The Role of Hazard Perception in Speed Choice

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Abstract

It is a fact that drivers' poor speed choices play a significant role in crashes, leading to many fatalities and injuries worldwide (WHO, 2012). Young novice drivers are about twice as likely to be killed in a speed-related crash than older, more experienced drivers (NZTA, 2017). We also know that novice drivers' hazard perception is often poor and predictive of crash likelihood (Horswill & McKenna, 2004), yet its relationship to their speed choices is virtually unknown. This thesis aimed to fill this critical gap.

The first step (Experiment 1) was to examine the ecological validity of a new laboratory-based video speed choice task, which was similar to the task developed by Horswill and McKenna (1999). The speed choices of two gender-balanced groups comprising 24 'Novice' drivers (mean age of 19.3 years) and 24 'Experienced' drivers (mean age of 29.5 years) were recorded. Participants were shown video clips of various urban and rural road situations filmed from a driver's perspective, and following each clip, asked to select the 'appropriate' speed they would feel most comfortable and safe travelling. An eye-tracker (SR-Research II) recorded their eye movements, which allowed for a detailed examination of drivers' visual search behaviour. Compared to the Experienced drivers, the Novice drivers chose significantly faster overall speeds and adapted their speeds to a lesser degree under the differing road, weather, and lighting conditions. Novice drivers predominantly focused their visual attention immediately ahead of the simulated vehicle, with rapid glances at salient visual features, while the more experienced drivers focused their visual search more broadly and further ahead to include inspection of roadside cues. Road markings were also found to influence drivers' speed choices, with the presence of clearly defined road-markings associated with higher speed choices. These laboratory-based results were consistent with what would be observed in real driving conditions based on data from naturalistic driving studies, real-world speed choice statistics, and crash data (Turner et al., 2014; Ministry of Transport, 2017). We concluded, therefore, that the speed choice task had considerable ecological validity.

In Experiment 2, we replicated the speed choice task conditions of the first experiment but added a separate video-based hazard perception task (Isler, Starkey, & Williamson, 2009), and tested 138 participants, divided into five gender-balanced groups based on age, experience, and licence type (mean age: 'Learner'= 16.5 years, ‘Restricted’= 18.8 years, and ‘Full (<25)’ licence= 23.2 years; ‘Full (25<50)’= 34.9 years, ‘Full (>50)’= 57.5 years). Our prediction, based on the reviewed literature (e.g., McKenna, Horswill, and Alexander, 2006), was that more advanced hazard perception skills would facilitate increased awareness of risk, prompting the selection of slower appropriate speeds. The results indicated that both the number of perceived hazards and hazard perception times significantly improved with experience as anticipated. Drivers’ chosen speeds, however, increased with age, with ‘Experienced’ drivers choosing faster speeds than novice drivers (‘Learner and Restricted’) and, to a lesser degree, ‘Full (>50)’, older drivers. This indicated that higher levels of hazard perception skills were often related to choices of faster speeds in the speed choice task, and this finding was unexpected. We concluded that it might be possible that experienced drivers only select slower speeds at the time when they become aware of immediate hazards. This hypothesis required further clarification, forming the basis of the rationale for conducting Experiment 3.

In Experiment 3, the same hazard perception task as in the second experiment was merged with the speed choice task to form an experiment measuring speed choices under the immediate influence of hazards. Two groups of participants, 52 ’Novice’ drivers (mean age of 19.9 years) and 37 ‘Experienced’ drivers (mean age of 37.4 years), were asked to select the speed they considered most appropriate immediately following each hazard perception trial. Visual search patterns were recorded using an eye-tracker. This time, longer hazard perception times were associated with choices of faster speeds. Overall, novice drivers showed less efficient visual search strategies when perceiving hazards, requiring about double the number of fixations to identify each hazard, but they also chose faster speeds than their more experienced counterparts. We concluded that if there is a causal relationship between improved hazard perception skills and speed choices, we might reduce drivers chosen speeds in Experiment 4 by improving hazard perception, particularly in novice drivers.

Experiment 4 consisted of two studies. In the first study, forty participants were randomly assigned either to a control group or a training group, each composed of twenty drivers ‘Novice’ (mean age of 16.6 years) and ‘Experienced’ drivers (mean age of 31.1 years). Both Novice and Experienced drivers showed significant improvements in hazard perception following road commentary, accompanied by a change in visual focus, compared to the control group. In the second study, we tested the hypothesis that improved hazard perception will lead to slower speed choices. Twenty-two participants, ten ‘Novice’ drivers (mean age of 21.3 years) and twelve ‘Experienced’ drivers (mean age of 29.1 years), were assigned randomly to either a control or test group. We found that immediately following the road commentary, the test group showed significant improvement in hazard perception skills and chose slower speeds compared to the control group.

In summary, this thesis revealed several significant new findings and insights, leading to a much better understanding of the underlying factors influencing speed choices of novice and experienced drivers. More efficient hazard perception was clearly related to choices of slower speed when hazards were presented within the speed choice trials, possibly mediated by visual search behaviour. There was strong evidence of a causal relationship when road commentary improved hazard perception and caused drivers to select slower speeds, directly influencing speed choices. Future research could investigate the potential for hazard perception to reduce speed choice in real-world traffic situations, especially for young novice drivers. The knowledge that improving hazard perception can influence safer speed choices is of great value for future road safety initiatives. Such research may be instrumental in the quest to decrease the number of speed-related crashes both in New Zealand and around the world.

Acknowledgements

FOR ELISE

AND IN THE MEMORY OF 'POPPA'

DOUGLAS GORDON STEVENSON

(1923 – 2019)

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Literature Review

The Kaimai ranges split the central North Island of New Zealand down the side like a great seam. Narrow roads weave throughout, connecting the coastal cities of the Bay of Plenty to the fertile Waikato planes. While accommodating the many commuters travelling between cities, the many corners and inclines of this route require drivers to carefully assess the road conditions with an acute awareness of tolerable speed. It was on one of these corners during the light autumn rain where a 19-year-old travelling at an excessive speed lost control of his vehicle and collided with an oncoming car. Despite the sudden force shearing his vehicle in two and showering the countryside with debris, the young man survived. The driver of the oncoming car was not as fortunate. The impact crushed the chassis, forcing the engine bay contents into the vehicle's interior. The crash provided sufficient energy to throw a quad bike in tow several hundred meters into a nearby paddock. The driver of the car did not survive. His name was John. He was my uncle.

Stories like this are commonplace, though their regularity does not make them trivial. The World Health Organization in 2012 indicated that more young people aged between 15 and 25 are killed in vehicle crashes than by drugs, alcohol, disease, or violence across the developed world. What makes many of these stories even more tragic is that there is often a significant amount of collateral damage and loss of life. Half of all fatalities on New Zealand roads are the direct result of the behaviour of another driver (Ministry of Transport, 2017). Speeding has been studied extensively, and millions, if not billions of dollars, have been spent on education and public safety campaigns and the development of infrastructure and enhanced enforcement. However, speed-related crashes continue to claim lives despite these interventions. Surprisingly, little research has focused on how visual risk factors, particularly hazards, are related to speed choice; and how this relationship changes with increasing driver maturity and experience. If understanding the characteristics that influence drivers' perception of risk and subsequent choice of speeds can reduce the number of fatal crashes, it is an essential, not merely academic, field of research.

The following literature review focuses on three key themes in the road safety literature; the Psychology of Speed Choice (p. 4), the Critical Skill of Hazard Perception (p. 33), and the Vulnerability of Young and Novice Drivers (p. 61), with age and experience as significant human factors related to crash risk.

The first section of the literature review focuses on how drivers select speeds, particularly the factors that make roads appear risky, and how these factors are related to drivers' perception of risk. Speed choice is one of the fundamental ways drivers balance the goal of reaching a destination against the risk of being involved in a crash. We will review how drivers frequently become accustomed to routinely travelling within a range of particular 'comfortable' default speeds and why drivers' ability to adjust their speed to suit the road and traffic situation is critical for safe journeys. We will examine several factors which may cause roads to appear more or less dangerous to drivers, the extent to which these factors influence drivers ability to perceive risk, and their willingness to accept and compensate for these changes through their choice of speed.

The second section of the literature review will examine the critical skill of hazard perception. Hazard perception is recognised as the greatest skill gap separating novice from experienced drivers and is defined as the ability to rapidly identify dangerous or risky traffic situations and anticipate how these situations may evolve. This literature review will focus on how hazard perception is acquired and how this skill becomes increasingly automatic with driving experience. Furthermore, as driving is a visually intensive task, drivers must efficiently detect and interpret the visual cues that precede a change in risk. In this respect, hazard perception requires drivers' visual attention, and the deliberate allocation of cognitive resources. Hence, the literature will focus on the importance of strategic and active visual search as a necessary component of safe driving.

The final section of this literature review will focus on the vulnerability of young and novice drivers. Young novice drivers typically have under-developed hazard perception and visual search abilities and are over-represented in speed-related crashes. These deficiencies are often the consequence of a lack of quality driving experience and factors related to pre-frontal maturation. We will review how the many emotional and cognitive changes occurring during adolescence predisposes these young drivers to greater risk-taking and errors while driving.

These three areas, which we will cover in the literature review, have individually received considerable focus within the psychological study of driver behaviour. While it seems reasonable to assume that speed choice and hazard perception are related, there is an intriguing absence of scientific examination of this potential relationship in the road safety literature. Given this absence linking the most critical driving skill of hazard perception to a significant cause of fatal crashes - speed choice - a thorough scientific investigation is needed to understand how these two critical factors are interrelated. Understanding how hazard perception may influence drivers' speed choice could mark an essential step towards mitigating drivers involvement in speed-related crashes.

