who all reference Taylor's findings in terms of the consistency of skin conductance responses. This view was also influential on earlier models of driver behaviour such as Risk Homeostasis Theory (Wilde, 1976; Wilde, 1988). The idea of skin conductance response consistency is not universally accepted however. In particular, Taylor's findings have been challenged on the grounds that skin conductance is a quite reactive and relatively non-specific measure. Skin conductance responds to many other factors in addition to, or instead of, emotional changes (Fuller, 2005; Heino, 1996; McKenna, 1988; Summala, 2007). For instance, it is possible that Taylor's findings in terms of skin conductance could be explained as simply arising through the motor control of the vehicle required for driving (Summala, 2007) rather than reacting to any changes in, or reflecting the maintenance of, emotional or risky elements. The zero-risk theory of driver behaviour (Näätänen & Summala, 1974; Summala, 1997) and the later multiple comfort zone model (Summala, 2005; Summala, 2007) have also challenged the idea of maintaining and targeting a constant level of risk or anxiety. These two models, instead, argue that most of the time drivers experience, both consciously and unconsciously, no risk or anxiety when driving and that when it is experienced it acts as a warning to change behaviour, unless drivers are otherwise motivated to accept the experienced risk.

Putting aside the differences between the particular theories, there is no doubt that driver behaviour models are trending towards a functional role of emotion and feelings in the control of driving, particularly when it comes to risk judgment. This trend in traffic psychology is a reflection of a wider trend in psychology where the functional importance of emotions and feelings in decision making is being stressed (Fuller, 2007; Fuller, 2011; Keltner & Gross, 1999; Vaa, 2011). For example, in Slovic et al.'s (2004) view of risk assessment there are 'affect heuristics' which are fast and automatic emotive reactions to risky situations that can be used in guiding decision making. This affect based system is contrasted to the more traditional, analytic, and subjective utility maximization view of risk assessment, which can still operate in certain situations. However, the 'affect heuristic' is hypothesized to be commonly used in day-to-day decision making.

While the idea of implicit or unconscious emotional effects on decision making has become popular, it presents an interesting challenge to experimentally test in a complex task like driving. Exactly how can an emotion be generated in a participant without it entering into awareness and becoming a feeling? And then, how can its impact be tested without again explicitly alerting the participant?

One possible solution to this challenge is the use of masked images. This is where emotionally charged images are very briefly shown to participants with other, longer lasting images shown before and after the emotionally charged image in order to 'mask' it from the participant's conscious perception. The idea is that the image can still generate an emotive response but it does so without entering into the conscious awareness of the participant, or at least without the participant becoming explicitly aware of it. This process is also referred to as priming, in that the target images used are associated with situations that prime or trigger certain emotions, feelings, and cognitions in individuals via preconscious processing. In the case of this study, for instance, it was hoped that the negative images used would prime reactions in the physiology of participants and lead to slower speeds and faster reaction times to road safety relevant stimuli, such as a stop sign. The idea that emotionally negative images can be processed preconsciously is well in line with functional thinking in terms of emotions and feelings, in that it would be potentially evolutionary advantageous to react to threatening or emotionally negative situations as fast as possible. However, it should also be noted that whether masked images are truly unconscious, or subliminal, is a matter of great debate (Pessoa, 2005; Robinson, 1998; Siegel & Weinberger, 2009). As such, they will be referred to as simply masked, rather than subliminal, in this paper.

Using masked images has certain merits. Past studies have shown that emotionally negative masked images produce skin conductance responses (Kimura, Yoshino, Takahashi, & Nomura, 2004; Öhman & Soares, 1994; Öhman & Soares, 1998) and activate areas of the amygdala that are in accordance with fear or threat detection (Carlsson et al., 2004; Gläscher & Adolphs, 2003; Whalen et al., 1998; Öhman, 2005) without being able to be reported as perceived by participants. Further evidence for the emotional influence of unconscious images comes from research on patients with blindsight. Blindsight is a condition where, due to damage to the visual cortex, individuals are unaware of visual stimuli but still retain a limited ability to make judgements about visual aspects of the world around them (Weiskrantz, 1996). Research with blindsight patients, or with individuals in which blindsight has been induced (Jolij & Lamme, 2005), has shown that they still have some ability to detect visual emotional stimuli and that these stimuli activate relevant fear or threat detection areas of the amygdala despite not entering into explicit conscious awareness (De Gelder, Vroomen, Pourtois, & Weiskrantz, 1999; Jolij & Lamme, 2005; Pegna, Khateb, Lazeyras, & Seghier, 2004).

Masked images have also been shown to impact on attitudes and judgements about others (Krosnick, Betz, Jussim, & Lynn, 1992), as well as the level of hostile behaviour performed towards them (Bargh, Chen, & Burrows, 1996). Additionally, masked images have been found to affect risky decision-making based on masked monetary rewards in simple gambling-like experimental tasks (Pessiglione et al., 2007; Pessiglione et al., 2008). There is also some evidence that masked images can affect attention and mental workload. For example

Carlson, Fee, and Reinke (2009) found that participants would react faster on a dot-probe task when the dot occurred on the same side as a threatening masked image. In other research (Hirschberger, Ein-Dor, Caspi, Arzouan, & Zivotofsky, 2010) it has been found that presenting masked images showing death and mutilation or physical threats (such as a growling dog or striking snake) increased gaze duration towards the images that showed the physical threat, and decreased gaze duration towards the images that simply contained physical injury or death.

Ultimately the above studies suggest that masked images can have some influence on an individual's decision making or attention. However, these studies have been carried out with relatively easy tasks in relatively simple conditions and we are unaware of any research examining the influence of masked images on a complex task such as driving.

Driving is generally viewed as a self-paced task (Michon, 1985; Michon, 1989; Näätänen & Summala, 1974; Taylor, 1964), in that drivers can, to a large extent, set their own pace of movement through the road system and generally can alter and control the challenge of the driving task. This is mostly done through highly automated actions (Summala, 2007). It is, however, a task that involves many individual drivers interacting within a large and varied road system and with a wide range of regulative control. Navigating this complex system properly is important because, objectively speaking, at most times drivers and other road users are only moments away from death or serious injury; a fact that is sadly well represented in road accidents being the leading cause of death for people aged 15-29 worldwide, and the 9th leading cause of death overall across all age groups (World Health Organization, 2009). It is, therefore, important to develop a good understanding of what variables shape and affect driver behaviour.

The study described in this paper therefore sets out to experimentally test the influence of implicit or unconscious emotional signals on driver decision making, with a focus on driver speed choice. Speed is one of the most prominent road safety issues. Not only because of the influence of inappropriate speed choices on the chance of having an accident, but also because of the undeniable influence of velocity on physical trauma and property damage when an accident does occur (Fuller et al., 2008; Patterson, Frith, & Small, 2000). Speed is also one of the main ways in which drivers can regulate the task demands of driving and therefore can 'self-pace' the driving task (Michon, 1985; Michon, 1989; Näätänen & Summala, 1974; Taylor, 1964).

Participants in the present study were asked to drive a simple rural road in a driving simulator while paying attention to a series of images presented just below the rear view mirror. The images were presented under the pretence of carrying out a memory task. Each participant drove the road twice, with one drive involving the presentation of emotionally negative target images and the other of emotionally neutral target images. These images were in both cases backwards and forwards masked by different emotionally neutral masking images. At some point these masking images would change to include a stop sign. When this occurred participants had to stop the car as quickly as possible. Information on speed and stopping time along with subjective impressions of effort and feeling of risk were collected alongside physiological measures of skin conductance, heart rate, and respiration.

In line with the functional account of emotion provided by the various models of driver behaviour discussed above (Fuller, 2007; Fuller et al., 2008; Fuller, 2011; Kinnear, 2009; Ljung Aust & Engström, 2011; Summala, 2005; Summala, 2007; Vaa, 2003; Vaa, 2007; Vaa, 2011) it was predicted that when participants were exposed to the negative target images they would drive at a slower speed than when exposed to the neutral target images. This was predicted to occur due to the production of uncomfortable emotions associated with the images, which signal to the drivers that something is amiss with their behaviour or the road environment and therefore leads them to take action to remove or reduce this emotion. Due to the use of masking, these emotions should occur unconsciously or at least without explicit awareness, and therefore it is also hypothesised that any behaviour changes will occur without any meaningful change in risk or effort ratings between the two different target image conditions. In addition, in line with a physiological and functional account of emotion, it was also predicted that the psychophysiological measures taken would show a significant response in line with a negative emotional reaction arising from the emotionally negative images. Finally, it was predicted that when participants were exposed to the negative target images that they would become more alert to potential road safety related stimuli and therefore respond faster to the stop sign image in bringing their vehicle to a stop.

6.2 Method

6.2.1 Participants and Ethics Statement

Ethics approval, including permission to deceive the participants, was gained from the University of Groningen Psychology Ethics Committee. Participants were informed that their information would be treated anonymously and that they could withdraw from the experiment at any time with no penalty. Participants were also debriefed at the end of the study and the masking procedure was fully explained.

Participants were recruited through the English speaking University of Groningen participant pool and given course credit for participation. Participants were required to have held a valid car drivers' licence for at least one year. This resulted in 74 females and 39 males being recruited for the study. However, one female reported feeling uncomfortable with the simulator during the practice drive and therefore did not progress in the study. In addition, two female, and six male participants reported being explicitly aware of the target images and were also removed from the sample. Furthermore, seven males and 12 females mentioned that they thought that perhaps there was an image being shown that they could not see even though they could not report what it was. In order to present results that are as conservative as possible in terms of the awareness of the target images, these participants have also been excluded.

This results in a final sample size of 85 participants. The remaining 59 females were 21.09 years old on average (SD 2.07) and had held their licence for an average of 3.19 years (SD 1.97). The remaining 26 males were 21.62 years old on average (SD 1.83) and had held their licence for an average of 3.44 years (SD 1.41).

6.2.2 Materials

6.2.2.1 Driving Simulator

The University of Groningen driving simulator was used in this study. It is a fixed base simulator running on STSoftware software©. The simulator consists of three high definition plasma screens, all set to a refresh rate of 60 Hz. The graphics engine of the simulator software itself runs at 60 frames per second, which was confirmed via the FRAPS© software package. In total the simulator provided participants with a 210-degree view of the road environment.

The road environment resembled a simple rural road with a consistent gentle s-curve in order to create some steering demand during the task. During all drives, speed information was concealed through the use of a cardboard cut-out. This was to force participants to rely on their own perception of speed rather than the speed provided by the speedometer. The simulated car was set to operate in automatic gear mode in order to minimise any movement related artefacts in the collection of the psychophysiological data.

6.2.2.2 Images

The images used during the task were taken from the International Affective Picture Set (IAPS) (Lang, Bradley, & Cuthbert, 1999). The following images where used as negative target, neutral target, and masking images:

- Negative target images: IAPS numbers 3000, 3010, 3015, 3053, 3060, 3064, 3068, 3069, 3080, 3102, 3110, 3120, 3150, 3400, 9410, 9433, 9901, 9910, 9911, 9920
- Neutral target images: IAPS numbers 5130, 6150, 7000, 7009, 7010, 7020, 7030, 7037, 7040, 7050, 7060, 7080, 7090, 7190, 7217, 7234, 7235, 7500, 7700, 7705
- Masking images: IAPS numbers 7002, 7004, 7006, 7031, 7035, 7036, 7038, 7042, 7052, 7055, 7056, 7057, 7059, 7100, 7150, 7175, 7224, 7233, 7491, 7950

The negative target images mostly consisted of mutilated and deceased humans along with some images of car accidents. According to the IAPS standardised scores, the negative images had valence ratings between 1.31 and 2.5 (mean 1.80), and arousal ratings between 5.70 and 7.26 (mean 6.59). The neutral target images and masking images consisted mostly of household items such as mugs, bowls, and forks, along with some pictures of buildings. The neutral target images had valence ratings between 4.23 and 5.55 (mean 4.86), and arousal ratings between 2.17 and 3.84 (mean 2.78).

The images used for masking (the masking images) had valance ratings between 4.45 and 5.55 (mean 4.97), and arousal ratings between 1.72 and 4.02 (mean 2.76). It was these masking images that were used to forward and backwards mask the above neutral and negative target images during the trials. Variations of the masking images were also created for the reaction time task that had standard stop street signs placed in the centre of the images (see Figure 6.1). All of the images were stored in JPG format, with a resolution of 256 x 192 pixels.

Figure 6.1. An example of a masking image with the stop sign added.

6.2.2.3 Psychophysiological Measures

Participants were asked to wash and dry their hands and Tin (Sn) electrodes with some saline paste where taped to the distal phalanxes of the index and third finger of their left hand to measure skin conductance. This method of attachment is somewhat unusual but has been used successfully in the past and allows for good control of steering without creating interference in the skin conductance measures (Petit, Clarion, Ramon, & Collet, 2009). Participants were also fitted with Polar© and Respitrace© belts in order to collect cardiovascular and respiration data. Profiles of skin conductance and respiration information were created using the Brain Vision Analyzer© software package and mean skin conductance and respiration levels were calculated. Heart rate was processed via the CARSPAN software package, with each file also being visually inspected for artefacts and manually corrected if necessary (Mulder, de Waard, & Brookhuis, 2005). Along with the collection of heart rate, spectral analysis was also run in CARSPAN to calculate heart rate variability in the high (0.15-0.40 Hz) and mid (0.07-0.14 Hz) frequency bands (Mulder, 1992). Finally Brain Vision Analyzer© was also used to calculate mean heart rate, and mean heart rate variability.