The Psychology of Speed Choice

Speed is one of the most important determining factors in predicting the likelihood and severity of a vehicle crash. Elvik et al. (2004) have noted that speed probably has a more substantial effect on road safety than any other known risk factor. As vehicle speed increases, there is an exponential increase in the likelihood that a serious crash resulting in loss of life will occur. Hence, determining the factors contributing to speeding is of utmost importance (Berry, Johnson, & Porter, 2011), particularly for New Zealand roads[1].

The factors identified relating to drivers' choice of speed are complex and range from perceptual, behavioural, emotional, attitudinal to cognitive in explaining why drivers speed. It is not surprising then that Berry, Johnson, and Porter (2011) suggested that defining the specific factors contributing to poor speed choice is challenging - if not impossible - to quantify fully. Considering this fact, it is certainly outside the scope of this literature review to exhaustively examine all the factors contributing to speed choice. However, as driving is an intensely visual process, with a significant proportion of the information that drivers rely upon being visual (Rogé et al., 2004), visual factors will be a point of emphasis in this thesis.

Researchers examining the human factors in transport psychology have argued that understanding crashes requires a holistic system-based approach that examines the vehicle, road, and driver as contributing factors. While technically accurate, simply citing human error as the primary cause of crashes overlooks the many contributing factors that precede a crash (Charlton, Alley, Baas, and Newman, 2001). In discussing the potential for speed-reducing perceptual countermeasures, Charlton and O'Brien (2001) emphasise the importance of visual behaviour as an essential human factor contributing to inappropriate speeding that may result in a crash.

Some researchers have categorised the factors between novice and experienced drivers that contribute to increased crash risk as either related to the style of driving (e.g., willingness to speed) or driving skill which is a function of experience (e.g., hazard perception). Driving style refers to how drivers choose to travel based on their

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[1] Around the time of publication, road speed limits were under serious scrutiny in New Zealand, with about 80% of roads not matching the calculated threshold of a 'safe and appropriate' speed. The New Zealand Transport Agency (NZTA) recommended that the speed limits on open arterial roads be reduced, and particularly, roads which were rated as high-risk or associated with multiple crashes. The NZTA's suggestion was that only 5 percent of open roads should have a 100km/h speed limit, with most roads requiring a recommended reduction of speed limits to 60-80 km/h, and an appropriate speed in most urban areas of 30-40 km/h rather than the current 50km/h (NZTA, 2019). This makes the subject of speed choice particularely relevant within a New Zealand context.

attitudes, preferences, personality, and beliefs towards risky behaviours (Bianchi & Summala, 2004; Taubman-Ben-Ari & Yehiel, 2012; Zimbardo et al., 1997). Driving skill, by comparison, refers to the factors that contribute towards the performance of the driving task, and notably, the capacity to detect hazards and respond appropriately. Driving skill is thought to increase as drivers become more experienced (Elander et al., 1993; Horswill, 2016). Elander et al. (1993) note that driving style is established during the early years of driving. While driving style accompanies the development of skill, it does not necessarily become safer with experience.

Speed choice has been conceptualised as an outgrowth of driving style, and this is not unjustified, as many adolescent drivers accept high speed related risks and have riskier attitudes towards speeding contrasted with more mature drivers (Cantwell, 2010). Risky behaviours and lenient attitudes towards risk when driving have often been associated with adolescence and the 'problem young driver' (Scott-Parker et al., 2013). Many studies indicate that speeding behaviour declines in frequency over time and generally stops once these drivers enter adulthood (McNally & Bradley, 2014). Some researchers have considered that the changes that occur with increased driving experience shift the way motivational factors, task performance, and driving competence influence drivers on-road behaviour (Kuiken & Twisk, 2001). Novice drivers' subjective perception of control over the driving situation through vehicle handling (e.g., task performance) may be disproportionately higher than their actual capability. It is thought that this gap between actual and perceived ability may close with increased experience and maturity.

Personal and motivational factors, such as the desire to gain peer approval or a predisposition toward sensation seeking, may exert a severe adverse influence on drivers' attitudes toward speeding and their subjective perception of control. These adverse influences may mean that young drivers are less responsive or may even be oblivious to the actual risks present, leading to greater crash-likelihood (de Craen, 2010). This lack of awareness may be why novice drivers accept greater risk. As hazard perception skills increase with experience, drivers can become more aware of risks in the road and traffic situation, encouraging them to reduce their speed (Wilde, 1982; Fuller, 2005).

This section will examine the factors contributing to poor speed choices, including the role of road characteristics related to the perception of risk, how drivers' speed habits develop over time, and how drivers' view of the road influences their speed behaviour.

Speed Choice and Risk-Appraisal

While many theories have attempted to explain how drivers choose speeds appropriate for the conditions[2], two principal approaches will be reviewed. These risk-management theories provide a framework for understanding how individual differences and developmental factors elevate drivers' willingness to engage in risky driving. Risk in driving has been described as "the subjective experience of risk in potential traffic hazards" (Deery, 1999, p. 226), which is determined by a drivers ability to process and appraise information related to the potential hazards and traffic environment (Brown & Groeger, 1988).

A review of the literature suggests drivers make speed choice decisions based on essentially three factors. First, the riskiest speed which a driver can travel according to the risk they are willing to accept (Wilde, 1982). Second, the safest speed the driver believes is best suited to the conditions (Näätänen & Summala, 1974); and third, the most pleasurable speed where the driver receives the most enjoyment (Musselwhite et al., 2010; Vaa, 2007). Some researchers have examined drivers' speed choice based on their responsiveness to the level of acceptable risk and how influential personality variables are to driving behaviour (Fuller et al., 2007; Stradling et al., 2020). This has often resulted in speed choice being considered more a style of driving than a trainable skill, as speed is often examined within the context of personality factors. Indeed, while speeding is an issue in driver training, it is often considered more enforced than learnt (ECMT., 2006). In considering the term, 'speed choice' implies that drivers make a conscious or deliberate decision (i.e., a choice). While this is undoubtedly the case for drivers who undertake deliberately risky driving, it neglects the fact that many speeds are simply the outcome of learnt habitual behaviours (Charlton & Starkey, 2011; De Pelsmacker & Janssens, 2007). Due to conceptualising speed solely as a choice, speed has often been examined in light of driving style, which

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[2] For an excellent – albeit dated – survey of models of risk-taking, I refer the reader to the article by Michon (1985). Additonally, Ben Lewis-Evans (2011) conducted a thorough test of several models of risk-appraisal in his widely published doctoral dissertation.

involves their attitudes, beliefs, and values (Stephens et al., 2015; Stradling et al., 2020).

Broadly reviewing the relevant literature, the consensus among researchers is that drivers frequently rely on their own personal judgements and what can be considered ‘acceptable risk’, irrespective of the theoretical perspective of risk-taking. However, there is no consensus concerning risk-taking models, mainly due to a lack of understanding of how human emotion and cognition interact. The concept of a threshold of acceptable risk is foundational in the overwhelming majority of models, describing the level of risk a driver is willing to accept and act within (Näätänen & Summala, 1974; Wilde, 1982). These models assert that drivers select the amount of risk they are willing to tolerate and control the traffic situation through deliberate action, such as slowing down (Fuller, 2005). Drivers selection of speed to manage traffic risk seems reasonable, given that driving is primarily a self-paced activity and risk-acceptance is mainly at the driver's discretion.

Wilde’s (1982) Risk Homeostasis Theory

One of the earliest and well-known theories developed to understand risk-taking is Risk Homeostasis Theory (RHT), initially proposed by Taylor (1964) and developed by Wilde (1982). Risk homeostasis generally suggests that drivers select their speeds in line with perceived risk, continually maintaining a balance between the dangers in the situation against an acceptable subjective level of risk. In Näätänen and Summala (1974) ‘zero-risk theory’, the level of acceptable risk is effectively zero, and drivers continually strive to diminish risk as much as possible. In risk-homeostasis, drivers have an individual and subjective level of acceptable risk determined by personal attitudes, beliefs, and human factors such as self-perceived skill and emotional state. While several variations have grown out from risk homeostasis theory over the years, we will consider the original theory, as this is both well-known and simple in its formulation.

One popular analogy used to explain risk homeostasis theory is considering the function of a thermostat on an air-conditioning system. In order to maintain a consistent temperature, as the temperature rises above a certain level, the system begins to cool the room, and if the temperature drops, the air-conditioning heats the room so that the average temperature remains stable over time (Shinar, 2007). In homeostatic risk models, there is a central adjustment ‘comparator’. This cognitive mechanism weighs subjectively perceived risk from the current traffic and road situation against the driver's preferred, acceptable level of risk. The risk homeostasis model proposed by Wilde (1998) is represented in Figure 1:

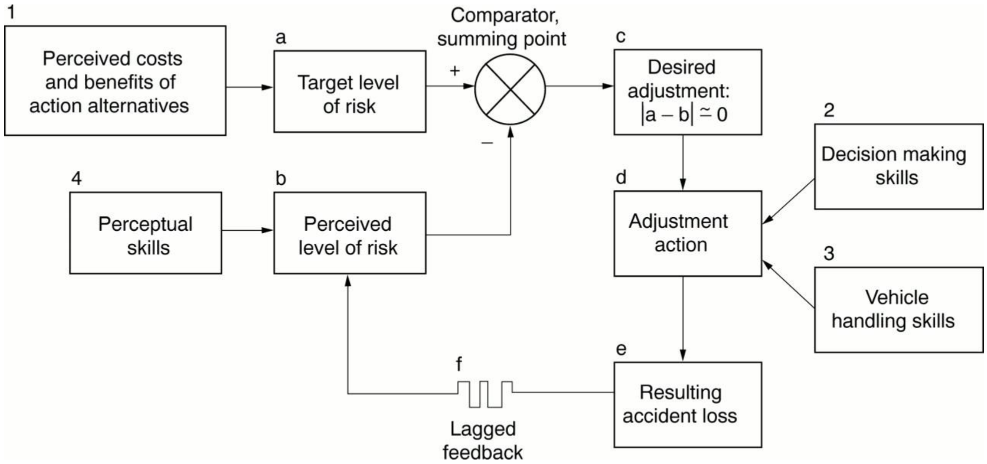

Figure 1: A diagrammatic representation of Wilde's Risk Homeostasis Model

This mechanism regulating risk needs to continuously monitor the level of risk for the theory to hold (much like the continual monitoring of the thermostat on the air-conditioner). One of the significant criticisms of risk homeostasis (e.g., McKenna, 1990) is that the comparator mechanism requires drivers to have an unreasonably comprehensive and continually updated awareness of situational risk, which would require excessive perceptual and cognitive resources.

While there is a certain sense that risk homeostasis is reasonable and even natural, considering that many regulatory systems in the body function in similar ways nevertheless, the theory has also received a great deal of criticism. The strongest criticism is primarily based on Wilde's (1998) supposed selective usage of crash statistics to validate his argument, discounting unfavourable evidence of effective interventions as the outcome of a natural trend in the reduction of accident casualties (McKenna, 1990; Robertson, 2002; Wilde, 2002). Furthermore, according to McKenna (1987, 1990), the theory ultimately paints a bleak prospect for any preventative measures. As drivers will always compensate as roadways and vehicles are made safer, the only effective method to change drivers' speed, according to risk-homeostasis theory, would be behavioural modification through enforcement.

Despite these criticisms, the concept of risk-homeostasis is not without its merits, as Wilde's theory accounts for the role of experience. As experience is gained, drivers' perceived acceptable risk levels might be lowered (safe calibration) as they identify more danger in complex traffic situations. Novice drivers may have a very low level of acceptable risk due to the lack of basic driving competence and may drive with extreme caution while their confidence level is low. However, as car handling skills are acquired relatively quickly, this can over-inflate young drivers' confidence (deCraen, 2010). Over-confidence fuelled by sensation-seeking may result in a higher acceptable risk level that exceeds the drivers' actual competence (unsafe calibration). Consequently, poorly calibrated drivers may choose speeds that are much faster than they might be able to manage (de Craen, 2010; Rosenbloom et al., 2008).

For the most part, driving is a ‘self-paced task’, in that drivers can control the demands of the driving situation to align with personal goals and predictions of how traffic events will unfold. This gives drivers a certain ability to determine how difficult or risky the traffic situation can become by adjusting their driving behaviour. It is thought that drivers typically try to balance the demands of the situation against their competencies to maintain the stability of the system, which leads us to consider Fuller’s (2005) Task-Capability Interface theory.

Fuller’s (2005) Task-Capability Interface Theory

The Task-Capability Interface (TCI) theory was developed by Fuller (2005) to account for the evolving concept of driving as a process that requires attentional resources. In Fullers’ theory, a crash may result when the demands of the situation exceed the driver’s capability to manage the situation. When the driving task demands are within the driver’s ability to manage them, they feel a sense of safety (Fuller, 2005, 2008). However, as the driving situation becomes more demanding of the driver’s capabilities (e.g., increased traffic), there is a compensatory response where the driver adjusts their behaviour to reduce the task demand (e.g., slowing down). If the task demands exceed the driver’s abilities, loss of control may occur, and a crash is more probable as the driver may be prone to errors or lapses in judgement or mishandling of the vehicle (e.g., overcorrected steering). Fuller et al. (2007) examined why drivers selected ‘inappropriately high speeds’ from a review of ten years of crash statistics across the United Kingdom and noted that drivers overestimation of capability, or underestimation of task demand, may lead drivers to interpret the driving task to be more comfortable than it is objectively. This misidentification of demands against ability may cause drivers to view posted speed limits as lacking credibility and potentially resulting in dangerous speed adjustments to compensate for lower perceived risk level.

Central to Fuller's Task-Capability Interface theory is the driver's speed choice. Fuller (2005) considered that speed choice is both a task demand and the driver's primary method of regulating a stable level between their capabilities and the driving task demands. Fuller reasoned that the drivers' ability to regulate the amount of risk in the driving situation was primarily controlled through the drivers' choice of vehicle speed. Fuller's Task Capability Interface model is represented diagrammatically in Figure 2. Researchers have used speed choice as a proxy measure for risk-taking or risk-acceptance because of this close relationship between drivers' speed choices and perceived risk in the traffic situation. For example, using a video-based task, Horswill and McKenna (1999) found that drivers' choice of speeds was a good indicator of their willingness to engage in risky driving behaviour. Drivers who chose faster speeds have a higher probability of having been previously involved in a speed-related accident.

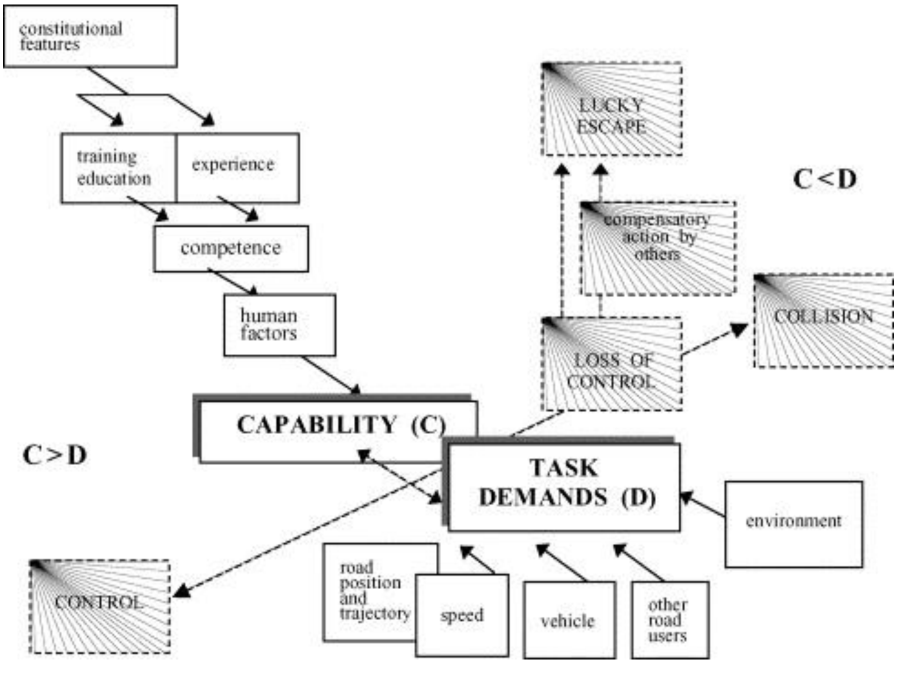

Figure 2: The TCI Model as proposed by Fuller (2008) with an indication of the various factors that could add to the Task Demands (D) or to Driver's Capability (D). If C>D, the driver is in control. If C<D, the driver is in danger of losing control.

As shown in Figure 2, factors such as the road condition and traffic situation, as well as personal variables (e.g., fatigue, emotions such as anger), are in a state of continual fluctuation, there is the need for a compensatory feedback mechanism similar to the comparator in Wilde’s (1998) theory. Consequently, the target level of risk can change as external and internal demands increase or decrease. Speed then is an essential safety-related factor to consider when examining driving behaviour, as it acts both as a predictor of crash likelihood and the main method drivers’ use to regulate their level of risk in the traffic situation (Elvik et al., 2004). An example of this relationship between speed and perceived risk is that the corresponding stopping distances dramatically increase as vehicle speed increases. This means that the driver must be vigilant for risk factors that may require urgent braking, such as encountering a hidden queue of vehicles or changing traffic signals (Terry et al., 2008).

The initial conceptualisation of Fuller’s (2011) TCI theory required that drivers’ perception of risk or task difficulty linearly increase as speed increased. However, this formulation was subject to the same weakness Wilde’s (1982) risk-homeostasis theory had been criticised. Namely, drivers need to continually experience incremental changes in the feeling of risk – that is, have an unreasonably and continuously revised feeling of risk that increases co-linearly along with speed. Due to this weakness, Fuller et al. (2008) revised the theory so that drivers’ perception of risk remains stable until a certain threshold is reached, providing a range of acceptable speeds where drivers feel comfortable (Fuller et al., 2008). This reformulation was more in line with the zero-risk theory proposed by Näätänen & Summala (1974), which held that drivers possessed a threshold of acceptable risk.

Lewis-Evans (2012) replicated the study by Fuller et al. (2008), finding that drivers had a preferred comfortable range for speeds, within which they felt safe. Only once vehicle speed exceeded these comfortable speeds did the drivers report feeling increasingly uncomfortable with faster speeds. This finding indicated that feeling of risk does not increase in a linear relationship to speed, but the perceived risk remains stable with speed, and only increases after drivers speed exceeds this threshold (Lewis-Evans. 2012; Fuller et al., 2008). From his simulator-based work, Lewis-Evans (2012) determined this comfort threshold for acceptable speed to be approximately 50km/h in urban settings and 110km/h in open-road settings for the average New Zealand driver.

One of the main advantages of Fuller’s (2005, 2008) theory is that it includes the driver as an essential human factor as part of the equation in understanding why drivers speed. Drivers vary in the amount of driving experience, and this has a significant role in the amount of task-demand the driver can accommodate before the driving task becomes too difficult. For example, when a driver is still learning as a novice, task demands such as basic vehicle handling (e.g., steering control) are at the threshold of the drivers' capabilities. Consequently, many novice drivers often practice on quiet urban streets when there are low traffic levels and excellent visibility. As drivers gain experience, they become more comfortable in adding additional task demands, such as coping with greater amounts of traffic, or driving at night. However, this gain in comfort with experience, despite increases in task demands, can mean that drivers underestimate the risks of specific tasks such as using a mobile phone while driving.