Due to the variation in the moment the stop sign was shown, the psychophysiological data was shortened to only account for the first 180 seconds of driving. Furthermore, there is an immediate effect of beginning to drive on all the physiological measures, so the first 30 seconds of data was also removed to eliminate any biasing effect that this may have caused. This left 150 seconds of data for use in later analysis. In addition, four males and 16 females had distorted or missing psychophysiological data and had to be excluded from analyses, resulting in a sample size of 65 participants for the analysis of the psychophysiological data. The participants in this smaller sample did not significantly differ ($p > 0.05$) in gender, age, licence status, speed of driving or any of the subjective measures from the larger 85 person sample and, therefore, are assumed to have come from the same underlying population.

6.2.3 Procedure

Participants first filled out a demographic questionnaire to gather data on their age, gender, and driving experience. The experimental procedure was then described to them under the pretence of being a study about the effect of memory tasks on driving. Participants were told that they were to drive at whatever speed they found comfortable but that while doing so they were to carry out a memory task. This memory task involved paying attention to constantly changing images that were presented in the upper centre of the screen (just under the rear view mirror as shown in Figure 6.2.)

The participants were told that they had to count the total number of times that the currently presented image was the same image that they had seen presented directly before. Participants were able to do this, as there was a noticeable flash when each image was presented which signalled that a new image had appeared. So, if the participants saw a shoe, and then a shoe again, they would have to add one to the count of image couples that they had observed. However, if they saw a cup, then a chair, and then a cup they were to ignore that as none of the images were repeated directly after each other. They were told that they did not have to remember what the images were, only the total number of direct image repeats that they had seen during the drive, and that they would have to write this down at the end of the trial. Participants were also told that at some point during the drive a stop sign would appear over top of the normal (masking) images and that when they saw this sign they were to stop counting repeats and bring the car to a full stop as quickly as possible.

The images that the participants were instructed to pay attention to were the masking images mentioned above, which were presented on the screen for 50 frames (800 ms). Unbeknownst to the participants, in between each masking image a target image was

Figure 6.2. Screenshot of the simulator's centre screen showing the road environment and an example masking image in the position in which the images were presented during the trials.

presented for 2 frames (32 ms). With the timing of the image presentation confirmed through the use of a high speed digital camera over three, four-minute periods during the initial setup of the experiment. The target images shown were either negative or neutral in emotive content depending on the trial. The presentation of the images began once the participants had driven 100 metres, and continued until the participants brought the vehicle to a complete stop. After three minutes a random timer was started that triggered the presentation of the stop sign variant images to replace the masking images within 1–60 seconds.

The masking and target emotive images were selected randomly every time they were presented and programmed to usually avoid directly repeating themselves so that the same image would not often be shown twice in a row. However, this was allowed to randomly occur on occasion, creating the supposed 'memory task' for the participants when the masking images would repeat two times in a row.

Participants were asked to sit in the driving simulator and adjust the seat so that it was comfortable. They were then given a practice drive to get familiarised with the simulator and the memory task. During this practice task no data was recorded. The practice drive lasted 3–4 minutes, depending on the timing of the stop sign and was identical to a neutral image experimental trial. Also, at the start of the practice drive the experimenter verbally pointed out the first directly repeating image to the participant. This was done to make sure that the exact nature of the memory task was understood.

After the practice drive participants were asked if they felt comfortable with the simulator and the memory task. At this point all participants stated that they were comfortable and wished to continue. Then the participants were asked to hold the steering wheel, but to otherwise sit still and quietly while baseline physiological measures were taken. These baseline measures were then collected for 3 minutes.

After the baseline data collection period participants were asked to drive the road again twice, while carrying out the memory task. During these two drives data on travelling speed was collected at a rate of 10 Hz. Also the braking reaction time to the stop sign image was calculated as the time from when the first stop sign appeared until the participant had depressed the brake pedal by more than 5 percent. One trial for each participant involved the neutral target images and the other the negative target images. The order was counterbalanced across participants, however, due to scheduling issues and loss of participants due to the earlier mentioned incomplete data sets, the end result was that 43 participants (32 female, 11 male) drove with the negative target image trial first and then the neutral, and 42 (27 female, 15 male) with the neutral target image trial first and then the negative.

After each trial participants were asked to fill in a questionnaire containing the following open ended questions:

1. How many times during the drive did you see paired presentations of images?
2. On average, what speed (in km/h) do you think you drove at during the last trial?
3. On average, what speed (in km/h) would you typically drive while following the route you just saw?

Then participants were also asked to provide a driving effort rating for the trial they had just completed on the rating scale for mental effort (RSME). The RSME is a unidimensional scale ranging from 0 to 150, with several unevenly placed anchor points along it going from ‘absolutely no effort’ at the bottom (a RSME score of 2) to ‘extreme effort’ near the top (a RSME score of 112). A modified version of the RSME was also used to assess feeling of risk, with the effort related anchors being replaced with the following risk related anchors; absolutely no risk, almost no risk, a little risk, some risk, rather much risk, considerable risk, great risk, very great risk, and extreme risk. After the second trial the participants were additionally asked the following two open ended questions which served as manipulation checks to make sure that the negative or neutral images had not been detected:

4. What was/were the difference(s), if any, that you noticed between the first and second roads you drove?
5. Did you notice any images during either drive that seemed out of place, unusual or particularly disturbing? If so, what were they?

Once participants had completed the practice drive and both experimental trials, the psychophysiological recording equipment was removed and they were fully debriefed about the use of the hidden, neutral and negative images in the experiment. This included an additional verbal check to see if they had detected the negative or neutral images, and an opportunity for participants to ask any questions that they may have had.

6.2.4 Analysis

Due to the variable nature of when the stop sign was displayed (1–60 seconds after the first 3 minutes of driving) only the first 3 minutes (180 seconds) of driving were used for analysis of the effects of the images on speed of travel. This is in contrast to the 150 seconds of data used in the analysis of the psychophysiological measures mentioned in section 6.2.2.3 above.

The dependent measures analysed in this experiment were actual speed driven, stopping reaction time, the subjective ratings of speed, effort and risk, performance on the memory task, and the psychophysiological measures of heart rate, heart rate variability, skin conductance and respiration. In addition, qualitative data on differences between the roads and on whether the participants noted anything unusual were also examined.

Using PASW SPSS 18.0.3 for Windows, individual full factorial repeated measures analyses were carried out to examine the effect of the independent variable of the target image type within the subjects (2 levels, emotionally negative or neutral target image). In addition, the between subjects factors of condition order (2 levels, neutral image presented first or negative image presented first) and gender were also examined. Possible interactions effects were examined and post-hoc tests with a Bonferroni correction were used where appropriate. The above analyses were run for both the total dataset and separately for the males and females.

6.3 Results

6.3.1 Subjective ratings of speed, effort and feeling of risk

In general the participants gave higher ratings for effort than for feeling of risk, with average scores between 53.77 and 59.12, corresponding approximately with a level of 'Rather much effort'' on the RSME. Whereas feeling of risk scores averaged between 30.50 and 34.93, placing them somewhere between 'A little risk' and 'Some risk' on the modified version of the scale. As shown on table 6.1 there was no significant main effect of the target image type (negative or neutral) on subjective ratings of speed, typical travel speed, effort, or feeling of risk.

Table 6.1. Subjective ratings of speed, effort, and feeling of risk by target image type, gender, and condition order for the combined dataset (N=85)

	Negative then Neutral order				Neutral then Negative order			
	Negative		Neutral		Neutral		Negative	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Subjective Speed (km/h)	60.41	20.53	69.88	20.66	60.69	18.21	72.50	21.02
Typical Speed (km/h)	92.33	15.97	94.07	15.78	88.81	18.04	90.36	15.94
Effort	59.12	24.10	55.62	25.38	57.52	24.83	53.77	26.20
Feeling of risk	31.73	25.92	34.93	26.46	30.50	25.09	34.36	24.71

Statistical tests																		
	Main effects									Interaction effects								
	Image			Gender			Order			Image * Order			Image * Gender			Image *Order*Gender		
	F	p	η^2	F	p	η^2	F	p	η^2	F	p	η^2	F	p	η^2	F	p	η^2
Subjective Speed (km/h)	1.94	.17	.02	1.45	.23	.02	.18	.68	.00	42.87	<.001	.35	1.3	.26	.02	2.36	.13	.03
Typical Speed (km/h)	.17	.68	.00	3.89	.052	.05	1.06	.31	.01	3.05	.09	.04	.70	.41	.01	.02	.88	.00
Effort	.39	.54	.01	.38	.54	.01	.50	.48	.01	8.54	< .01	.10	2.26	.14	.03	1.4	.24	.02
Feeling of risk	1.43	.24	.02	2.05	.16	.03	.04	.84	.00	1.40	.24	.02	4.15	<.05	.05	4.16	< .05	.05

There was however a significant interaction of target image type and condition order for the subjective ratings of travelling speed ($F(1, 81) = 8.21$, $p < .001$, $\eta^2 = .35$) with the second trial generally resulting in higher average perceived speeds. In combination with this, trials where the negative target image condition was second resulted in larger increases in ratings of subjective travelling speed between the two drives. This indicates that the participants perceived a speed increase between the first and second drive, but perceived it as being a greater increase if they had been exposed to the negative image in the second, rather than first, trial.

A significant ($F(1, 81) = 4.16$, $p < .05$, $\eta^2 = .05$) interaction of target image type, gender and order was also found for ratings of feeling of risk. This appears to have resulted from the males tending to give higher average ratings of feeling of risk for the negative target image than the females (40.72 or 41.70 on average for the males compared with 28.30 or 30.82 for the females). This also points to a different effect in terms of the order of image presentation, in that the males appear to decrease ratings of risk from the first to the second trial by 6.64 points if the negative target images were presented first, and increase ratings of risk by 3.86 if the negative target images were presented second. Conversely the females always increased their ratings of feeling of risk from the first to the second drive, and did so more if the neutral target images were presented second (an increase of 6.59 versus an increase of 3.86 if the negative target images were second).

There was also a significant ($F(1,81) = 8.54$, $p < .01$, $\eta^2 = .10$) order and target image type interaction on ratings of effort, with ratings of effort generally decreasing in the second trial, but doing so more if the negative target images were second (a decrease of 3.75 compared with a decrease of 3.50 if the neutral target images were second). However if the male and female datasets are examined separately then this significant order and target image type interaction is only apparent in the male data ($F(1, 24) = 6.19$, $p < .05$, $\eta^2 = .21$) and is different from the combined dataset. This is evident by the decreases in effort ratings from the first to second drive which are still apparent in the male data set but are greater when the neutral target images were second (a decrease of 9.76 compared with a decrease of 3.10 when the negative target images were second). No significant main ($F(1, 57) = .64$, $p = .43$, $\eta^2 = .01$) effects of the images or interaction effects ($F(1, 57) = 2.48$, $p = .12$, $\eta^2 = .04$) with order on ratings of effort were found for the female participants However, the females did tend to also decrease effort ratings from the first to the second trial, and did so somewhat less if the neutral images were second (a decrease of 1.35 compared with a decrease of 4.11 if the negative images were second), although again this effect was not significant.

When data from the males and females was examined separately then a main effect of target image type ($F(1, 24) = 4.56$, $p < .05$, $\eta^2 = .0.16$) was found on ratings of typical speed for the males ($N = 26$), which is not in the combined dataset. In addition, in the male dataset significant target image type and order interactions were found on typical speed ($F(1, 24) = 7.45$, $p < .05$, $\eta^2 = .24$), subjective travelling speed ($F(1,24) = 8.87$, $p < .01$, $\eta^2 = .27$), and effort ($F(1,24) = 6.19$, $p < .05$, $\eta^2 = .21$). Finally, in the male data there was no significant main effect ($F(1, 24) = 2.81$, $p = .81$, $\eta^2 = .11$) nor any interaction effects with order ($F(1,24) = .20$, $p = .66$, $\eta^2 = .01$) of target image type on feelings of risk. In the case of the above effects it seems that the males tended to report higher subjective travelling speeds in the second trial, although more so when the negative target images were second; with an increase of 11.07 km/h on average compared with an increase of 3.64 km/h if the neutral target images were second. The impacts in terms of effort are discussed above, with lower effort being generally reported in the second trial, but more so if the neutral target image trial was second. The effects seen for typical speed seems to have arisen because the male participants who received the neutral and then negative target image trial order, on average only increased their ratings of typical speed by 0.33 km/h between trials. Whereas those who experienced the neutral and then negative target image trial order increased their ratings by 2.73 km/h between the first and second trial. This result is unlikely to be meaningful.

In terms of the results for the females ($N = 59$), they were similar to those of the total sample, with significant target image and order interactions for subjective travelling speed ($F(1, 57) = 54.37$, $p <.001$, $\eta^2 = .49$) and feeling of risk ($F(1,57) = 9.98$, $p < .01$, $\eta^2 = .15$). Again, it seems that for the females their perceptions of the subjective travelling speed increased from the first to the second drive with larger increases when the negative target images were presented second (12.22 km/h versus 11.48 km/h when the negative images were first). As described above, the effect on feeling of risk for the females was an increase between the first and second drive, with a larger increase if the neutral target image was second (6.59 versus 3.86 if the neutral target image was first). As mentioned above, no significant main or interaction effects of the target image type or order were found for ratings of effort in the female dataset. As with the combined dataset, there were also no significant main ($F(1, 57) = .11$, $p = 0.74$, $\eta^2 = .74$) or interaction ($F(1, 57) = 2.16$, $p = .15$, $\eta^2 = .04$) effects of the target images on ratings of typical speed either.

6.3.2 Stopping reaction time

There was no significant ($F(1,81) = 2.98$, $p = .09$, $\eta^2 = .04$) main effect of target image type on stopping reaction time in reaction to the stop sign, with an average reaction time of 2.04 (SD = 1.03) seconds for the negative target image trial and 1.87 (SD = .61) seconds for the neutral target image trial. There were also no significant interactions or main effect of order or gender ($F(1,81) = .12$ to 2.59, $p > .11$, $\eta^2 = .00$ to .03).