Theories of risk-appraisal such as Risk Allostasis based on the balancing of task-demand and feeling of risk can account for divided attention that drivers often experience. Drivers' can reduce their speed and the corresponding workload, which allows them to allocate the released cognitive resources to a secondary task such as using a mobile phone (Shinar et al., 2005).

Fuller (2005) suggested that drivers experience changes in risk as a 'feeling' (i.e., akin to a gut instinct) and that drivers are motivated by this feeling to maintain a level of task demand within the boundaries of what is comfortable. For instance, research conducted by Varotto et al. (2018) indicated that when task difficulty or perceived risk exceeded acceptable levels, drivers will take manual control of a vehicle's speed rather than rely on cars' inbuilt dynamic cruise control. The willingness for a driver to assume control from an in-vehicle radar-based system was most noted in scenarios where there was a higher perceived level of risk, such as driving on motorways where there are multiple lane transitions and significantly denser traffic.

Varotto et al. (2018) also observed that drivers had different minimum and maximum acceptable-risk thresholds. For example, drivers who self-reported as having a patient and careful driving style had a smaller range of acceptable risk. Hence, careful drivers take manual control of vehicle speed when the feeling of risk is higher in low-risk situations and when the change in feeling is lesser in high-risk situations. This suggests that drivers can vary substantially in the levels of risk they are willing to accommodate into their everyday driving behaviour. While Varotto et al. (2018) study had an immediate application for enhancing comfort and acceptability with automated vehicle control systems, it also lends significant support to Fullers (2011) development of a 'feeling-based approach' to risk-taking. This somatic or feeling-based approach to risk-appraisal is known as allostasis, the process where stability in the level of risk in a situation occurs at a physiological level between feelings of comfort and discomfort in response to changes in perceived risk. Allostasis theories have the advantage in some respects over other theories of risk-taking in that the psychophysiological state (i.e., arousal level) of the driver plays an important role.

Risk-appraisal has been conceptualised as both an outcome of an analysis at a conscious level of awareness using reasoning and logical evaluation, but also through the experience of risk as a feeling (Loewenstein et al., 2001; Slovic et al., 2004). For instance, Epstein (1994) observed:

> … people apprehend reality in two fundamentally different ways, one variously labelled intuitive, automatic, natural, non-verbal, narrative, and experiential, and the other analytical, deliberative, verbal, and rational. (p. 710)

Fuller (2011) developed earlier concepts of feeling-based theory into the Risk Allostasis Theory (RAT), in which the role of emotion and visceral feeling (i.e., somatic markers) play a more integral part in determining drivers behaviour. Fullers (2011) theory of Risk-Allostasis is shown in Figure 3:

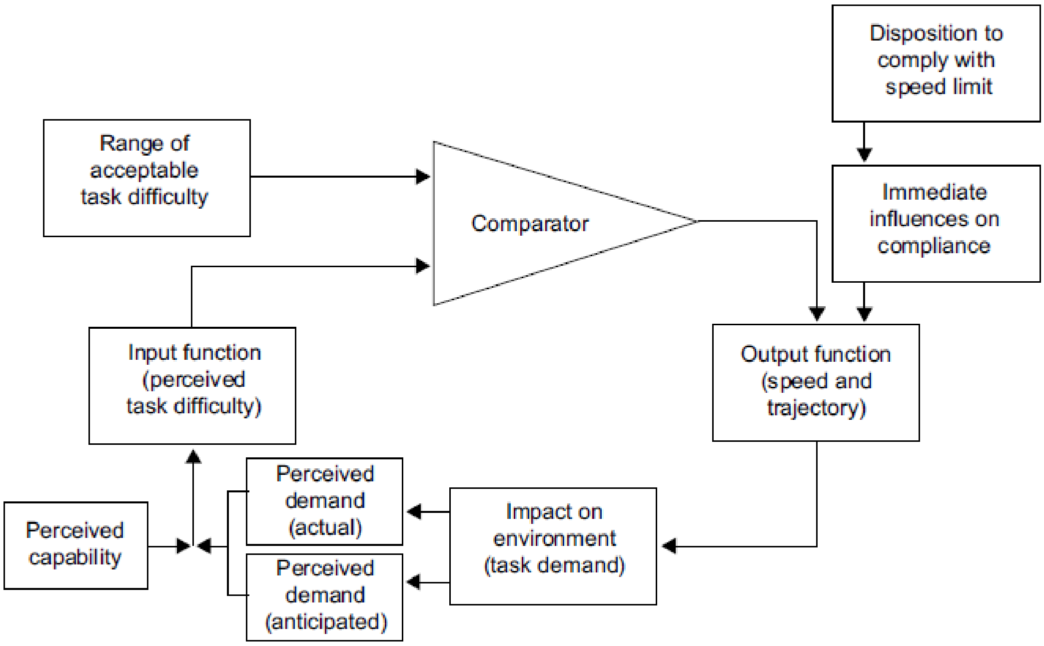

Figure 3: Fuller's (2011) representation of Risk Allostasis Theory, in an application concerning driver’s willingness to comply with Speed Limits (from Porter, 2011).

The inclusion of drivers feeling of risk in extending Fuller’s (2011) Task Capability Interface functions similarly to its predecessor while incorporating drivers' felt sense of risk. While a threshold of risk may challenge the concept in allostasis theories that risk is processed in a subconscious emotional loop, it is reasonable to consider that the physiological perception of risk is not easily interpreted or mapped by drivers onto a conscious scale.

Fuller (2011) considered speed choice to be either the outcome of feelings of fear (which directs the driver to reduce speed) or frustration (which encourages the driver to increase speed). This theory was tested by Kinnear (2009) in measuring the physiological response that accompanies response to hazards.

In one experiment, Kinnear (2009) showed three groups of participants with differing degrees of experience video clips containing hazardous traffic scenarios while measuring skin conductivity as a measure of their physiological response to risk. Additionally, participants were able to represent their perceived danger in the traffic scenes using a sliding scale, ranging from 'safe' (1) through to 'hazardous' (10), which provided a measure of their cognitive appraisal of risk. Kinnear found that while there was no difference between the three groups' cognitive evaluation of risk, there was a significant difference in the physiological responses during the anticipatory stage, just before the hazard occurred. Kinnear (2009) found that the experience of risk-feelings, measured by skin-conductance, was not observed in novice drivers who had less than 1000 miles of total on-road driving experience. Only once drivers had accrued sufficient driving experience did they show changes in physiological arousal corresponding to increases in risk.

Kinnear's research indicated that there is an aspect of risk-appraisal that is perceived as a gut feeling (e.g., somatic marker), consistent with the rapid cognition that allows for the almost instantaneous and effortless detection of danger before its presence enters conscious awareness (Kinnear et al., 2013; LeDoux, 1998, 2003). This rapid subconscious process is continually operating, informing our conscious (higher-cognition) perspective of the world, and is capable of assuming control over conscious processes in the event of an emergency, assigning top priority to self-protective actions (Kahneman, 2011). While this is a critical adaptation and is usually highly efficient and accurate, it is not free from erroneous judgments (Wickens et al., 2008).

While it is outside the scope of the current thesis, the role of emotional wellbeing has recently become of interest, as emotional dysregulation can reduce a drivers mental resources and sensitivity to risk, increasing the likelihood of being involved in a crash (Isler & Newland, 2017; Zimasa, 2018; Zimasa et al., 2017). Young drivers are particularly vulnerable, both due to inexperience as well as the effects of neurological maturation (Scott-Parker, 2017; Scott-Parker & Weston, 2017).

What Factors cause a Driver to Perceive a Road as Risky?

Within Fuller's (2005) theory, driving demands are easier to quantify than in Wilde's (1998) risk-homeostasis model. Demands on the driver may be a human factor unique to each driver, such as the amount of driving skill or experience, mental and emotional states, attitudes, fatigue, or the influence of drugs or alcohol. Demands are also external and involve factors related to both the vehicle (e.g., braking and acceleration, drivers field of view) and the road environment, such as road condition, weather, illumination, traffic, lane width and markings (Charlton, 2007; Shinar, 2007). As discussed previously, a growing base of evidence supports an allostasis model of risk-assessment, as drivers physiological state changes when the perceived difficulty or task-demand increases (Kinnear & Stradling, 2011). As suggested by Fuller (2011); Fuller et al. (2008), drivers typically counteract increased task-demand by reducing speed, such as while negotiating intersections (Liu & Lee, 2005) or narrowing roadways (Lewis-Evans & Charlton, 2006; Uzzell & Muckle, 2005).

Extensive research has found that specific fixed road characteristics, such as the presence of a median strip and barriers, influence drivers' perception of speed and subsequent speed choice (Elliott et al., 2003). Many aspects of the road environment, such as the presence of buildings and parked vehicles, interact to influence vehicle speeds, with increased roadside activity being a strong determinant for drivers to choose slower speeds. Increasing the visual complexity of the road environment (e.g., buildings and cars parked parallel to the road) has been found to reduce drivers speed choices, likely by increasing the visual and cognitive load, with higher perceived risk playing an important role (Charlton & Starkey, 2016; Elliott et al., 2003; Wilmot & Khanal, 1999). Edquist et al. (2011) investigated the role of visual cues on speed choice, where participants were required to drive on simulated roads with varying numbers of on-street parked cars. They found that as the complexity of the traffic environment increased, drivers tended to select slower speeds. They suggested that this effect on drivers' speed choices could be related to potential hazards to be present but obscured (e.g., hidden pedestrians) when there were more parked cars (Edquist et al., 2011).

It has also been observed that changes in lane width can influence driver's perception of risk, which results in changes to the speed they are willing to travel (Godley et al., 2004; Melman et al., 2018). Weller, Schlag, Friedel, and Rammin (2008) found that the presence of certain road characteristics, such as shoulders (e.g., margins) and clear lane-markings, significantly influenced drivers' perceptions of how 'demanding' and 'comfortable' the road will feel about travelling on. For example, several studies have found that narrow shoulders lead drivers to be more cautious and slow down in compensating for greater perceived risk (Stamatiadis & Council, 2009). While physical characteristics of the roadway are fixed and unchanging, many visual cues may influence speed choices that do change at different times, such as weather conditions, illumination, and the presence of pedestrians and other road users (Royal, 2003; Yannis et al., 2013). For instance, Konstantopoulos et al. (2010) found that learner drivers had degraded visual performance when driving in simulated rain compared with expert driving instructors, providing support for the notion that wet-weather driving is more demanding on the driver.

In support of the premise that particular road (lane) characteristics influence drivers behaviour, Lewis-Evans and Charlton (2006) conducted a simulator-based study in which participants drove on several simulated roadways of varied lane width and road-margin size. Participants were also presented with images of the simulated roadways and asked to rate the level of risk for each, along with the speed they would feel most comfortable driving. The results from the simulated roadways showed that drivers selected slower speeds on narrow roads and faster speeds on wider roads. Risk ratings showed that drivers rated the risk highest for narrow roads and lowest for wide roads. Lewis-Evans and Charlton (2006) noted that more than half of the participants failed to identify lane width as one of the variables being manipulated in the experiment. This finding indicated that risk-appraisal was an implicit perceptual process occurring at a subconscious level and not an explicit, conscious decision (Lewis-Evans & Charlton, 2006). Their finding supports Fullers (2011) theory that the 'feeling of risk' (i.e., somatic markers) occurs below the level of conscious awareness (or preconscious as some drivers become acutely aware of the sensation after the fact), which has also been observed by Kinnear et al. (2013).

Lewis-Evans (2012) analysis revealed a threshold for comfortable speeds across different simulated roadways. Despite comparing residential roads to dual carriageways and noting that the feeling of risk and loss of control increased rapidly on the residential roads compared with non-residential roads. However, in his study, Lewis-Evans (2012) did not address the role that perception of hazards might have played in drivers speed choices. While the effect of lane-width concerning speed choice and the feeling of risk has been well examined, it is not well-known what role the presence of hazards might have on speed choice. Based on the somatic-marker component, which is at the heart of the allostasis theory proposed by Fuller (2000), hazards themselves may be good predictors of drivers behaviour by triggering somatic responses corresponding to the perception of fear or discrete change in the level of risk.

The presence or absence of hazards in a traffic and road situation could be conceptualised as a difference in the amount of complexity. That is to say, the number of features a driver may be required to represent and anticipate mentally. Elliott et al. (2003) found in their review of speed countermeasures that as a general principle, drivers perceived an increase in cognitive load and situational risk when the environment was more complex, and drivers correspond by reducing their speeds.

Currently, several countries have attempted 'shared spaces', which are areas where traditional roads are turned into a setting where vehicle drivers as well as other road users such as cyclists and pedestrians (Hamilton-Baillie, 2008). Analysis of the way different road users navigated these 'shared spaces' was performed by Schönauer et al. (2012). One finding was that drivers largely accommodated the other road users, and with greater complex factors to consider in the space, as well as the best means to negotiate other users in reaching the destination, drivers selected slower speeds (Schönauer et al., 2012)

As previously discussed, in order to evaluate and respond to risks in making appropriate speed judgements, drivers need to be adequately informed through the perception of both static (e.g., road surface) and dynamic (e.g., traffic, pedestrians) hazards (Aarts & van Schagen, 2006; Royal, 2003). Both Renge (1998) and McKenna et al. (2006) found that accumulated driving experience was related to slower speed choices. This might demonstrate a schema[3] that dynamically controls speed for changes in the traffic environment. However, this system does not always function adequately. For example, Renge (1998) observed that drivers chose faster speeds under night driving than daytime conditions. Under night conditions, participants noticed fewer hazards, which may have influenced their reduced perception of risk. Furthermore, crashes occurring at night-time are four times more likely to involve

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[3] A schema is a basic element of knowledge (such as a rule) as conceived by Cognitive scientists. As the brain is exposed to repeated information, it develops cognitivly economic ways of processing that information – and schema are a simple way of handling that information efficiently (Gazzaniga, 2009). More can be found in Appendix 12.

fatalities compared with day-time driving, despite the lower number of vehicles on the road (Clarke et al., 2006).

Speed Choice and the Credibility of Speed Limits

The credibility of the speed limit has been shown to have an important relationship to how likely it is for drivers to comply with said speeds, and ensuring that road limits are credible is a significant problem[4], both internationally as well as in New Zealand (Starkey et al., 2017; Turner et al., 2014). As the crash rates on both rural and urban roads are elevated for young and novice drivers, further research may be beneficial in determining how drivers' visual search and the perception of specific cues relates to speed choices for different road conditions.

While numerous factors influence drivers' speed choice, such as road geometry (Savolainen et al., 2016) and markings (Godley et al., 2004), drivers perception of risk seems to be one of the critical determinants of how credible the speed limit is perceived to be and the likelihood that drivers will comply with said limits (Wilmot & Khanal, 1999; Yao, Carsten, Hibberd, et al., 2019). In a study conducted by Yao, Carsten, Hibberd, et al. (2019), the relationship between drivers perception of risk and the credibility of speed limits was examined using multiple hierarchical regression upon drivers speed selection in a simulator. It was found that as drivers' perception of risk increased, drivers comply more with the speed limits. However, when drivers do not perceive the roads as risky, they tend to view the road speed limit as less credible and are more likely to speed (Yao, Carsten, Hibberd, et al., 2019). Yao, Carsten, Hibberd, et al. (2019) go on to propose that this is in keeping with the allostasis theory proposed by Fuller (2011), who suggested that drivers consider the feeling of risk and task-demand when making judgements.

Credible roads are those in which the drivers' perception of risk at a certain speed is under the speed limit threshold, which has important implications for road design. The road geometry usually establishes the speed limit. The general rule is that the limit is based on the 85th percentile of free-flowing vehicle speed and is often based on the safest speed determined for the highest-risk section of road (Stamatiadis & Gong, 2004). The shortcoming of using this approach to *design speed* is that it assumes

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[4] As many factors determine whether a speed limit is credible, dynamic speed limits have been introduced in New Zealand, with a digital speed sign displaying slower speeds at certain times of day (e.g., reduce speed during school recess) and under certain road conditions (e.g., slower speeds in wet or fog conditions). While effective to an extent, dynamic speeds are a costly intervention, and impractical to use on a large scale.

that drivers will be provided with adequate information to base an appropriate speed; in other words, the road is assumed to be self-explaining. However, as sections of the road can vary in the level of objective risk, this can lead to inconsistencies in what drivers perceive to be credible and inconsistencies in speed limits between similar-appearing stretches of road (Stamatiadis & Gong, 2004). Suppose the speed limit of a road is not supported by the features of the road and characteristics of the traffic environment. In that case, countermeasures may be needed to match the road with a credible and safe speed limit (Yao et al., 2019b). In New Zealand, a significant proportion of roadway developed before 1985 was under a regime of limiting speed to 80km/h, and although sections of road have been upgraded since, many roads remain with limitations to what can be considered safe, with many New Zealand drivers travelling too fast on open roads (ACC, 2000). In this regard, most drivers tend to favour reducing speeds on urban and suburban roads but are less likely to agree with speed restrictions on motorways (SARTRE, 2004).

In one study investigating the reduction of speed at road-works, Gardner and Rockwell (1983) found that drivers were more likely to select a speed they considered appropriate rather than conform to the posted speed limit. Mustyn and Sheppard (1980) found that the majority of drivers indicated they drove at a speed that the road conditions permitted, irrespective of the speed limit. Goldenbeld and van Schagen (2007) indicated that as road conditions change, drivers may view the speed limit as being more or less credible and may consequently exceed the speed limit under circumstances where they consider the posted speed limit to be a poor indication of actual safe speed to maintain control of the vehicle (Aarts & van Schagen, 2006). The key finding of these researchers is that drivers tend to rely on their personal judgements based on their perception of safe speed regardless of speed limits (Gardner & Rockwell, 1983; Goldenbeld & van Schagen, 2007; Haglund & Åberg, 2000), with the notable exception being when there is an increased presence of enforcement (Wegman & Goldenbeld, 2006).

Previous research investigating drivers speed choices under different road and traffic conditions has shown that drivers judgement (or perception) of appropriate speed is related to age and the amount of driving experience, and likely, a corresponding sensitivity to risk and credibility of speed limits. Cantwell (2010) examined the speed choices of New Zealand drivers across a selection of different commonly encountered road types using a video-based task similar to that developed by Horswill and McKenna (1999). The study's findings indicated that ‘Novice’ drivers tended to select speeds nearer to the speed limit compared with the speed choices of 'Experienced' drivers, who had more conservative speed choices below the speed limit. In the study, drivers were provided with no indication of the actual speed limit for each road (i.e., there were no road signs), so that they were reliant on their own judgement of what the speed limit may be given the traffic and road situation.