6.3.3 Driving Speed

As shown in table 6.2 there was no main effect of target image type ($F(1, 81) = 1.69$, $p = .20$, $\eta^2 = .02$) on average speed driven during the first 3 minutes of the experimental trials. There was, however, a significant main effect of gender ($F(1, 81) = 8.21$, $p < .01$, $\eta^2 = .09$), with males tending to drive faster on average (114.61 km/h) than the females (96.47 km/h) across all trials.

Table 6.2. Average speed by target image type, gender and condition order for the combined dataset (N= 85)

	Negative then Neutral order				Neutral then Negative order			
	Negative		Neutral		Neutral		Negative	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Speed (km/h)	98.65	31.16	105.72	29.68	99.10	24.34	102.53	27.39

	Statistical tests																	
	Main effects									Interaction effects								
	Image			Gender			Order			Image * Order			Image * Gender			Image *Order*Gender		
	F	p	η²	F	p	η²	F	p	η²	F	p	η²	F	p	η²	F	p	η²
Speed (km/h)	1.69	.20	.02	8.21	<.01	.09	1.31	.25	.02	20.25	<.001	.20	.65	.42	.01	.48	.49	.01

There was also a significant interaction effect of target image type and condition order ($F(1, 81) = 20.25$, $p < .001$, $\eta^2 = .20$). This means that speed during the second trial tended to be higher than during the first, but also that this effect did not appear to be as pronounced when the negative target images were presented to participants second. Specifically, when the negative target images were second there was an increase of only 3.43 km/h on average from the first to second trial compared with a 7.08 km/h increase in speed when the neutral target images were second.

As shown in Figure 6.3, when the speed data for the males and females was examined separately there were quite different outcomes. In the case of the males ($N = 26$) it appears that there was no significant difference (F (1, 24) = .06, $p = .81$, $\eta^2 = .00$) in the speed they drove when exposed to either the negative (113.29 km/h on average) or neutral target images (113.19 km/h on average). Neither was there a significant interaction of target image type and order (F (1, 24) = 3.62, $p = .07$, $\eta^2 =.13$) for the males. Conversely, if only the females ($N = 59$) were examined, then a significant main effect of target image type was found (F (1, 57) = 4.51, $p < .05$, $\eta^2 = .07$) along with a significant interaction of target image type and order (F (1, 57) = 27.33, $p < .001$, $\eta^2 = .32$). Therefore, in the case of the females, it seems that on average, the trials with the negative images resulted in lower driving speed (94.96 km/h on average) than trials with the neutral images (97.72 km/h on average). Furthermore, as with the total sample, it appears that females tended to increase their speed from the first to second drive, but did so to a lesser extent if the negative target image trial was experienced second. In the females, this resulted in an increase of 7.91 km/h when the neutral target images were second, compared with an increase of 3.34 km/h when the negative images were second. As shown in Figure 6.3, the speed difference between the negative and neutral target image conditions in the females began to become apparent after less than 10 seconds of driving, and is pretty much established by 20–30 seconds into the drive and then remains relatively constant. When looking at Figure 6.3, this same initial speed pattern does seem to appear for the males, but quickly disappears, with some later average speeds for the negative target image trial exceeding those of the neutral target image trials. This is not statistically significant however.

6.3.4 Heart rate, heart rate variability, respiration and skin conductance response

All recorded psychophysiological measures were compared between the two target image trials, but also to the baseline measurement as a third variable. Furthermore, as with the above analyses, condition order and gender were included as between subject factors. It should be noted that, as explained in section 2.2.3, the analysis of the psychophysiological data was carried out on only 150 seconds of data and with a smaller sample size of 65 participants.

Significant (F (2, 60) = 19.16 to 50.02, $p < .001$, $\eta^2 = .39$ to .63) main effects were found on average heart rate, as well as mid and high band heart rate variability. However post hoc tests with a Bonferroni correction revealed this was only due to significant differences between the baseline measurement and the measurements collected during the target image trials ($p < .001$). This means that no significant differences in these measurements between the target image trials was found ($p = 1.00$).

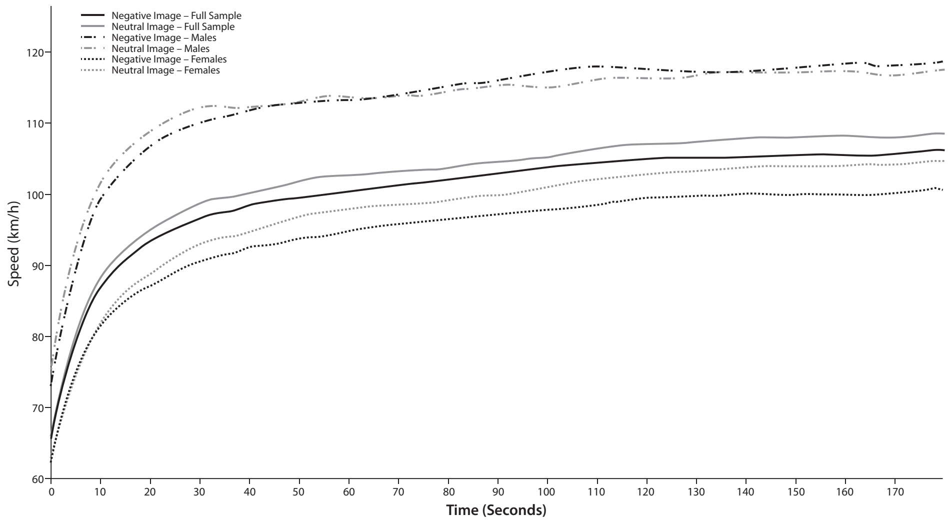

Figure 6.3. Average speed across the first 3 minutes of driving for the negative and neutral target image trials for the whole sample (N = 85), as well as for the males (N = 26) and females (N = 59) separately.

There was also a significant ($F(2, 60) = 5.85$, $p < .01$, $\eta^2 = .09$) main effect of gender on mid band heart rate variability, with males having a higher variability than females on average. However, there were no interactions of the target image type with gender ($F(2, 60) = .07$, $p = .92$, $\eta^2 = .00$) or condition order ($F(2, 60) = .35$, $p = .71$, $\eta^2 = .01$) for mid band heart rate variability.

A significant ($F(2, 60) = 5.12$, $p < .01$, $\eta^2 = .15$) main effect of target image type on skin conductance was found with the experimental trials seeming to produce a higher average skin conductance response than the baseline. However, subsequent post hoc tests with a Bonferroni correction only found a significant difference between the baseline measurement and the negative target image trial ($p < .05$) but no significant difference between the baseline measurements and the neutral target image trial ($p = .07$) nor between the target image trials themselves ($p = 1.00$). No significant effects for any of the variables or conditions were found for the respiration measurements.

There were also significant interaction effects between image type and condition order for average heart rate ($F(2, 60) = 42.14$, $p < .001$, $\eta^2 = .58$) and high band heart rate variability ($F(2, 60) = 5.02$, $p < .01$, $\eta^2 = .14$). The average heart rate decreased and the average high band heart rate variability tended to increase in the second trial. As can be seen in table 6.3, the average decrease in heart rate was smaller between the first and second trials when the negative target image trial was second (a decrease of 6.39 beats per minute versus 6.82 when the neutral target image trial was second), and the average increase in high band heart rate variability was higher in these conditions (an increase of 0.34 versus 0.31 when the neutral target image trial was second).

Table 6.3. Average heart rate, heart rate variability, skin conductance response and respiration amplitude by target image type, gender and condition order for the combined dataset (N = 65)

	Negative then Neutral order						Neutral then Negative order					
	Baseline		Negative		Neutral		Baseline		Neutral		Negative	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
HR (bpm)	79.92	11.39	90.05	11.15	83.22	10.35	79.38	12.80	89.27	11.43	82.89	12.05
Mid HRV (mi²)	6.94	.87	6.22	.89	6.27	1.20	7.48	1.18	6.51	1.00	6.60	1.05
High HRV (mi²)	7.32	.92	6.36	.80	6.66	.90	7.78	1.24	6.64	1.00	6.98	1.11
SCR (Ω)	.16	.29	.23	.28	.16	.35	.07	.08	.23	.32	.19	.18
Respiration amplitude	1.04	.70	.72	.52	.75	.62	1.89	4.81	1.03	1.39	.87	1.45

Statistical tests																		
	Main effects									Interaction effects								
	Image			Gender			Order			Image * Order			Image * Gender			Image *Order*Gender		
	F	p	η²	F	p	η²	F	p	η²	F	p	η²	F	p	η²	F	p	η²
HR (bpm)	44.19	< .001	.60	.06	.82	.00	.06	.81	.00	42.14	< .001	.58	.05	.95	.00	.16	.86	.01
Mid HRV (mi²)	19.16	< .001	.39	5.85	< .01	.09	3.64	.06	.06	.35	.71	.01	.07	.92	.00	.39	.70	.01
High HRV (mi²)	50.02	< .001	.63	1.13	.29	.02	1.63	.21	.03	5.02	< .01	.14	.26	.78	.01	.03	.97	.00
SCR (Ω)	5.12	< .01	.15	.57	.45	.01	.01	.92	.00	2.43	.10	.08	.70	.50	.02	1.64	.20	.05
Respiration amplitude	1.49	.23	.05	0.86	.36	.01	.96	.33	.02	.34	.72	.01	.05	.95	.00	.42	.66	.01

When the male (N = 22) and female (N = 43) participants were examined separately then similar results to those mentioned above were found, with two exceptions. The first was a significant ($p < .05$) difference for the males between their average baseline respiration measure and the average respiration measure during the negative target image trial. There was, however, no significant difference in respiration for the males between the baseline measures and the measures during the neutral target image trial ($p = .20$), nor any significant difference between the average respiration in the neutral and negative image trials ($p = .69$). The second difference is that for the females there was no main effect of condition (baseline, negative, or neutral target image) on skin conductance response at all ($F(2, 40) = 2.47$, $p = .10$, $\eta^2 = .11$).

6.3.5 Memory task accuracy

While the memory task was simply an excuse to have images presented on the screen, it is worth noting that there was no significant effect of the type of target image (negative or neutral) on the number of pairs reported. Rather the participants performed this task well in both conditions with an average reported number of image pairs of 11.67 (SD = 3.15) during the negative target image trials and 11.49 (SD = 3.81) during the neutral target image trials. The actual number of image pairs was 12.06 (SD = 2.84) and 11.33 (SD = 2.79) for the negative and neutral target image trials respectively. This indicates that the 'memory task' was equally demanding during both conditions, and that the participants were paying attention to the images. If the male and female participants are examined separately then their performance on this task and the average number of images presented to them is similar to the combined dataset.

6.3.6 Reported differences between the roads

At the end of the experiment participants were asked 'What was/were the difference(s), if any, that you noticed between the first and second roads you drove?' This question, along with a question about the images, was primarily to check if the participants had seen any of the target images (as the road did not differ between the two drives). However, only 43.53% (11 male, 26 female) of the participants correctly reported that there was no difference between the roads. A further 38.82% (9 male, 24 female) reported that something about the construction of the road had differed. Out of these people, 19 (7 male, 12 female) stated that either the road in the negative image trial was more curvy (12; 4 male, 8 female) or that the road in the neutral image trial was less curvy (6; 3 male, 3 female) or, in the case of one female, that the roadside trees were further away during the neutral trial. Conversely, 14 participants (2 males, 12 females) said that either the road in the neutral image trial was more curvy (9; 1 male, 9 females) or had more hills (1 female), or that the road in the negative image trial was less curvy (4; 1 male, 3 females). In nearly all of the cases (18; 5 male, 13 female), if a road was labelled as more curvy it was the road that was driven second. Therefore, it is likely that this impression of more or sharper curves was created by the fact that participants tended to drive faster during the second drive. In answer to this question, a further 9 (3 male, 6 female) participants commented that they had detected more image pairs during the 'memory task', or that the images were placed in a different position on the second drive (1 female). Of the remaining 4 participants, 2 did not answer this question and the other 2 just mentioned being more used to the road on the second drive.

6.4 Discussion

According to many models of driver behaviour (Fuller, 2007; Fuller et al., 2008; Fuller, 2011; Kinnear, 2009; Ljung Aust & Engström, 2011; Summala, 2005; Summala, 2007; Vaa, 2003; Vaa, 2007; Vaa, 2011) our feelings and emotions play important functional roles in guiding driver behaviour. What is more, it is claimed that this can occur even when emotions aren't necessarily felt or explicitly considered as part of the decision making process. The present study set out to investigate the impact of these implicit or unconscious emotions on driving behaviour. As such, masked images were used in an attempt to provoke an emotional response in drivers in a simulator under the guise of performing a memory task.

The primary behavioural variable examined was driving speed and if the total dataset of males and females is examined then there was no significant main effect of the target image type on driven speed. However, there was a significant interaction effect of type of target image, negative or neutral, and the order in which the images were presented to the participants. This showed that there was a general tendency for participants to drive faster on the second trial, most likely due to familiarity and learning effects. However, this general effect also interacted with the type of target image being used, with the increase in speed being smaller if the second trial contained the negative target images (an increase of 3.43 km/h on average) than if the neutral target images were presented second (an increase of 7.08 km/h). This suggests that the negative target image could have had a suppressing effect on speed in terms of reducing the normal increase associated with familiarity or learning effects.

Gender also played a role in this effect. When the male and female datasets were examined independently then was no effect, interaction or otherwise, of the target images on the males' speeds. However, for the females there was the above interaction effect mentioned for the combined dataset, and also a further significant main effect of image type on driving speed. This resulted in significantly lower average speed overall, for the female drivers, during the negative target image trials (94.96 km/h) than during the neutral target image trials (97.72 km/h). This gender difference is apparent in the statistics and also easy to see from the graph of speed over time shown in Figure 6.3 and suggests that most, if not all, of the effects seen in terms of actual driven speed in the larger combined dataset are due to the reactions of female participants.