Novice drivers also displayed less variation in their speed choice between different road environments, despite the difference in road characteristics and the objective level of risk. For example, in the study, the speed limit for both Motorway and Rural roads was identical at 100km/h. However, the objective amount of risk on the Rural road environment was arguably higher at the speed limit when compared to the safer Motorway environment (ACC, 2009). Despite this difference in risk level, novice drivers chose similar speeds under both environments. Experienced drivers, by comparison, chose much slower speeds on the Rural road compared to the Motorway. Drivers speed choices under different road environments is shown in Figure 4:

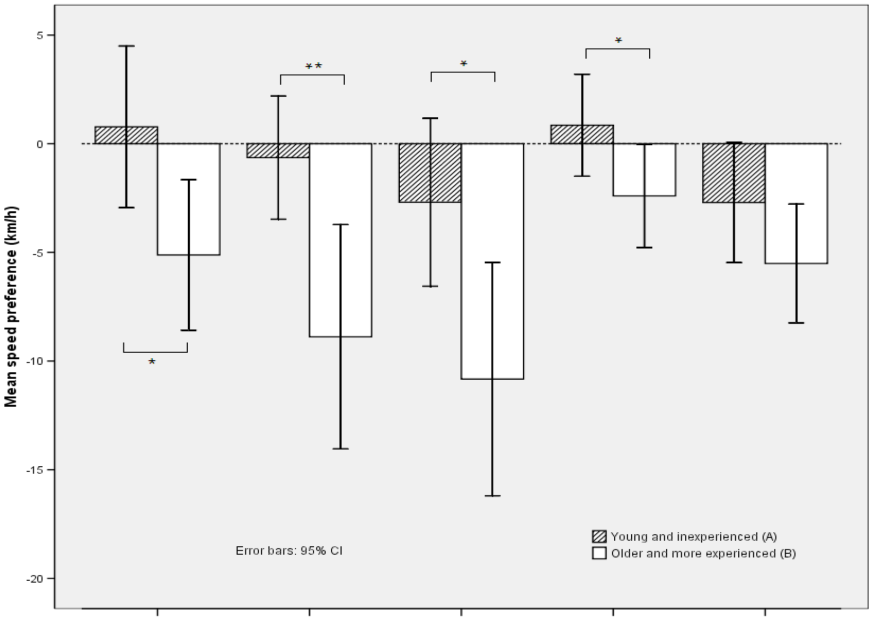

Figure 4: The difference between Novice and Experienced drivers' Speed Choices across a range of commonly encountered Road Environments. Cantwell (2010) found that Novice drivers appear to align their speed choice with the maximum legal speed limit, while Experienced drivers appear to base their 'ideal' choice of speed on the traffic and road conditions.

Cantwell (2010) argued that this finding indicated that Experienced drivers were more correctly calibrated. Their perceived level of risk was more aligned with the objective level of risk, as demonstrated by their more appropriate speed choices. The lack of adjustment by Novice drivers could be related to a lack of ability to perceive risks present in the road and traffic situation and overconfidence, which is evidence of poor calibration. Cantwell (2010) found that drivers with faster speed choices had a higher self-rated driving skill, greater enjoyment in taking risks, a relaxed attitude towards dangerous driving in general and speed in particular, and the number of traffic fines/convictions for speeding received in the previous twelve months. While in general, the speed choices of drivers were not 'excessive' (i.e., much faster than the speed limit), there was sufficient evidence to suggest that drivers' do not all view speed limits in the same way. Many drivers chose speeds that were faster than the legal posted speed limits but under a speed that would result in penalties such as traffic conviction. While enforcement can be an effective means of managing drivers' speeds, drivers should choose suitable speeds for the road conditions. By combining the speed choice task with an eye-tracker, one could determine what characteristics contribute to the driver's choice of speed and provide valuable information to assist future speed management solutions where enforcement is impractical.

Poor speed adaptation may be intentional, driven by individual preferences (Ahie et al., 2015), but seems more likely to be unintentional due to inadequate hazard perception (McKenna et al., 2006). While the vast majority of drivers do adapt their speed to road conditions, this is often insufficient to offset adverse conditions (DaCoTa, 2012). Drivers who are less competent in judging what speed is appropriate may be more vulnerable due to limited visual search (Underwood et al., 2002; Crundall et al., 2004) as well as an inaccurate evaluation of risk (Charlton et al., 2014; De Craen et al., 2008; Horswill & McKenna, 2004; McKenna et al., 2006).

Furthermore, drivers do not frequently consult their speedometers and are often unreliable at accurately predicting speed (Recarte & Nunes, 1996). Certain perceptual limitations may predispose drivers to either overestimate or underestimate their speed, known as adaptation effects (Denton, 1976). Adaptation effects can lead to significantly dangerous judgements, as underestimating ones own vehicle speed is likely to occur in conditions where there is limited visibility, such as night-time or wet weather driving (Mueller & Trick, 2012). Kloeden et al. (1997) noted that one cause of speed-related crashes could be that drivers misjudge the speed of other vehicles to be slower than what they actually are, resulting in a crash situation. At speed, drivers cover a greater distance, meaning reaction times can be too long to compensate through braking or other vehicle manoeuvres, resulting in a high-speed, high energy collision (Kloeden et al., 1997).

Driving involves processing a vast amount of visual information, and this continuous stream of information is essential for drivers to perceive how fast their vehicle is travelling (i.e., ego-speed), determine the direction the vehicle is heading, and estimate the distances to certain objects, and ultimately, accurately estimating safe stopping distances.

While the mechanism that allows humans to perceive self-motion is complex and beyond the scope of this thesis, it is nevertheless important to recognise that, like other biological systems, perception of self-motion does not function at a continuous level of performance and is subject to fatigue and the natural limitations imposed by biology. Humans are the only living beings that have developed means of travelling faster than they can otherwise naturally move. As this development is recent, our biological systems have not evolved fast enough to adapt and meet the challenges inherited by fast driving (Rumar, 1999). Humans likely evolved to experience fear of height rather than fear of speed. Hence, speed may not be perceived as dangerous in the same way height is commonly perceived (Rumar, 1999, in Yannis et al., 2013).

For instance, because of these biological limitations, humans are generally poor at judging speeds that exceed approximately 30mph - the speed of a large cat - which can adversely influence drivers' behaviour. Denton (1978) observed one well-known effect: drivers' perception of speed becomes 'adapted' to the speed they are travelling, making changes in speed appear greater in magnitude. A good example of this is demonstrated when a driver encounters a situation requiring them to reduce speed in response to a posted speed limit after travelling at a faster speed for an extended period. Despite their speed reduction, they may find themselves inadvertently speeding as they perceive themselves to be travelling slower than they actually are (see Sugihara et al., 2013 for a review of traffic and road illusions). This effect also has an influence on drivers' perception of the speed of other objects such as vehicles or roadside features. Recently, researchers at Waikato University demonstrated that on approaching a level-crossing, drivers might perceive a train that is travelling at 100km/h to be moving at a slower 80km/h, meaning that they may believe they have adequate time to cross the tracks before the arrival of the train (Clark, Perrone, & Isler, 2013). Additionally, drivers' perception of speed can be negatively influenced by the time of day or weather conditions such as fog (Kim, Perrone, & Isler, 2017). (DeLucia, 2013)

Speed Choice as a Habitual Process

Given enough time and exposure, almost all complex behaviour becomes easier to perform, including driving. When learning to drive, novices often need to focus their full attention on steering and using the gear-shift, and over time, as they gain experience, they will find these early driving challenges almost trivial. Speed, too, appears to be an aspect of driving that becomes automated with experience.

Charlton and Starkey (2017b) found that drivers speed tends to reflect a habitual process rather than a moment to moment explicit decision as to whether speeds are appropriate for the traffic and road conditions. The speeds drivers choose may meet their individual goals and the perception of risk and task-demand and become reinforced if performed frequently enough without adverse consequences (e.g., loss of control, speeding tickets). Hence, speed choices made by drivers under certain conditions in the past are likely to be repeated when encountering similar conditions in the future. These repeated, reinforced choices ultimately lead to the development of an automatic speed choice selection for a given traffic and road circumstance, stored in the form of a cognitive rule known as schemata.

Such schemata are 'proceduralised' in that they can be easily deployed when required without being actively attended to by the conscious mind. This allows for accurate and rapid responses in complex situations, as schemata can be retrieved from long-term memory in response to environmental cues with the advantage of placing minimal demand on working memory (Emmott & Alexander, 2014). The consequence of automatised, schematized behaviour is that drivers revert to a default speed on roads that have become familiar and routine – or roads that fit the pattern in long-term memory that is most appropriate (Charlton & Starkey, 2017b). These default speeds are strongly determined by utilisation of cues or pattern recognition, which have been suggested to play a more prominent role in drivers choice of speed than personality factors or cognitive ability (Lheureux et al., 2016; Verplanken & Aarts, 1999).

Repeated exposure, mentioned above, might involve travelling along a road during a particular time of day under specific conditions in traffic, which naturally raises the question of what happens should the conditions on the road suddenly change? Charlton and Starkey (2017a, 2017b) acknowledge that the speed choice of participants is based on schemata that represent what is most likely to occur on familiar roads. These schemata might not necessarily accommodate the operations a driver needs to perform should the road situation become unfamiliar or complicated through the addition of hazards or other unanticipated road or traffic features (Malhotra et al., 2018; Prabhakharan & Molesworth, 2011).

Drivers who are overly dependent on associative cues in order to determine appropriate behaviour are also susceptible to miscuing – a situation that occurs when a salient cue engages an inappropriate schema or interferes with the accurate recognition of an event or object of significance (Brouwers et al., 2018). This incorrect assessment due to inadequate or faulty appraisal may lead drivers to choose an inappropriate speed which increases crash likelihood (Accident Compensation Corporation & Land Transport Safety Authority, 2000; Broughton et al., 2009; De Craen et al., 2011; De Craen et al., 2008; Yao, Carsten, & Hibberd, 2019; Yao, Carsten, Hibberd, et al., 2019).

As much of the driving task is automatic, this leaves cognitive resources open to be assigned to other (often non-driving) related tasks (Berry et al., 2011). This explains in part why mind-wandering is a common phenomenon amongst modestly experienced drivers (Burdett et al., 2016), as subconscious and automatic processes manage the majority of driving behaviour (i.e., as a kind of autopilot), leaving the drivers' mind free to attend to other thoughts or activities. In this state of 'autopilot', a driver may use schemata to make habitual speed choices. As with many other driving behaviours (e.g., steering) moderating speed to accommodate other vehicles or increased attention to in-vehicle devices, passengers, or other causes of distraction can be performed almost effortlessly by drivers, even though it increases suceptability to cognitive lapses or errors (Haigney et al., 2000; Patten et al., 2006; Regan & Young, 2003).

Using Radar-measurements and roadside interviews, Ahie et al. (2015) found evidence that drivers self-reported default speed choices and actual observed on-road speeds were highly consistent and that individual differences such as motives and beliefs accounted for only a fractional proportion of the variance in observed speed. This supports the theory that drivers choose the speeds they travel due to habit and familiarity. Furthermore, they suggested:

> Because usual speed was the most influential component in the speed preference term, one could suggest that speed preference involves a consistent liking for certain speeds over others, rather than mere momentary motives. (pp. 62-63)

Ahie et al. (2015) noted that it is reasonable to assume that the selection of speed is out of familiarity with certain roads, and the formation of a cognitive rule to govern speed works well when there is little demand on the driver for attention directed toward the driving task. Habits are the automatic responses to everyday situations learned through repeated performance, and there is growing evidence that habits can be triggered in the associated context (e.g., accelerating to 100km/h on turning onto a rural road), often overriding more deliberate conscious intentions (Gardner, 2012).

Evidence of the habitual nature of drivers speed choice was found by De Pelsmacker and Janssens (2007) using an approach based on the Theory of Reasoned Behaviour. This theory incorporated drivers' attitudes, beliefs, and social norms and the amount of perceived control the driver has over the situation as forming the underlying intention to behave in a particular way (Ajzen, 1991). After conducting a comprehensive survey of drivers and using a model which was based upon Ajzen's (1991) theory, they found that self-reported speeding behaviour was either the outcome of a conscious choice, though equally, merely the result of pre-established habitual patterns of behaviour. In support of the more cognition-based perspectives, De Pelsmacker and Janssens (2007) noted that much of drivers speed choice is based entirely on habit and not on conscious decisions or deliberate choices. The results of their analysis are shown in Figure 5:

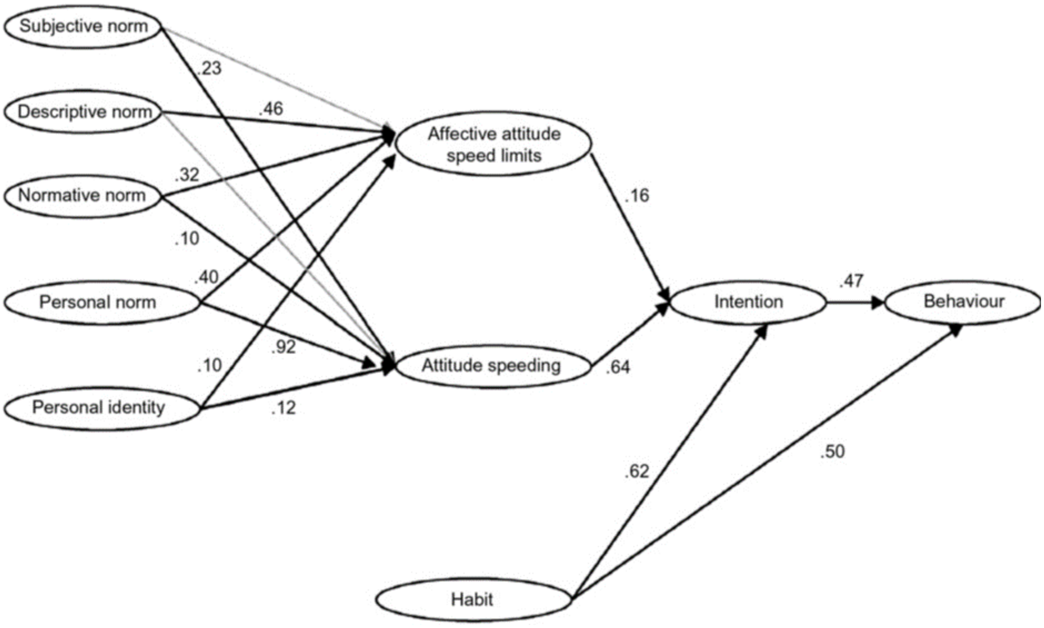

Figure 5: Using a model based on the Theory of Planned Behaviour, De Pelsmacker and Janssens (2007) found that habitual speed choice contributed to drivers speed behaviour as much as intentional or deliberate speeding.

The conclusion from De Pelsmacker and Janssens (2007) research is that speed choice at some level can involve little to no deliberate conscious awareness. While the traffic scenarios were hypothetical and were measured using self-report items, their research provides additional weight to the argument that the credibility of the road and traffic situation, as well as automated responses to commonly encountered driving situations, accounts for more than half of drivers speed choices, over and above deliberate intention for drivers to select certain speeds.

The degree to which a driver perceives control over the situation may influence how likely they are to engage in deliberate speeding, as predicted by Azjen's (1991) Theory of Planned Behaviour. While perceived control over vehicle speed undoubtedly plays a role over drivers behaviour, it is possible that with experience, drivers take into account actual control over their driving behaviour unconsciously, which may potentially explain why drivers perceived control contributes to self-reported speeding but not recorded speeding (Warner & Åberg, 2006). Parker et al. (1996) found that training drivers to have greater perceived behavioural control had the unexpected effect of causing these drivers to become less confident that they could control their vehicle at a steady speed, possibly because of an increased awareness that the traffic situation may have a stronger role in influencing their choice of speeds.

Hence, while speed choice may be classified as a driving style, there is also likely to be good evidence to consider that speed choice may also be a type of driving skill – automated and largely operating below a driver's conscious awareness. Research by Haglung and Åberg (2002) may provide evidence to support this speculation. Haglund and Åberg (2002) measured the speeds of the same drivers over several days on two different road sections while changing the posted speed limits. They found a high correlation between drivers speed choices between both road sections, despite altering the posted speed limits. The high degree of correlation showed that drivers were highly consistent in their choice of speed, even when speed limits were changed. Haglund and Åberg (2002) argued that rather than deliberately choosing to violate the speed limits, this shows the extent to which drivers' speed choice is automatic. Furthermore, a deliberate violation of the speed limit might indicate that drivers will favour their default speed preference over the posted limit when speed limits do not seem credible.

The Problem with Habitual Speed, and the Role of Perceptual Countermeasures

One of the challenges associated with the habitual nature of speed choice is that it is extraordinarily difficult to change once it becomes automatised. This is evidenced in drivers' behaviour following a crash, where they will drive at a more cautious speed for some time, then revert to their previous driving behaviours. Although drivers do show a reduction in risky driving over time, this trend seems unrelated to crash involvement and more with general driving experiences (af Wåhlberg, 2012; O'Brien et al., 2017).

Habitual behaviour has been recognised as automatic, uncontrolled, and challenging to repress naturally without deliberate conscious attention (Lheureux et al., 2016; Verplanken & Aarts, 1999). This means that drivers learn to quickly revert to speeds that seem credible given the road and traffic situation, even though there may be unperceived risks that warrant slower and more cautious driving speeds.

The difficulty associated with modifying habitual speeds can result in numerous problems, especially when drivers are required to decrease speed when transitioning from rural to urban settings. In New Zealand, the open-road limit is 100km/h, while the typical urban limit is 50km/h, with many open roads interspersed by small townships requiring drivers to slow down on a region of road referred to as a 'transition zone'. While many drivers do reduce speeds when encountering a transition zone, often due to the effects of sensory adaptation, drivers may have the perception they have decelerated adequately, while they are actually still travelling well over the posted speed limit (Denton, 1980; Recarte & Numnes, 1996).

As previously mentioned, increasing the visual complexity of the road environment has a strong effect on drivers speed. Increasing the number of structures surrounding the road is thought to increase drivers' perception of 'edge rate', that is, the speed at which specific roadside features pass by the moving observer's peripheral field of view. This can create the perception that the speed has increased, triggering the driver to become acutely aware of the speed at which they are travelling. As drivers become aware of their speed, they switch from relying on automated behaviour to more deliberate decision making, choosing speeds that are judged appropriate for the condition.

This thinking is behind the concept of the 'Urban Gateway', which has been used in part to solve drivers' speed when entering towns following prolonged travel on the open road (Charlton & O'Brien, 2001; Makwasha & Turner, 2013). Urban Gateways are large oversized signs on either side of a road, which drivers pass when entering an area with reduced speed limits. These gateways turned out to be quite effective in triggering an immediate reduction in drivers' speed. Drivers were found to reduce speeds when passing an Urban Gateway even when the speed limit was not explicitly shown, indicating the effectiveness of this countermeasure was primarily perceptual. However, what researchers found was that the speed-reducing effect was quite limited and that within a relatively short distance of about 250 meters, drivers had returned to their previous default speed. On occasion, it was found that drivers eventually settled at a faster speed than the speed they were travelling before encountering the Urban Gateway (Charlton et al., 2001). Additionally, over time and with repeated exposure, familiarity meant that drivers' became accustomed to the gateways, decreasing their overall effectiveness as a speed-reducing countermeasure.

While Urban Gateways have been widely adopted, they are usually utilised alongside a range of other perceptual (e.g., road markings) or geometric countermeasures (e.g., the use of chicanes to create 'pinch-points[5]'). Combining other traffic calming methods has proven necessary to maintain any speed reduction downstream from the point where the driver transitions from high to low speed (LTSA, 2002). Concerning this, it has been noted that "the speed reduction achieved by a gateway alone is not likely to be significant unless used in combination with other measures" (pg. 18. NCHRP, 2012).

Considering the challenges in reducing drivers speed through perceptual and infrastructural countermeasures, this demonstrates the difficulty in changing drivers' choice of speed once it has become habitual. As speed choice almost inevitably becomes automated, the ability for drivers to interpret the traffic and road situation and respond appropriately must have a central role in driver education. This leads us to consider the importance of drivers' ability to learn to read the road well before their behaviour becomes habitual.