The difference between the male and female participants could be explained in several ways. Firstly, it is possible that the negative target images were more emotionally impactful for the female participants than the males. Certainly, there is a difference in both valence and arousal ratings by gender for many images in IAPS (Lang et al., 1999), and specifically, if the negative target images used in this experiment are examined, then the female IAPS ratings are lower in valence (1.52 on average) and higher in arousal (6.98 on average) than the average provided by the male IAPS ratings (2.16 valance, 6.15 arousal on average). An increased reactivity to negative emotional images in females is also supported by studies reporting greater neurological (Lithari et al., 2010; Williams & Gordon, 2007) and autonomic reactions (Bradley, Codispoti, Sabatinelli, & Lang, 2001; Chentsova-Dutton & Tsai, 2007) to explicitly presented negatively emotional images in females. This is especially so if the negative images contained humans (Proverbio, Zani, & Adorni, 2008) as many of the images used in the current experiment did. It is entirely possible, therefore, that the increased emotional reaction to consciously or explicitly processed stimuli in females may also hold for stimuli that have been implicitly or preconsciously processed. If this is so further studies should use different image sets depending on the gender of the participant.

Another possible explanation for the gender difference is that, given the effect sizes observed, that there may not have been enough males to detect any consistent effect of the images on behaviour. This study did set out to recruit a large number of both male and female participants to take part, however, we did not succeed in the case of the male subjects.

Interestingly, at least in the case of the females, the effect of the negative target image on driving speed seems to be mainly on the initial setting of the speed, which is then generally maintained throughout the drive (see Figure 6.3). This pattern of a slower average driving speed for the negative image occurring near the start of the drive does also seem to appear briefly for the males, but then disappears quickly as the drive continues. The fact that the effect on driving speed occurs so quickly could be taken as support for the assertions of various models (Fuller, 2007; Fuller et al., 2008; Fuller, 2011; Kinnear, 2009; Ljung Aust & Engström, 2011; Näätänen & Summala, 1974; Summala, 1988; Summala, 2005; Summala, 2007; Taylor, 1964; Vaa, 2003; Vaa, 2007; Vaa, 2011) that driver behaviour is influenced by a tendency to return to or maintain some kind of homeostatic body balance or preferred safety margin. Unfortunately, it cannot throw light onto the differences between these models in terms of suggesting whether this body balance is itself constantly monitored and a set level targeted (Fuller, 2007; Fuller et al., 2008; Fuller, 2011; Kinnear, 2009; Taylor, 1964; Vaa, 2003; Vaa, 2007; Vaa, 2011) or if it is arrived at through an aversion to signals that arise because of a unbalance in this body state (Fuller, 1984; Näätänen & Summala, 1974; Summala, 1997; Summala, 2005; Summala, 2007).

Moving away from speed to the recorded psychophysiology, there is a significant target image type and order interaction effect in both heart rate and high band heart rate variability that is potentially interesting. This interaction effect is found in the combined dataset, in the males and, most importantly in light of the above speed effects, in the female dataset. The interaction indicates decreases in heart rate and increases in high band heart rate variability between the first and second drive. This is consistent with a familiarity or relaxation effect with the second drive becoming less stressful or effortful for the participants. Interestingly, however, the decrease in heart rate and increase in high band variability was lessoned if the negative target images were second. This, when combined with the above speed data where the increase in speed was also less when the negative images were second, is suggestive of a physiological effect of the negative target images. Specifically, it appears that the usual familiarity effect in terms of increasing speed, but also in terms of decreased physiological load for the second trial, was lessened if the negative images were presented second. That this effect is seen in the cardiovascular measures but not in skin conductance, which does not seem to meaningfully differ between the trials, or in the case of the female participants even between the baseline and the driving task, is interesting. While both cardiovascular and skin conductance measures are sensitive to changes in emotional arousal, heart rate and high band heart rate variability are generally considered to be more reflective of changes in mental workload or effort (Mulder & Mulder, 1981; Mulder, 1992). This may imply that the negative target images used are actually impacting on the mental workload or effort required by the task rather than creating feelings or emotions of risk, and it is the physiological reaction to this increase in effort that leads to the reduction in driving speed. If so this would be more in line with predictions made by models such as the multiple comfort zone model (Summala, 2005; Summala, 2007) or Task Difficulty homeostasis (Fuller, 2005; Fuller et al., 2008) which claim that emotions and feelings associated with the difficulty or effort required in the driving task are more common guides of driver behaviour than emotions related to risk..

Care should be taken with this interpretation however. Another way to interpret the lack of an impact on skin conductance response would be to say that because the participants (at least the females) drove, on average, slower when influenced by the negative image, they were bringing their body state back into its normal range. This process of returning to a normal, comfortable, or set body state may occur quite quickly during the first few seconds of driving, and therefore, may not show up in the averaged psychophysiological data presented here; especially since the first 30 seconds of psychophysiological data had to be excluded from analysis. This data was excluded because there was an immediate large impact of beginning to drive and starting to perform the memory task, on the cardiovascular and skin conductance measures. The above mentioned physiological consistency or homeostasis is what would be predicted by models of driver behaviour such as RAT (Fuller, 2011) or RMM (Vaa, 2003; Vaa, 2007; Vaa, 2011) which more closely embrace the work of Taylor (1964). Therefore, as already mentioned it is difficult to use this data to distinguish between the competing models in traffic psychology.

A related explanation for the lack of a meaningful response to the target images in skin conductance could be due to ceiling effects related to performing the driving task. Previous studies which have shown an effect of masked images on psychophysiology have tended to involve simple experimental tasks carried out in a standard lab environment (Kimura et al., 2004; Öhman & Soares, 1994; Öhman & Soares, 1998). This relatively simple task environment means that any physiological impact will be easier to detect. Furthermore, the physiological impacts of the masked images reported in these previous studies are often relatively small. On the other hand, simply driving has a large impact on psychophysiological measures, even with the simple road design used in this study (de Waard, 1996). This driving task related impact may therefore have masked the detection of any physiological effect of the emotional images. This, however, does make it even more significant that the order effect on heart rate and high band heart rate variability discussed above was found.

It was also thought that the negative image may have primed the participants to be aware of any possible threats and made them ready for action, resulting in a faster reaction time in response to an image of a stop sign being presented on the screen. However, no such effect was found in the combined, male, or female datasets. This could again be explained through the above mentioned return to a normal body state at the start of the drive. If participants had indeed quickly eliminated or balanced out the effect of the negative image on their body state by lowering their speed, then the negative image would possibly have no further impact, and could not help in raising their alertness to the onset of the stop sign. Another explanation could be that the stop sign in itself, while a road safety related stimulus, is not threatening enough when it occurs in an open road situation with no other traffic. Therefore, perhaps future experiments investigating the influence of masked negative images on threat detection could use a more relevant stimulus such as a car unexpectedly pulling out from a parking spot.

There was also a significant interaction effect of target image and order on participants' perceived speed in the combined, male, and female datasets. This reflects that actual travel speeds increased between the two trials. However, in this case the perceived increase in speed was larger if the negative images were presented during the second trial (a perceived average increase of 11.8 km/h compared to 9.48 km/h if the neutral target image was second). At least for the female participants, this is the reverse of the effect on actual driven speed, with the speed increase in this case being smaller when the negative target images were presented second. This could be interpreted as exposure to the negative target images creating an impression of faster driving speeds and therefore influencing the speed actually driven. However, it is clear from the data that this difference in speed perception, while present in the female participants, is mostly contributed to by the male participants who did not seem to be significantly affected by the target images in terms of their actual driving speed.

The results for the subjective ratings of feeling of risk and effort are somewhat difficult to interpret for the combined dataset. In the case of ratings of risk, there is not only a significant interaction of target image type and order, but also a significant interaction with gender. This means that in the case of the male participants, they decreased their ratings of feeling of risk from the first to second trial if the negative target images were presented first (a decrease of 6.64 on average), but increased their ratings if the negative target images were second (an increase of 3.86 on average). However, if the male dataset is analysed separately, there are no significant target image or order effects or interaction on ratings of feeling of risk, which makes it difficult to draw any conclusions from this finding. Conversely, if only the female participants are examined, there is a significant target image type and order effect with a tendency to increase ratings of risk between the first and second drives, with larger increases occurring if the neutral target images were second (an average increase of 6.59 compared with an increase of 3.86 if the negative target images were second). This again is difficult to explain, but perhaps could be related to the participants', correct, perception that speeds were increasing from the first trial to the second. It is, therefore, possible that participants rationalised that since they were driving faster, then the risk must also be greater. Although why this effect occurs significantly more in the presence of the neutral image for the females is not clear. However, it does at least in the case of the female participants, suggest that the emotionally negative images were not having any significant increasing effect on the female participants' feelings of risk.

The situation in the case of ratings of effort differs from that for ratings of feeling of risk. In the combined dataset there is a significant order and target image type interaction, with ratings of effort generally decreasing between the first and second trials, and this effect seems to be larger if the negative target images were second (a decrease of 3.75 compared with a decrease of 3.50 if the neutral target images were second). However, if the male and female datasets are examined separately it appears the majority of this effect comes from the male participants, who in contrast to the combined dataset and the female participants, decrease their ratings of effort more if the neutral target images were second. In the case of the female participants, their data appears similar to that for the combined dataset, although there were no significant main effects or interactions.

The above findings for ratings of effort are particularly interesting in light of the previously discussed impacts of the target images on perceived speed, actual speed driven and on the psychophysiological measures of heart rate and high heart rate variability. In this case, the target image type and order interaction effect observed in the other variables is reversed in the combined dataset for ratings of effort, or in the case of the females is non-significant. This, when combined with no consistent effect on ratings of subjective feelings of risk, does seem to suggest that the participants' subjective feelings were not altered by the images, despite producing the observed effects on speed, perceived speed and psychophysiology.

Finally, when asked about the differences between the roads they had driven, only 43.53% of the participants correctly identified that the roads had not differed. If the remaining participants are examined, then 38.82% reported something had changed about how the road was constructed. Typically, participants mentioned that the second road they drove had more curves. The rest of the participants either commented on the memory task, suggesting that they had seen more pairs on one of the trials, or did not answer this question. That some participants did report a difference in the road is likely due to the demand characteristics of being in an experiment and being asked if there were differences. Having been asked, they perhaps felt pressured to say that there were. It is interesting, however, that this resulted in the second drive being generally attributed the characteristic of being more curvy, and this is likely to do with the fact that the second road tended to be driven at a higher speed. A similar finding was made by Lewis-Evans and Charlton (2006) where drivers ascribed risky characteristics such as heavier traffic, missing road marking and more curves to a simulated road that had been narrowed by 2 meters but was otherwise identical to other roads they had driven.

Apart from the points already made above, there are several other potential issues that can be raised with this study. One obvious issue is the question of whether the participants really were unaware of the images. As mentioned in the introduction, this is a controversial issue (Pessoa, 2005; Robinson, 1998; Siegel & Weinberger, 2009), and therefore care has been taken to ensure that, at the very least, our participants could not explicitly report having seen the images. As such, during the setup of the experiment, the timing of the image presentation in the simulator was confirmed over three separate four minute periods using a high speed camera. Also, a manipulation check question was included, asking participants if they had noticed anything unusual about the images and they were also debriefed after the experiment and asked if they had seen any of the images. Based on this manipulation check, two females and six males who explicitly reported seeing the images were removed from the study, and data from an additional seven males and 12 females were removed on the grounds that they mentioned that maybe they saw something in between the masking images. These last 19 participants generally made statements along the lines of 'perhaps there was an image between the ones I saw, but I could not tell you what' or 'I think I saw flashes of colour'. The removal of these participants means that the remaining data is only from participants that explicitly stated that they did not see anything unusual with the images, and did not at any time during the experiment, including during the debrief, mention explicit awareness of the target images nor any suspicion that a masking procedure was occurring. As such, we are relatively confident that the participants were not explicitly aware of the target images. Future studies may, however, want to consider using a forced recognition task for each subject as part of the experiment in order to confirm that participants were completely unable to consciously perceive the target images.

A greater proportion of males (15.38%) explicitly saw the target images compared to the female participants (2.78%) although a similar proportion of males (17.95%) and females (16.67%) were in the group that was removed for suspecting that masking was occurring. This gender difference could be related to the generally better visuospatial abilities typically attributed to males (Halpern, 2000; Kimura, 2000). Also, anecdotally, most males who explicitly saw the images, also reported during the debriefing period that they considered themselves to be gamers. Since video games are also suggested to improve visual attention (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003; Hubert-Wallander, Green, & Bavelier, 2010; Subrahmanyam & Greenfield, 1994), particularly for fast moving or rapid stimuli, this may also be a contributing factor in noticing masked images.

Another issue is with the order effect that was encountered. The general tendency for participants to increase their speed from the first to second trial is not uncommon in simulator research (Schaap, Van Arem, & Van der Horst, 2008), but could still be of concern. On one hand, this may have been because the practice time given to the participants was not sufficient for them to become comfortable with the memory task and simulator. However, as reported in section 6.2.3, participants were asked if they felt comfortable with the memory task and the simulator after the practice drive and offered the option of repeating the task if they felt it was necessary. None took this opportunity. Nevertheless, this could be addressed in future studies through the provision of a longer practice period. It is also worth noting that the order effects found were always in interaction with the target image variable, and that there were no main effects of the trial order alone on any of the variables.

In addition to a longer practice period, longer experimental driving trials could also be investigated. These could, perhaps, include changes from emotionally neutral to emotionally negative image targets occurring on several occasions during the drive itself. This would also allow for the psychophysiological data to be collected for longer periods, and reduce the problem of having to remove the initial increase in these variables caused by simply starting to drive. All this said, at least in the case of the female participants, the effect of the negative target images on speed behaviour appears to occur within the first 20 seconds or so after the images have been presented and then maintained overtime. Therefore, the time periods used in this experiment do appear sufficient to catch at least this critical moment in terms of the impact of the target images on driving speed.

Another potential issue is the high level of variability in the speed data. This was likely caused by the fact that participants were denied the use of a speedometer and told to drive at whatever speed they were most comfortable at, resulting in large between subjects differences in speed. However, due to the nature of the within-subjects repeated measures analyses used in this study, the large variability between the subjects should not have had a negative impact on the results.

The fact that the participants were denied the use of the speedometer could also challenge the validity of this experiment. The speedometer was removed in an attempt to force participants to rely on their own perception of speed, and, therefore, hopefully encourage them to use the automatic or implicit control processes that are most likely to be affected by the masked target images. Furthermore, it allowed for the question about participants perceived speed of travel to be asked. Still, the lack of a speedometer is not a common occurrence in everyday driving. However, evidence from studies of drivers' gaze patterns show that they typically devote very little time, as low as 0.6% of total gaze time during a drive, glancing at their speedometers (Harbluk et al., 2007). This indicates that most of the time, drivers on the road, are relying on their own perception of speed, not information from the speedometer, much like they had to in this experiment.

The type of target images used could also be questioned, especially in terms of the negative target images. In the case of this study the images were selected as being some of the lowest valence and highest arousal negative images in IAPS, along with four motor vehicle accident related images. This means that the majority of the negative target images were of mutilated and deceased humans, removed from the typical driving context. These IAPS images were used as they were of a known quality, taken from an internationally recognised sample and had been previously used in masking studies (Hirschberger et al., 2010; Kimura et al., 2004). As such, this experiment should be taken as a proof of concept. Future studies could perhaps use more driving relevant stimuli, such as risky traffic situations or images related to the presence of police enforcement.

The validity of the "memory task" that the participants were performing, in terms of normal driving, could also be challenged. It is indeed a somewhat unusual task to be paying attention to an additional visual element and trying to detect repeated patterns in it while driving. However, driving is a visual task and often does require that visual attention be split, and that changes or the lack of change in the visual environment be detected and remembered. For example, it may be important to recognise landmarks and know if you have seen them before, when trying to navigate from A to B. Also, given that the same task was required of all participants and seems to have been consistently well performed, it is unlikely that it impacted on the results of the experiment in any meaningful way.

6.5 Conclusions

It appears that the masked negative target images did have an impact on at least the female participants in this experiment. This seems to primarily have occurred via suppression or a lessening of the normal familiarity effect between the first and second experimental drives when the negative target image was shown in the second drive. The data from the psychophysiology measures in terms of heart rate and high band heart rate variability support this interpretation and when coupled with the lack of any meaningful effect on subjective ratings of effort or risk suggests that the impact of the negative target images was not explicit. Interestingly, there does seem to be one clear subjective effect, with the participants perceiving the second drive as faster in general, but more so when the negative target image was second. This also, therefore, suggests an impact of the negative target image on speed judgement, although care should be taken with this interpretation as the majority of this effect seems to be amongst the male, rather than the female, participants.

The explanations given above for the results of this study could be labelled as speculative. However, this study does represent the first attempt to use masked images as part of a driving task, which in itself is noteworthy. We are unaware of any other studies examining the effect of masked images on a behaviour as complex as driving, which just by itself can have a large impact on psychophysiology (de Waard, 1996). Therefore, the very fact that any effect in behaviour was found, despite the usually somewhat small changes in physiology in reaction to masked images reported by other studies (Kimura et al., 2004; Whalen et al., 1998; Öhman & Soares, 1998) is significant. That the masked images can produce an effect on such an important variable for road safety as speed, suggests that the influence of implicit or unconscious emotions on driver behaviour should be further studied. With this in mind, the results of this study are an interesting starting point and could hopefully be used to help to guide future research.

CHAPTER 7 **DISCUSSION**

Some parts of this chapter will be published as Lewis-Evans, B., de Waard, D., and Brookhuis, K.A. *Contemporary theories of behavioural adaptation*. In Jamson, S. and Rudin-Brown, C. (Eds) Behavioural adaptation: Theory, Evidence and Action. To be released in 2012.

As stated throughout this thesis, traffic psychology does not have any one unifying model or theory of driver behaviour. This could potentially reduce the impact and adoption of traffic safety interventions due to mixed messages and conflicting paradigms. However, a point that has not yet been made is that this is not a problem that is limited to Traffic Psychology. Rather, psychology as a wider science also lacks any unifying model or theory of human behaviour and is broken into many competing and even contradictory schools of thought. Since driving is ultimately just another form of human behaviour it is, therefore, no surprise that the lack of consensus in psychology as a whole is also reflected in traffic psychology.

However, within traffic psychology specifically, one of the primary reasons given for the lack of consensus is that models of driver behaviour tend to lack testability and that even where testable models exist, the testing of them has not been common (Michon, 1985; Michon, 1989; Ranney, 1994; Rothengatter, 2002). As such, the studies presented in this thesis were attempts to, at least a small way, explore this issue. This was primarily carried out by taking four models: TDH (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008), RAT (Fuller, 2008; Fuller, 2011), RMM (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011), and the multiple comfort zone model (Summala, 2005; Summala, 2007), and testing some of their assumptions.

These four models were selected because they all claim to be different from the models that preceded them in that they are clear about the pathways through which they function and, therefore, they produce testable hypotheses. Indeed, one distinction that seems to separate these theories is whether they suggest that a subjective variable, such as feeling of risk, is continuously felt, targeted and impacts on driver behaviour, or if such variables only affect driver behaviour when certain thresholds are crossed. In particular, the TDH (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008), RAT (Fuller, 2008; Fuller, 2011), RMM (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011) all take the first approach, with only the comfort zone model (Summala, 2005; Summala, 2007) advocating the second. Chapters 3, 4, and 5 were all aimed primarily at addressing this distinction and all seem to favour a threshold account for these variables. Chapter 6, on the other hand, addressed the issue of the influence of emotions, as unconscious body states, on driving behaviour. The main findings of each of the chapters are discussed below.

7.1 Chapter 3 That is fast enough

The study described in this chapter is a variant of an earlier study by Fuller, McHugh and Pender (2008) (see section 2.1.3.3 in chapter 2 and section 3.1 in chapter 3 for detailed descriptions of this study). In this variant participants were asked to provide ratings for two different roads which they drove, or observed being driven, at nine different fixed speeds in a driving simulator. The different speeds were presented to the participants in random order and after each drive participants had to provide ratings of task difficulty, feeling of risk, effort, comfort, how typical the speed driven was, and the crash risk for themselves and a theoretical identical other. This differed from the original experiment in that participants were actively driving, that more subjective measures were collected and that the speeds in the original study had been presented in increasing order (Fuller, McHugh et al., 2008).

Rather than the systematically increasing trend in ratings of task difficulty and feeling of risk which was reported in previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008), in this study a threshold effect was seen, where participant's ratings of task difficulty and feeling of risk started low, or were absent, and stayed relatively stable until a certain speed was reached, and only then did these ratings begin to systematically increase. This occurred at around 50 km/h for the residential road and around 110 km/h for the dual carriageway. That there was no correlation between speed and ratings of risk and task difficulty all the way up to 50 or 110km/h is a finding that seems to be in sharp contrast to the claim made by some supporters of TDH that "…feelings of risk have been shown to be strongly correlated with speed, other than for relatively low speeds"(Broughton et al., 2009, pg 421).

Similar threshold type trends were also found for ratings of comfort and effort, although in some cases these took on more of a U-shape. Ratings of how typical the speed driven was produced quite a strong U-shape, with ratings closer to the threshold point being rated as more typical and those further away as less typical. Furthermore threshold relationships were found for participants ratings of crash risk. This is in line with the findings of the earlier Fuller, McHugh et al. (2008) study. Although, it is worth noting that when asked to provide crash risk ratings for a hypothetical, identical, other driver, the participants rated the other driver as more likely to crash than themselves. This likely explains the differences in the variable of crash risk between two previous studies in this area, the first of which asked about personal crash risk (Fuller, McHugh et al., 2008), and the second about the crash risk of a hypothetical, identical, other driver (Kinnear et al., 2008).

One other similarity between previous studies (Fuller, McHugh et al., 2008; Kinnear et al., 2008) and the study reported in chapter 3 was found. This was a relatively high correlation between ratings of task difficulty, feeling of risk, and effort. This is unsurprising as from a naturalistic standpoint, task difficulty, effort, and risk are all tightly connected. Indeed, the difficulty of a task is part of its risk as difficulty essentially indicates the chance of failure. However, as mentioned in section 2.1.4 of chapter 2 it is possible that this high correlation between these variables may be an artifact brought on by analytical thought prompted by simply asking for ratings from the participants (Summala, 2005; Summala, 2007). In other words, it is possible that simply asking for ratings may have provoked the participants to analyze and introspect in a way that does not necessarily represent their true experiences while driving.

One other aspect of the study reported in chapter 3 which is interesting, is that participants were given a chance to drive once at a speed that was of their own choosing. This allowed ratings of the subjective variables to be arrayed around this preferred speed and revealed that the preferred speed tended to match the speed just before ratings of risk, task difficulty, and effort would increase. This indicates that people prefer to drive at a speed at which they don't experience any subjective feelings of risk, task difficulty, or effort and that this speed seems to fall just before such feelings begin to be felt in a systematically increasing fashion. This finding seems to lend further support to threshold theories such as the multiple comfort zone model (Summala, 2005; Summala, 2007).

7.2 Chapter 4 That is close enough

The second experiment reported in chapter 4 reinforces the findings of chapter 3, with similar threshold trends in ratings of subjective variables being observed during a car following task. This is important as models of driver behaviour need to be able to explain all facets of driver behaviour not just the, admittedly important, aspect of speed choice. Once again, as was found with speed in chapter 3, when given the chance, participants selected a following distance which corresponded to the point just before ratings of feeling of risk began to strongly increase. Although in this case, when scores were arrayed around the participants preferred following distance, no threshold effect was seen for ratings of effort or task difficulty which stayed relatively stable. This is likely due to issues with some participants following quite close to the lead vehicle, which meant that there were often not three complete data points below this following distance that could be used in the analysis. However, it does seem to highlight that feeling of risk could be seen as a potentially more reactive variable. On the other hand, it is also possible that feeling of risk may merely be something that participants are more sensitive to reporting when explicitly asked, rather than a true reflection of what was felt in the moment.

Also, in chapter 4 the issue of driver experience was examined to see if there was any difference between inexperienced and experienced drivers. Since the accident involvement of these individuals differ, it is perhaps possible that their perception of the subjective variables assessed could also differ. However, the same threshold effect was found for both the inexperienced and experienced drivers. This seems to indicate that the triggers for these feelings, at least in the case of simple car following tasks, are created early on in the process of learning to drive. It would be illuminating to repeat the experiment with truly novice drivers .This may show much greater reactivity and perhaps even produce results more in line with a constant perception of feelings of risk and task difficulty, since the experience is still new to them. It is also likely that at this very early point, when nearly constantly feeling risk and difficulty, that the novice driver is relatively safe. However, learning to drive is learning not to fear and it is possible that the transition to only threshold perception of risk and difficulty is relatively rapid as drivers gain experience. This may outpace a driver's true skills in recognizing hazards on the road their own limitations and help create the typical overconfidence associated with drivers (McKenna et al., 1991; McKenna, 1993).

This process of habituation could be related to the other aspect addressed in chapter 4, that of habit. Since driving is known to be a highly automatic learnt task, past behaviour and habit obviously play a large role in driver behaviour. It is in fact through disturbances to mostly automatic safety margins that the multiple comfort zone model says that uncomfortable feelings, such as risk or effort, will arise (Summala, 2005; Summala, 2007). Also, in three of the studies reported in this thesis (chapters 3-5), participants ratings of what was 'typical' for them in terms of speed or following distance, tended to be the most reactive in terms of indicating where the threshold point would be. That is to say, that this variable took on a U or V shape, with the bottom of the U/V tending to correspond to the speed or following distance just before the other ratings provided began to increase significantly. It was, therefore, thought that maybe a small change in what was usual would cause these thresholds to be crossed earlier. This was tested by having participants drive on both the unfamiliar and familiar sides of the road while carrying out the car following task. However, no meaningful effect was found. This may be because the change was too small, or perhaps it was too obvious, and because it did not actually objectively increase the difficulty of the task the participants were able to rationalize away any effects that it may have otherwise had.

7.3 Chapter 5 Maintain that speed

The idea of habit and preferred speeds indicating a threshold point played a large role in the experiment reported in chapter 5. In this case, participants' own preferred speed was used as a set point, and then they were asked to drive at speeds higher or lower than this speed, while in some cases performing a secondary task to increase mental workload.

Again the results of this experiment point to threshold perceptions of the subjective variables examined. Furthermore, when able to drive at a speed of their own choosing, the participants consistently rated their subjective experiences of risk, task difficulty, and effort as low or absent.

The addition of workload via a secondary task, moved the ratings for the subjective variables upwards, reflecting the increased difficulty of performing the secondary task, but interestingly the threshold effect in the data remained. From the perception of a threshold model like the multiple comfort zone model (Summala, 2005; Summala, 2007) this makes sense in that even when under secondary load, the automatic, learnt, safety margins are still operating and still the primary guide of driver behaviour. Then once they have been breached they create an additive effect on top of the feelings already being generated by the secondary task. It is less easy to address this finding in terms of TDH (de Waard, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008), RAT (Fuller, 2008; Fuller, 2011), or RMM (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011), however, as the addition of workload brought on by the secondary task would be expected to have made even clearer the systematically increasing and decreasing trends in the relevant variables, or variable, that each model claims are constantly monitored and targeted.

The findings in terms of the participants' objective speed of travel, during the experiment described in chapter 5, are also revealing. The fact that when under cognitive load, participants who were driving slower than their usually preferred speed had a tendency to increase, and not decrease, their speed, also speaks to the automatic control of speed. As does the speed adaptation effect observed between the baseline and after speeds, where driving slower or faster during the experimental conditions had a clear effect on the speed participants preferred to drive at the end of each trial. The finding of an increase in speed when under load, appears to be difficult for models such as TDH, RAT and RMM to address. As in this case, subjective task difficulty and feeling of risk increased, as did the objective difficulty of the task, therefore, these models should predict that action should be taken by the participants to decrease these feelings back down to their preferred level. However, what they actually did was to, likely unconsciously, increase their speed and thereby further increase the objective difficulty and demand of the task. This is probably because conscious control of maintaining the lower speed was being interfered with by the secondary task, which then allowed much more automatic performance based processes to take over. The result was a move towards certain learnt speeds. This occurred despite ratings of the difficulty, risk, and effort of the task being much higher than they usually would be if the participants had been operating at their preferred speed.

The finding that participants in this study who were under cognitive load increased their speed when attempting to maintain a speed which was lower than usually preferred, also has implications outside of the general discussion around models of driver behaviour. In particular, it indicates that at least some proportion of speeding behaviour may be unintentional, caused more by attentional issues rather than intent. This is a particularly challenging idea for those in road safety who may wish to have a more black and white view, where every speeder is intentionally and purposefully violating the rules of the road.

7.4 Chapter 6 Did you see that?

This chapter addresses the influence of emotions, represented as unconscious body states, on driver behaviour. Thanks in large to the Somatic Marker Hypothesis (Damasio, 1994; Damasio, 2003), but also the earlier work of Taylor (Taylor, 1964), the idea that emotions can affect driver behaviour is referenced, at least in part, by all four of the main models of driver behaviour examined most closely in this thesis (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008; Fuller, 2008; Fuller, 2011; Summala, 2005; Summala, 2007; Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011).

Provoking an emotional response in an individual without their consciously or explicitly feeling it is a challenge. However, in past experiments, masked emotional images have been shown to be able to produce emotional responses in individuals without their awareness (Carlsson et al., 2004; Gläscher & Adolphs, 2003; Kimura et al., 2004; Whalen et al., 1998; Öhman & Soares, 1994; Öhman & Soares, 1998; Öhman, 2005), and as such they were also used in the study presented in chapter 6, with participants being exposed to both negative and neutral, masked emotional target images taken from the IAPS image set (Lang et al., 1999).

What was found is that the emotionally negative images seemed to have a suppressing or reducing effect on the usually found familiarity effects seen in within-subject designs. This is evident in a significant order and target image type interaction for the actual speed driven and the physiological measurements of heart rate and high band heart rate variability. In terms of the results for speed, participants tended to increase speed from the first trial to the second, in line with a familiarity effect. However they did so less, if the negative target image trial was second. Similarly heart rate tended to decrease and high band heart rate variability increase, between the first and second trial. This is again what would be expected with familiarity and once again this effect was reduced if the negative image was second.

Significantly these effects occurred without any meaningful impact of the images on subjective ratings of effort or risk. This could imply that the results were not because of any conscious or explicit feelings on behalf of the participants, at least not in terms of changes in feeling of risk or effort.

It should be noted, however, that the majority of these findings were found only in the female participants and not in the males. Indeed, if only the female sample is examined, then the emotionally negative target images had a significant main effect on reducing overall driving speed in addition to the interaction with order, mentioned above. In my opinion, this is most likely because of the much smaller male dataset, particularly given the significant order and target image interactions. However, it is also possible that the female participants were more sensitive to the types of images used, or may react to emotional signals in a way that differs from the male population (Bradley et al., 2001; Chentsova-Dutton & Tsai, 2007; Lang et al., 1999; Lithari et al., 2010; Proverbio et al., 2008; Williams & Gordon, 2007).

As far as I am aware, the experiment in chapter 6 represents the first attempt to use masked images in an applied setting like driving. Given that previous studies which have found an impact of emotional masked images have tended to be carried out in relatively simple experimental conditions (e.g. Carlsson et al., 2004; Gläscher & Adolphs, 2003; Kimura et al., 2004; Whalen et al., 1998; Öhman & Soares, 1994; Öhman & Soares, 1998; Öhman, 2005), the fact that these images had any impact on driving at all is interesting. However, the study should be taken as a first step and unfortunately does not particularly aid in determining which of the four models examined in this thesis is more accurate, as they can all, to some extent, account for the effects that were observed. For example, the multiple comfort zone model (Summala, 2005; Summala, 2007), could state that the introduction of the negative images caused an emotional threshold to be crossed, leading to a reduction in speed. Whereas RAT (Fuller, 2011), could counter by saying that the participant's constant awareness of feeling of risk was altered by the introduction of the images and they had reduced speed in reaction to this, therefore, returning to their preferred level of experienced risk. While this is perhaps frustrating for anyone aiming to prove one model over another, it does highlight that these four models are all similar in terms of predicting behavioural adaptation in the face of negative emotional, or feeling based, stimuli.

7.5 General discussion

The findings of the studies featured in chapters 3–6, and discussed above, lead to several conclusions. The first is that the speed drivers travel at is not solely a conscious or reasoned choice. Rather it appears to be handled, at least at some level, by automatic processes. The existence of these processes can be inferred when the cognitive capability of drivers is loaded, such as in the study described in chapter 5. In this case it appears these automatic processes can actually act to increase the objective difficulty of a task when under cognitive load, rather than decrease it. The existence of unconscious processes in speed control can also be inferred by the influence of the negatively emotional masked images on driving speed, as described in chapter 6.

It is also relatively clear that the findings of the experiments described in chapters 3–5, support a threshold account for the perception of subjective variables such as task difficulty, effort, comfort, crash risk, and feeling of risk. This was not the case however for participants' ratings of how 'typical' the speed (in chapters 3 & 5) or following distance (in chapter 4) they experienced was. This variable tended to be the most reactive and took on a U or V shaped curve with the bottom of the curve tending to indicate participants preferred speed or following distance. The fact that participants were able to easily indicate awareness of what was typical, both with and without feedback from other subjectively experienced variables, indicates that these other variables may not be of primary importance when deciding what speed to travel at, or deciding what distance to follow a lead vehicle at. Rather, participants appear to be able to directly use the information provided by their perceptual system and current task performance to guide their driving behaviour.

The findings of this thesis therefore more strongly support models such as the multiple comfort zone model (Summala, 2005; Summala, 2007). This is due to the reliance of this model on actual performance measures in driving, such as time to line crossing or time to collision, rather than on the constant awareness of, and monitoring of, any one particular feeling or group of feelings as the primary driving force behind driver decisions.

However, there are several points that should be mentioned about the above conclusions. Firstly, in the case of the experiments described in chapters 3–5, it is apparent at times that there is a slight increasing trend with increasing speed ($r = .03$-$.07$) for participants' ratings of feelings of risk before what is described as the threshold point. This is not always present, and once the threshold has been crossed the trend becomes much more apparent. Even so, it could be taken as an indication of participants having a constant perception of changes in risk. However, as mentioned in the relevant chapters, this likely is an artifact from asking participants to engage in after the fact analysis of their feelings and impressions. This after the fact analysis could have biased ratings towards the reporting of these variables and may have resulted in the participants not accurately reporting on how they felt in the moment. In fact, given this likely heightened sensitivity to providing ratings, it makes the finding that a threshold type account was generally seen, even stronger.

One additional argument that a supporter of RMM (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011) could make in reply to the findings of this thesis, is the model refers to a best 'target feeling', and that it is possible that the experiments described in chapters 3–5 just did not collect data on the correct feeling. This is theoretically possible of course, but it should be noted that nearly all of the variables assessed in chapters 3–5 are included as possible 'best feelings' in RMM. This includes feeling of risk, a 'best feeling' that is given special prominence by the model, and is even featured in its name. Therefore, if this explanation that the correct 'best feeling' was not assessed is accepted, then it would not only run counter to the importance of risk in the Risk Monitor Model, but also bring the model dangerously close to being unfalsifiable, due to the broad nature of the potential 'best feelings' available.

A more serious and general concern that could be raised by supporters of TDH (Broughton et al., 2009; Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008; Kinnear et al., 2008), RAT (Fuller, 2008; Fuller, 2011), or RMM (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011) is that the continuous monitoring versus threshold account distinction between the models examined in this thesis, is false, and that the TDH, RAT and RMM do not suggest that subjective variables are constantly perceived. Indeed, if the latest publication on TDH and RAT is examined then the following statement is found

"RAT proposes that driver control decisions are motivated by a desire to maintain feelings of risk (and its corollary task difficulty) within an acceptable range, even though for much of the time these feelings may be below the level of conscious awareness." (Fuller, 2011, pg 36)

What can be seen from this statement is that Fuller appears to be proposing that feeling of risk is kept within a certain range, constantly monitored, and maintained, but at the same time is mostly not felt by drivers. This statement is in contrast to previous definitions of feeling of risk provided by Fuller which stated that feeling of risk was the same as experienced risk (Fuller, 2005; Fuller et al., 2008; Fuller, McHugh et al., 2008). For example:

"They [the participants] were also asked to rate their experience of risk (i.e. feeling of risk) for each sequence" (Fuller, 2005, p 468) - in reference to the experiment reported in Fuller, McHugh & Pender (2008) which uses ratings of feeling of risk to equal experienced risk

"We can tentatively conclude from the above results that Taylor and Wilde were correct in exposing experienced risk (i.e. feelings of risk) as a critical determinant of driver behaviour…" (Fuller, 2005, p 470).

"Increases in task difficulty may be experienced as increases in feelings of risk." (Fuller et al., 2008, p80)

In a similar way, task difficulty as part of TDH, was also often referred to as 'experienced', thereby implying some level of conscious awareness, and that it would be systematically related to speed (Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008). Furthermore, the evidence obtained from the Fuller, McHugh et al (2008) experiment, in which ratings of feeling of risk and task difficulty did clearly differ in conscious awareness across a range of speeds, was used several times to demonstrate the role of these variables within TDH (Fuller, 2005; Fuller, 2007; Fuller, McHugh et al., 2008). However, this assertion of unconscious feelings has now been made and should be examined.

The first point that can be raised is one of terminology and semantics. As covered in chapter 2 (see section 2.1.3.2) the authors of TDH, RAT, and RMM all appear to be aware of, and mention (e.g. Fuller, 2005; Fuller, 2011; Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011), Damasio's (1994; 2003) the definition of feelings as a conscious subjective experience of underlying emotional body states. Similar definitions are also provided in the APA dictionary of psychology (VandenBos, 2006) and the Penguin dictionary of psychology (Reber, 2009). These definitions also reflect the common usage of the term 'feeling' where it is implied that the 'feeling' is 'felt' and therefore conscious. Indeed even the phrase 'gut feeling' which refers to making a decision based on a hunch rather than via reasoning still implies that a 'gut feeling' is present and able to be felt and acted upon.

Still, strictly definitional issues aside, there is some philosophical argument over the possibility of unconscious feelings (see Lacewing (2007) for a summary), but at this moment no solid conclusions have been reached either way. As such, the possibility of unconscious feelings does exist, albeit in a fashion that is not widely accepted or proven. There is also another terminological issue can be raised with TDH and RAT in particular, in that they both refer to 'perceived' feeling of risk/task difficultly', 'perceived' capability and 'perceived' task demand (see Figures 2.2 and 2.3 respectively). Again the word 'perceived' carries with it the connotation of conscious awareness of the variable in question. Indeed, within psychology, perception is generally treated as the end result of the processing of sensory information to create a conscious awareness of the environment (Reber, 2009; VandenBos, 2006). Everyday use of the term 'perceived' also carries the connation of conscious awareness.

Even if one were to put aside the semantic and philosophical arguments over not feeling feelings and unperceived perceptions, it is still clear that these models posit the constant monitoring and presence of certain feelings, such as risk. Therefore, they can still be classified as constant monitor models rather than threshold ones. However, if the guiding feelings are truly unfelt ones, then it would appear that much of the work presented in this thesis cannot fully falsify these models. Indeed, given the difficulty of accessing and measuring such a construct as an unconscious 'feeling', it becomes quite difficult to falsify these models at all (Lacewing, 2007), although the experiment described in chapter 6 is a small, if inconclusive, attempt towards doing so.

It also appears that the very structure of the Somatic Marker Hypothesis on which RAT, and also RMM, is partly built, is against Fuller's (2011) implication of the constant presence, monitoring, and targeting a feeling of risk. As stated in various parts of this thesis, the Somatic Marker Hypothesis makes it clear that emotions, and, therefore, the feelings that can arise from emotions, only occur when triggered by previously learnt situations or stimuli (Damasio, 1994; Damasio, 2003). This is because, as mentioned in section 2.2.2 of chapter 2, our underlying biology, and indeed our chemistry, operates in a threshold manner. If our physiology operates in this way then our emotions and feelings must also follow, only occurring once chemical thresholds have been crossed within our bodies. The alternative, to be constantly having a feeling of risk that was above zero, unconscious or otherwise, would be a great drain on energy resources, especially seeing that in most cases there is no need to react, and there is no need to feel or have a physiological emotional response to risk. Rather, your body maintains its usual function and only reacts when certain learnt, or rarely innate, stimuli or situations are detected. In this way, RMM's assertion that the body is the monitor is a valuable one (Vaa, 2007; Vaa, 2011), this ensures that energy is spent when needed and reserved when it is not. The upshot of this is that nearly any emotion or feeling, of risk or otherwise, conscious or unconscious, only occurs in certain situations and it is only in these situations that it can impact on decision making.

Fuller (1984, 2011) and Vaa (2001, 2003) have also argued that the threshold account of feeling of risk provided by models like zero-risk theory (Näätänen & Summala, 1974; Summala, 1988) or the multiple comfort zone (Summala, 2005; Summala, 2007) does not make sense as, in Fullers words; "it is most important to stress that the stimuli which trigger avoidance responses must retain their emotive characteristic" (Fuller, 2011, p 28). This is supposedly because if they do not retain their emotive characteristics then they become neutral stimuli and could not be used in decision making. Therefore, feelings of risk must be continually present and able to be monitored. I disagree with this line of reasoning.

We are not born with innate emotive characteristics attached to everything. Rather as stated by Damasio (1994; 2003), we learn to associate emotions with stimuli, but more importantly I would add that this association tends to be with stimuli in certain set situations. If I am driving towards a brick wall at high speed then the stimulus of the wall is likely to possess very strong emotional characteristics. Does this mean that I am monitoring the position of every brick wall that I could possibly hit in my car and unconsciously 'feeling' the risk associated with them? No, the walls are in this case emotionally neutral and irrelevant stimuli. They mean nothing to me unless I am interacting with them in certain situations and it is in these situations that they play a role in my decision making. They do not have to be 'charged' with emotional characteristics beforehand to do so. All they really need to maintain is their wall-like characteristics. This is, as already stated previously, the energy efficient way for dealing with the world in which we have evolved.

Indeed, one could perhaps look to phobic individuals to see what occurs when this threshold, situation dependent functioning fails. Ornithophobic individuals, for example, have an irrational fear of birds and this may even extend to objects associated with birds such as the feathers in a feather duster. Here the linkage between a threatening emotional stimulus and situation, a bird flying at your head for example, has become decoupled from the situation in which it its appropriate. This causes it to be applied to the stimulus of 'bird', more generally. This is obviously maladaptive and a great waste of energy.

There are certain stimuli and situations that invoke 'innate' responses. For example, in the situation where anything looms suddenly in the visual field there is likely to be a startle response and an accompanying feeling of a threat being apparent. This, amongst other things, leads to the childhood game of 'made you flinch'. This occurs whether the suddenly looming stimulus is a playmates fist, or a soft fluffy pillow. So again, it does not seem to depend necessarily on the emotional characteristic of the stimulus but rather the situation in which it is encountered. This ties in well with models such as the multiple comfort zone model (Summala, 2005; Summala, 2007) which would suggest that we have certain, rather general, safety margins which can be called into play when needed. In the case of the above example that would be a general rule or schema that says if something moves quickly within our visual field towards us, we should move away, and as a result of the physiological startle reaction, feel aversion towards that object. It does not, however, rely on the object being labelled with emotional characteristics but rather on it being perceived visually as an object looming in the visual field. Furthermore if your playground friend continues to insist in waving her fist in your face then via habituation you will very soon stop to experience any threat from the situation at all, and even this quite strong 'innate' response will disappear, not only from your behavioural reactions, but also from any indications of risk in your psychophysiology. Does this mean the risk is gone? No, it does not, but it does mean that risk is no longer being monitored as it has been shown to be irrelevant, a fact that your playmate may take advantage of by punching you in the face. The generally forgiving nature of the driving task could lead to similar habituation to the dangers that drivers, objectively speaking, constantly face (Fuller, 1984).

Finally it is also worth noting that in order for Fuller (2011) to make the statement that feeling of risk or task difficulty is not constantly experienced as a subjective conscious feeling, he must therefore be at least partly discounting the findings of his earlier study in which this was the case (Fuller, McHugh et al., 2008). While this has not been explicitly done, Fuller (2011) does reference the paper which makes up chapter 3 of this thesis (Lewis-Evans & Rothengatter, 2009), suggesting that the impression that risk is not important in everyday decision making, is only because most of the time avoidance responses have been correctly made and therefore risk is not consciously experienced. While not stated by Fuller, one could perhaps assume then that task difficulty is also not always consciously experienced for this same reason. This in itself is an interesting statement, however, especially when combined with the earlier statement from Fuller about stimuli 'triggering' avoidance responses. Again, from a semantic point of view the term 'triggering' implies a more threshold type reaction, with a reaction only occurring once a certain trigger also occurs. Furthermore, if most of the time these triggers are correctly avoided then even if they do retain some emotional characteristic it must not often come into play and therefore will not be constantly monitored. In other words, if successful avoidance usually leads to feelings of risk not being consciously present, then why would it also not lead to risk being usually also absent at an unconscious level? One could easily theorize a learning process where an emotional stimulus is learnt to be avoided or escaped from, and then this learning itself becomes reinforcing due to the removal of the unpleasant stimulus without need to maintain constant monitoring of the potential emotion that may occur if avoidance fails. This type of avoidance or escape learning is known to be very strong and resistant to extinction (Skinner, 1953), and in fact the process described above is very similar to the idea of threat avoidance formerly put forward by Fuller in his earlier threat/risk avoidance theory.

The above discussion is not meant to imply that feelings and emotions are not an important part of human decision making. As reported by Damasio (1994, 2003), individuals with brain damage that inhibits or prevents emotional cues being used, tend to make poor decisions, although they are not completely incapable of decision making. Indeed if adults with these types of conditions are tested in formal situations where they have time to think, they often perform as well as brain 'normal' individuals. Therefore, they do appear to be able to make appropriate decisions despite the stimuli around them being effectively emotionally neutral. Since this ability to function is normally observed in adults who developed a non-emotive state later in their life, it is likely because they are able to rely on past learning and rules in these situations, even if they do sometimes have difficulty when dealing with the rapidly evolving nature of decision making in everyday life. It is also found that they appear to have problems learning to make favourable risk based judgments when the risk is initially ambiguous (Bechara et al., 1997). Although there is some discussion whether this is due to issues with emotion and somatic marking or other cognitive deficits such as problems with reversal learning (Fellows & Farah, 2005), working memory, or attention (Manes et al., 2002).

The above findings mostly highlight the learnt nature of behaviour, in particular the learnt associations of emotion and action, and suggest that threshold models, such as the multiple comfort zone model (Summala, 2005; Summala, 2007) provide a more parsimonious account for the role of emotions and feelings in driving, in that they maintain that what is monitored is the world around the driver and the performance of the driver within it. In this fashion, a driver can rely on generalized rules, for example about closeness of objects to their vehicle, in addition to any emotional cues, risk related or otherwise, that may arise. This means that risk, or any other feeling or emotion, is only perceived when certain learnt thresholds are crossed or certain learnt stimuli and situations are present and does not need to be constantly monitored.

Not that the multiple comfort zone model (Summala, 2005; Summala, 2007) is perfect. Rather, it is particularly vague in what exactly motivates individuals to establish these thresholds when they are first learning them. Also, what motivates drivers to ignore the feelings and emotions that signal that thresholds have been crossed? The model is also somewhat weak when it comes to detailing what role, if any, of social psychological attributes such as attitudes and personality, play in driving behaviour. Finally the model does not explicitly acknowledge the driver as part of a system nor incorporate many advances made in cognitive or neuropsychology. These factors ultimately make it a model that is still somewhat difficult to test and falsify, however, future research should attempt to do just that.

Despite the arguments presented above, and throughout this thesis, there are some commonalities that exist amongst TDH (Fuller & Santos, 2002; Fuller, 2005; Fuller, 2007; Fuller et al., 2008; Fuller, McHugh et al., 2008), RAT (Fuller, 2008; Fuller, 2011), RMM (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011) and the multiple comfort zone model (Summala, 2005; Summala, 2007). The first is the recognition of the important role that emotions and feelings play in decision making, alongside a move away from utility models in describing behaviour. This is a reflection of a general trend in psychology (Damasio, 1994; Damasio, 2003; Slovic et al., 2004), and may take on different forms depending on the driver behaviour model but as Fuller has already suggested, this does seem to represent a 'hidden consensus' between the models (Fuller, 2008; Fuller, 2011). Furthermore, in terms of their observed behavioural outcomes the models are quite similar and all four models agree that if experienced risk or task difficulty becomes higher than a certain level then action will be taken to reduce the experience of these variables.

Another similarity is that these models, and many of the other modern models mentioned in chapter 2, attempt to provide, at least some, clear, testable hypotheses. Although the actual testing of the models has currently been limited to only a few studies (e.g. Broughton et al., 2009; Fuller, McHugh et al., 2008; Kinnear et al., 2008; Kinnear, 2009; Lewis-Evans & Charlton, 2006; Lewis-Evans & Rothengatter, 2009; Lewis-Evans et al., 2010; Lewis-Evans, de Waard, & Brookhuis, 2011; Lewis-Evans, de Waard, Jolij, & Brookhuis, 2012; Rudin-Brown & Parker, 2004), and the models are still not perfectly clear. This is however a step forward from earlier models, and may lead to one model gaining prominence over the others.

The models examined in this thesis also share a move away from concentrating on accident risk. Although, in the case of RAT and RMM, they still do view risk, in the terms of a feeling, as a factor of central importance. I believe, like Michon (1985; 1989), Ranney (1994), and Rothengatter (2002) did, that it is time for traffic psychology to move away from this concentration on risk; a move that many of the driver assistance technology orientated models covered in section 2.4 of chapter 2 have already made. Driver behaviour is just one form of human behaviour and any truly comprehensive model that seeks to explain it should be able to both illuminate why a young driver drives at 140 km/h down a country road but also why they give up on reading a textbook for school. Risk, feeling of or otherwise, is unlikely to play a role in the individual's latter decision and, therefore, we must examine the possibility it does not play a major role in the young driver arriving at the former.

As stated in section 2.2.2 of chapter 2, from an evolutionary standpoint, risk is a poor candidate for a primary guiding force in animal and, therefore, human behaviour. Rather, the energy cost of an action is a much more readily available variable as it is immediately accessible and does not need to rely on the discovery of, and remembered association with, the consequences for any one action. This distinction is especially important in the driving context which occurs in quite a forgiving environment where it is unlikely that most drivers will ever experience any seriously negative consequences of their objectively risky behaviour. As road safety professionals and researchers we can of course see the aggregate and individual risk of decisions made in the traffic system but it does not mean that risk plays a major role in individual driver decision making on a day- to-day basis. To assume so, is in some ways acting on hindsight bias, in that we have all the information about how things turned out and, therefore, the risks seem to be obvious to us. But we must remember that, as put so well by Wagenaar (1992, p 279) "…people… run risks, but they do not take them", a statement that could just as easily be restated as 'people run risks, but they do not usually feel them.'

Here at the end of this thesis it is tempting for me to propose a new model of driver behaviour. If I were to do so, I believe it would somewhat resemble the Situation Control Framework (2011) described in section 2.4.18 of chapter 2. This model takes the multiple comfort zone model (Summala, 2005; Summala, 2007), including the rejection of risk as a primary variable of interest and strengthens it with the idea of the driver as a component in a system. This systems approach has long been championed by Human Factors psychologists (Reason, 1990) and is represented in traffic psychology in terms of initiatives such as Sweden's Vision Zero (Tingvall, 1997). However, it still often seems that models of driver behaviour concentrate solely on the driver as a singular causal point of failure. In particular, statistics along the lines of '90% of all accidents are caused by human error' are used far too often as excuses to blame the driver and institute what are often ineffective educational road safety efforts (Christie, 2001). The Situational Control Framework also references the Somatic Marker Hypothesis in a way that I feel is suitable, given the findings reported in chapter 6.

More than this though, if I were to propose a model I believe it would also attempt to, as suggested by Ranney (1994), incorporate the ideas of Rasmussen (1987). Indeed, it seems that moving from skill to rule to knowledge levels of operation, would go well with a threshold account of feelings in driving tied to actual task performance, in that as drivers move between these levels, there is a corresponding change in the mental effort required by the task. I also believe that the feelings that accompany underload and boredom could be included into existing threshold models. In particular, I hypothesize that the avoidance of boredom in particular is a strong motivating factor in driver behaviour due to the fact that it is likely to be more commonly encountered by drivers than any feelings of difficulty or risk. As such, any model I proposed would likely be a partly avoidance driven threshold learning model which predicts drivers learning not to fear, being driven by expectations and maintaining satisfactory, not optimal, performance levels.

Finally, any model that I did put forward would also aim to incorporate or explain Hedlund's (2000) principles for behavioural adaptation[3] and Elvik's (2006) laws of accident causation. Hedlund's (2000) principles for behavioural adaptation state that there are four principles to consider when designing a road safety intervention if you want to avoid behavioural adaptation: visibility, effect, motivation,, and control. In general, this means that if a driver doesn't know a change has occurred, if the change doesn't affect them, if they don't have any change in their motivations and/or if they simply cannot change their behaviour because of constraining environmental factors then behavioural adaptation will not occur. Although, it should be noted that in light of the work of researchers such as Damasio (1994; 2003), and the results of the research presented in chapter 6, that the principle of effect must also accommodate the idea of unconscious effects via somatic markers or emotional physiological states. These do seem to be quite broad principles but I feel in the absence of any agreed upon model of driver behaviour, they could serve as useful guidelines for the design of road safety interventions. This is a role that I believe Elvik's (2006) laws of accident causation can also play. These are the 'universal law of learning', the 'law of rare events', the 'law of complexity' and the 'law of cognitive capability'. These 'laws' state that: as exposure increases then accident rate per unit of exposure will decrease due to the increased experience of the driver (universal law of learning), that rarely accounted risks will account for a larger increase in accident rate than commonly encountered risks (law of rare events), that the more drivers have to attend to in the environment the more per time unit then their error rate will increase (law of complexity) and finally, that drivers have limited cognitive capability and that errors and accidents will increase as capability decreases or is pushed to its limits (law of cognitive capacity). Again, these are relatively basic assumptions but ones that I feel any model should be able to account for and that can serve as somewhat useful guidelines in the current absence of an agreed upon model of driver behaviour.

All this said, I will stop short of formally proposing a new model. I do so in part because I do not wish to add to the considerable pile of models that exist. Mainly, this is because I also believe that I could not at the moment provide a model that is more predictively, rather than descriptively, useful than those that already exist. More work must be done first and more questions answered. It may be that one of the existing models already has the answer but due to a lack of testing has not been validated. I also believe that I and other traffic psychologists must look more often outside of our discipline for answers on this issue. As stated above, driving is just another form of human behaviour, albeit one that contributes to large-scale loss of life around the world. Therefore, I feel that any model that can explain

[3] While these are referred to as principles of risk compensation in the original text, I feel the neutral term of behavioural adaptation is more appropriate.

driving should also, at the very least, be able to explain most other locomotion behaviours, and more likely, should also be able to account for a considerable amount of other non-locomotion related behaviours.

This then, is perhaps a disappointing way to end this thesis, particularly in light of my insistence that traffic psychology must present a more united front to policy makers and road designers. However, it is an honest way to end and I hope that this thesis can contribute to model development even if that is ultimately through a model of my own devising at some later date. Science advances most often through small steps of testing and replication rather than through leaps and bounds. As such, I humbly offer this thesis as a series of such steps.

CHAPTER 8 **DUTCH SUMMARY/NEDERLANDSE SAMENVATTING**

Geen enkel model van rijgedrag is het gelukt om algemeen geaccepteerd en gebruikt te worden in de Verkeerspsychologie. Echter, de motivationele modellen kunnen op zinvolle wijze in twee subgroepen ingedeeld worden en de verschillen hiertussen kunnen onderzocht worden. De ene subgroep stelt dat het zich richten op en constant monitoren van een bepaalde subjectieve variabele, vaak risico, de controlerende factor is in autorijden. De drie belangrijkste modellen die in dit proefschrift besproken worden die behoren tot deze subgroep zijn Task Difficulty Homeostasis theory (Fuller, 2002; Fuller et al., 2008; Fuller et al., 2008; Fuller, 2005; Fuller, 2007), Risk Allostasis Theory (Fuller, 2008; Fuller, 2011) en the Risk Monitor Model (Vaa et al., 2000; Vaa, 2003; Vaa, 2007; Vaa, 2011). De andere subgroep stelt dat subjectieve variabelen als risico alleen relevant zijn als een bepaalde grenswaarde overschreden wordt. Het multiple comfort zone model (Summala, 2005; Summala, 2007) is het belangrijkste model uit deze subgroep dat hier in detail besproken wordt.

Het onderscheid tussen de twee subgroepen wordt behandeld in de hoofdstukken 3-5 van dit proefschrift, en de belangrijkste resultaten worden hieronder samengevat. Ondanks genoemde verschillen, hechten alle vier de modellen veel waarde aan de rol van emoties en gevoelens van bestuurders bij het nemen van beslissingen. Allen verwijzen in het bijzonder naar het idee dat emoties, weergegeven als onbewuste lichamelijke toestanden, een invloed kunnen hebben op rijgedrag zonder dat dit leidt tot bewuste gewaarwording (Damasio, 1994; Damasio, 2003). In het experiment dat in hoofdstuk 6 wordt behandeld is een poging ondernomen dit idee te toetsen, en ook hiervan is hieronder een samenvatting te vinden.

8.1 Hoofdstuk 3 Dat is snel genoeg

Zoals hierboven vermeld stelt Risk Allostasis Theory (RAT) dat bestuurders proberen een risicogevoel binnen geprefereerde marges te houden (Fuller, 2008; Fuller, 2011). Het model geeft ook aan dat oordelen over risicogevoelens en taakmoeilijkheid hoog gecorreleerd zijn en dat deze oordelen systematisch toe zullen nemen met toenemende rijsnelheid. RAT is de laatste versie van Task-Difficulty Homeostasis theory, en is deels gebaseerd op resultaten van experimenten waarin aan deelnemers werd gevraagd om taakmoeilijkheid, risicogevoelens, en de botskans te beoordelen na het bekijken van digitaal bewerkte video clips (Fuller et al., 2008).

Dit eerder uitgevoerde video experiment is vertaald naar een rijsimulator experiment. De rijsimulator geeft deelnemers de gelegenheid om het voertuig te besturen in plaats van slechts als passieve observator te kijken. Bovendien kregen de deelnemers op deze manier extra informatie met betrekking tot hun rijsnelheid. De resultaten leveren ondersteuning voor eerdere bevindingen dat oordelen over taakmoeilijkheid en risicogevoelens gerelateerd zijn en dat deze ook sterk gerelateerd zijn aan inspanningsoordelen en matig gerelateerd zijn aan oordelen met betrekking tot comfort en gewoonte. Echter, de in het videoexperiment gevonden systematische toenemende trend voor taakmoeilijkheid en risicogevoelens werd niet gevonden in de simulator: de resultaten daarvan leveren ondersteuning voor een "drempel relatie" waarbij risicogevoelens (het gevoel en de kans op het verliezen van controle/het krijgen van een botsing), moeilijkheid, inspanning, en comfort eerst een periode van stabiliteit doorlopen en pas gaan stijgen nadat een drempelwaarde overschreden is. Bestuurders geven er overigens de voorkeur aan om te verkeren in de periode van stabiliteit waarin de subjectieve ervaring van risico en taakmoeilijkheid laag of afwezig is.

Ook werd vastgesteld hoe kenmerkend men de snelheid vond waarmee men had gereden. Hieruit kwam een trend naar voren met een U-vormige relatie waarbij snelheden meer en meer als kenmerkend werden beoordeeld vóór de voorkeurssnelheid, en minder erna. Het lijkt erop dat dit aangeeft dat eerder gewoonte en het zich bewust zijn van de werkelijke rijsnelheid belangrijker zijn voor het kiezen van de rijsnelheid dan een andere variabele zoals risicogevoel.

8.2 Hoofdstuk 4 Dat is dichtbij genoeg

De bevindingen uit hoofdstuk 3 hierboven zijn in strijd met resultaten uit studies die zich richtten op de relatie risicogevoelens en taakmoeilijkheid met rijsnelheid (Fuller et al., 2008; Kinnear et al., 2008). Om die reden is de studie beschreven in hoofdstuk 4 gericht op een ander aspect van rijgedrag, namelijk de keuze van de volgafstand ten opzichte van een voorligger en de relatie hiervan met eerder genoemde subjectieve variabelen.

Om dit te onderzoeken reden deelnemers met 50 km/uur in een simulator achter een ander voertuig met een vaste volgtijd tussen 0.5 en 4.0 seconden. Na iedere rit werden een subjectieve beoordeling van taakmoeilijkheid, risico, comfort, en inspanning gevraagd. Ook werd aan de deelnemers gevraagd om op een voorkeurs volgafstand te rijden. Om vertrouwdheid vast te stellen reden deelnemers zowel aan de linker als rechter kant van de weg. Tenslotte werd rijervaring als factor onderzocht, zowel relatief onervaren als ervaren bestuurders werden getest.

De resultaten leverden verdere ondersteuning op voor een drempel-relatie van taakmoeilijkheid, risico, inspanning, en comfort met volgtijd. Deelnemers scoorden laag op deze subjectieve variabelen, maar de beoordeling begon rond de 2.0 seconden volgtijd toe te nemen. Het gevoel van taakmoeilijkheid, risico, en effort correleerden hoog met elkaar. Er zijn geen effecten gevonden van rijervaring of de kant van de weg waar gereden werd.

8.3 Hoofdstuk 5 Hou die snelheid vast

De studie in hoofdstuk 5 richt zich weer op de waarneming van subjectieve variabelen in relatie tot rijsnelheid. Ditmaal is zowel rijsnelheid als cognitieve belasting van de deelnemers gemanipuleerd. Aan deelnemers werd gevraagd om eerst gedurende één minuut op hun voorkeurssnelheid te rijden in een rijsimulator. Daarna werd hun snelheid automatisch verhoogd of verlaagd met 10, 20, of 30 km/uur, of bleef deze onveranderd. Hierna werd aan hen gevraagd om gedurende één minuut met een nieuwe snelheid te rijden. Na deze minuut werd de snelheid opnieuw aangepast en moest deze gedurende één minuut vastgehouden worden, maar ditmaal moesten ze ook een mentale reken dubbeltaak uitvoeren.

Tenslotte werd aan de deelnemers weer gevraagd om één minuut met hun voorkeurssnelheid te rijden. Deze procedure werd zeven keer herhaald, één keer voor iedere snelheidsmanipulatie; -30, -20, -10, +0, +10, +20 en +30 km/h. Na ieder interval van één minuut werd verbaal een oordeel gegeven over taakmoeilijkheid, inspanning, risicogevoelens, en hoe kenmerkend die snelheid voor hen was geweest.

De resultaten lieten een drempel effect zien in oordeel met betrekking tot taakmoeilijkheid, inspanning, en risicogevoel met snelheid, waarbij geen significant verschil werd gevonden tussen de oordelen gegeven gedurende de baseline periode en de experimenteel verlaagde snelheidsperioden tot het moment dat de voorkeurssnelheid werd overschreden.

Verder werd gevonden dat het drempel effect ook onder cognitieve belasting bleef bestaan, echter wel in afgezwakte vorm. Tenslotte lijkt het erop dat bestuurders die cognitief belast zijn moeite hebben een rijsnelheid aan te houden die lager is dan de snelheid waaraan ze normaal gesproken de voorkeur geven. Snelheden boven hun voorkeurssnelheid lijken makkelijker vol te houden, in ieder geval op de korte termijn.

8.4 Hoofdstuk 6 Heb je dat gezien?

Veel theorieën over rijgedrag stellen dat er een functionele rol is voor onbewuste of impliciete emoties die het rijgedrag bepalen. Om die reden is in deze studie het effect van gemaskeerde emotioneel geladen beelden op rijgedrag onderzocht met het doel inzicht te krijgen in de rol van dergelijke emoties. Terwijl deelnemers in de simulator reden, werden ze herhaaldelijk blootgesteld aan negatief of neutraal geladen verborgen beelden die "als een sandwich" gemaskeerd werden door emotioneel neutrale beelden. Deelnemers reden 3–4 minuten op een landelijke weg, en kwamen deze beelden gedurende twee ritten tegen.

Uit het experiment kwam een aantal volgorde effecten naar voren. Als de tweede rit verborgen negatieve beelden bevatte, was de afname in hartslagritme, de toename in hoge band hartslagvariabiliteit, en daadwerkelijke rijsnelheid geringer.

Afgezien van deze bevindingen waren er geen effecten van verborgen beelden op subjectieve inspanningsoordelen of risicogevoelens. Er was echter wel een effect van geslacht, waarbij het grootste deel van de gevonden effecten beperkt is tot de vrouwelijke deelnemers. Deze resultaten geven aan dat het heel goed mogelijk is dat onbewuste of impliciete stimuli rijgedrag kunnen beïnvloeden zonder dat dit leidt tot expliciete gewaarwording.

8.5 Discussie en conclusies

Uit de studies die gerapporteerd zijn in hoofdstuk 3–6, en die hierboven kort besproken zijn, kan een aantal conclusies getrokken worden. De eerste conclusie is dat de snelheid waarmee bestuurders rijden niet alleen een bewuste en beredeneerde keuze is. Het lijkt er meer op dat deze keuze, in ieder geval tot op zekere hoogte, bepaald wordt door automatische processen. Dat deze processen bestaan kan afgeleid worden uit het gedrag van cognitief belaste bestuurders, zoals beschreven in hoofdstuk 5. In dit geval blijken deze automatische processen wanneer iemand cognitief belast is de objectieve moeilijkheid van een taak te verhogen in plaats van te verlagen. Dat onbewuste processen een rol spelen bij snelheidsgedrag kan ook afgeleid worden uit de resultaten van de negatief geladen verborgen beelden studie uit hoofdstuk 6.

De bevindingen van de experimenten beschreven in hoofdstuk 3–5 geven ondersteuning voor de drempel relatie tussen de perceptie van subjectieve variabelen als taakmoeilijkheid, inspanning, comfort, botsrisico, risicogevoelens, en rijgedrag. Dit was echter niet het geval voor hoe kenmerkend men snelheden (hoofdstuk 3 en 5) of volgafstand (hoofdstuk 5) had ervaren. Deze variabelen hadden de neiging het meest reactief te zijn, en namen een U of V-vorm aan met de neiging dat de bodem van de curve de geprefereerde snelheid of volgtijd weergaf.

Het feit dat deelnemers goed in staat waren aan te geven wat kenmerkend was met en zonder feedback van andere subjectieve ervaringsvariabelen geeft aan dat deze andere variabelen wellicht niet het belangrijkst zijn voor het beslissen met welke rijsnelheid gereden wordt, of op welke afstand gevolgd wordt. Het is eerder zo dat deelnemers direct de informatie uit hun perceptuele systeem gebruiken en zich baseren op de huidige taakuitvoering.

Daarom geven de bevindingen in dit proefschrift ondersteuning voor modellen zoals the multiple comfort zone model (Summala, 2005; Summala, 2007). Dit is vooral te danken aan het feit dat dat model berust op daadwerkelijke rijgedragsparameters, zoals time-to-line crossing, en niet op het constant bewust zijn en monitoren van een bepaald gevoel of bepaalde gevoelens als de drijvende kracht achter beslissingen die bestuurders nemen.

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