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[5] A pinch-point is a point where the road narrows significantly, typically by introducing a coloured concrete chicane in the road centre and along the roadside, which forces drivers to reduce speed while transitioning through the Urban Gateway. In combination, the estimated net reduction in crashes is 35% on New Zealand roads (Makwasha & Turner, 2013).

Speed Choice and 'Reading the Road'

As we have discussed, several theories have been proposed to explain how drivers adjust their speed according to changing road conditions. Many have emerged from either psychological theories of risk-management and theories grounded in visual perception (DaCoTa, 2012; Elliott et al., 2003; Goettker et al., 2018). Novice drivers not only tend to drive at excessive speeds but are also ill-equipped to process the nuances of the road and traffic situation. Thus, novice drivers are prone to either driving too fast for the conditions or failing to anticipate how other road users might behave – which introduces the significant role that hazard perception plays in safe driving behaviour.

Horswill and McKenna (1999) found laboratory measures based on a video speed task predicting drivers' previous involvement in speed-related crashes. Drivers with a speeding-related crash history both chose faster speeds in the laboratory task and responded more positively to questionnaire items measuring riskier attitudes towards speeding. McKnight and McKnight (2003) found that the major contributing factor to road accidents was an inability in motorists to adjust driving behaviour to the conditions of the road environment due to a combination of poor hazard recognition, poor visual search and attention, and an inappropriate speed selection.

Braitman and colleagues (2008) examined police reports in conjunction with interviews with drivers. They identified the primary factors contributing to increased crash risk: poor hazard awareness and perception, followed by excess speed and lost control or traction. For those crashes that involved a combination of excessive speed and loss of vehicle control, excess speed emerged as the primary factor, often preceding and contributing to a loss of vehicle control (Braitman et al., 2008). This indicates that both excess speed and poor hazard awareness may together contribute to the loss of vehicle control, elevating crash likelihood and severity. Many crashes have been traditionally attributed to lack of driver experience and inadequate perceptual training in hazard perception, and this lack of driving experience has been identified as playing a significant role in increasing crash risk for young drivers (Meir et al., 2014). Young novice drivers are more likely to be involved in accidents through lack of awareness of other vehicles at intersections or roundabouts, owing to a diminished hazard perception ability (Braitman et al., 2008).

Curry et al. (2011) found in their evaluation of crash statistics that poor risk assessment and hazard anticipation plays a greater role in crash prediction than reckless or dangerous attitudes – indicating that hazard perception is critical in ensuring safe driving. Excessive or inappropriate speed selection was a strong predictor of crash severity, whereas insensitivity to hazards and poor situational awareness were reliable predictors of crash likelihood.

As previously discussed, besides speed choice, hazard perception has been identified as one of the most critical skills for safe driving. According to Horswill and McKenna (2004), this higher-order ability is the most crucial driving skill related to crash involvement. Hazard perception and situation awareness refer to the capacity to 'read the road' and create continual mental representations of the traffic environment from which judgements can be drawn regarding potentially dangerous situations – both in regards to the anticipation of other road-users behaviour, as well as in regards to immediate and potential hazards related to the road environment.

The Critical Skill of Hazard Perception

Hazard perception has been the theme of many driving studies. A large volume of literature is related to the importance of this vital skill in improving drivers' safety and reducing their crash likelihood (e.g., Porter, 2011; Groeger, 2000; Shinar, 2010). Researchers have defined hazard perception to emphasize different aspects of driving, resulting in numerous and often inconsistent definitions. Despite this, there are common conceptual threads related to identifying risk that runs through the various definitions. A standard definition of hazard perception refers to a driver's ability to identify potentially dangerous or high-risk stimuli within the driving environment, and determine the probability of interaction, which would require adjusting driving behaviour to compensate for changes in perceived risk.

Horswill et al. (2004) define hazard perception as "the ability to recognize and anticipate dangerous traffic situations" (p. 179) and that drivers with advanced hazard perception have a more effective mental representation of the road environment (McKenna & Horswill, 1999). Helman (2009) used a similar approach and defined hazard perception as "the ability to identify potentially dangerous traffic situations as early as possible" (p. 8). Mills et al. (1996) expanded upon what constitutes a 'dangerous traffic situation' to include "any aspect of the road environment or combination of circumstances which exposes an individual to an increased possibility of an accident" (p. 1). The components of a hazardous situation could encompass any semi-permanent factor (e.g., road surface, power poles, etc.,) as well as temporary physical characteristics of the road environment (e.g., urban or rural roadway), the surface and visibility conditions (e.g., weather, nighttime), and the behavioural aspects of the surrounding traffic, pedestrians, and other road users (Fitzgerald & Harrison, 1999).

Deery and Love (1996) introduced the dimension of prioritising hazards on the driver's part, who needs to predict how the road situation is likely to evolve based on available cues to drive safely. Thus "the process of identifying hazardous objects and events in the traffic system and then quantifying their dangerous potential" involves a considerable overlap with drivers capacity to perceive risk by integrating top-down knowledge, visual awareness, and the feelings which may accompany the situation. Hazard perception has been described as drivers capability for "reading the road" (p. 28, McKenna & Crick, 1994) which McKenna (2004) adds drivers ability to anticipate change by stating that "By hazard perception I [sic] mean the ability to anticipate, the ability to read the road" (p.1). Such definitions of hazard perception begin to incorporate several features: the ability to detect dangerous situations or objects, assess the risk involved and compare the outcomes of each assessment to determine whether or not one can cope with the hazard (Brown & Groeger, 1988; Crundall et al., 2012).

With such a diverse range of definitions used by researchers, it is essential to acknowledge that the term 'hazard perception' may not refer to the same construct. For instance, some researchers may use hazard perception to refer simply to the ability of drivers to detect hazards against the background noise of traffic (Velichkovsky et al., 2003). In contrast, others may introduce aspects of risk-perception, anticipation, and behavioural response. Vlakveld (2011) reviewed commonly cited definitions condensing the definitions of hazard to two components: a) the ability to anticipate road and traffic events, and b) the ability to assess risks based on priority (Lemonnier et al., 2015). Furthermore, Vlakveld (2011) noted that perception was just one stage of the process of dealing with hazards. It is not only recognising a possible hazard but also the preparatory actions that allow for timely intervention to avoid a crash should the hazard materialise. For immediate hazards, Isler et al. (2009) provide the following definition in their commentary paper:

> Immediate hazards were defined as hazards that would require some preventative or evasive actions from the driver (e.g., braking or being prepared to brake, sounding the horn or/and changing direction) in order to avoid a potentially dangerous interaction with another road user. (p. 447)

While Isler, Starkey, and Williamson (2009) apply a standard definition involving some stimuli that drivers need to identify and then subsequently use to modify their behaviour in avoiding a crash, a definition could be interpreted as having quite a broad operational scope. However, hazards are restricted to other road users and pedestrians, and not certain road and traffic environment features that are fixed, though still pose a potential threat. For example, does a wet road qualify as a hazard? Driving on wet surfaces is potentially dangerous and may require evasive action from the driver (e.g., reducing speed to retain traction). However, road surface condition is not generally considered a hazard, though it most certainly can influence the level of risk present when conditions are not favourable.

In the absence of immediately visible hazards, assessing and anticipating a hazardous road environment may still influence a driver’s eye movements as well as other behaviours such as speed choice (Konstantopoulos et al., 2010; Lemonnier et al., 2015; Salvucci & Gray, 2004; Salvucci & Taatgen, 2011). This detail, however, is neglected in many hazard perception studies.

Here a distinction needs to be made between the detection and the anticipation (or perception) of hazards. A driver may anticipate potential hazards, but until the hazard manifests itself, it is not detectable. This distinction between hazard anticipation and hazard detection is of importance. Although the terms ‘perception’ and ‘detection’ are sometimes used equivocally or interchangeably in the literature, there are some important differences in their meaning. Detection generally refers to the ability of a driver to notice some novel stimuli amongst the background noise of the traffic environment. On the other hand, perception involves the correct identification of a hazard as opposed to a non-hazard and then the potential for interaction to occur, which may require a change in the driver's behaviour (e.g., braking, steering away). While the two terms are interrelated, one obviously is more weighted on the visuospatial search and visual attention. At the same time, the other involves more cognitive processing based on stimulus detection and knowledge-based identification.

Fitzgerald and Harrison (1999), using recognition-primed decision-making models (Klein, 1993), suggest that hazard perception can be thought of as a chain of mental events starting with the detection of a hazard (i.e., situation recognition). Detection involves classifying the situation as either familiar or novel based on matches within existing memory. If the situation is familiar and benign, it is essentially disregarded. In contrast, novel situations demand more intensive processing and decision-making, which ultimately results in a behavioural outcome and memory modification. Fitzgerald and Harrison (1999) suggested hazard perception is generally viewed at the situation recognition stage and not at the point of behavioural response.

A broader perspective has been adopted by Vlakveld (2011), who argues that the term ‘hazard perception’ would be better replaced with ‘hazard anticipation’. In doing so, this broadens the scope to allow for the drivers' recognition of a potential hazard approaching and include the preparatory actions (such as braking or slowing down) that allow for timely intervention to avert a crash the recognised possible hazard materialise. It involves recognising potentially adverse outcomes from approaching events and the course of action that would most effectively reduce negative consequences. In a study by Alberti et al. (2014), it was found that experienced drivers slowed on the approach to hazards sooner than inexperienced drivers, which supports the notion that anticipation of potential threats is a significant component of the hazard perception chain. However, making the definition of hazard perception synonymous with hazard anticipation opens the doors to an almost limitless number of potential factors requiring the driver's mental awareness, which is naturally restrictive in an operational sense.

Additionally, anticipation is dependent on the capacity of a driver to assess and entertain the risks associated with a particular region of road and traffic. While Vlakveld (2011) makes a valid point, as many existing definitions involve an aspect of anticipation, it is not a distinction without a difference. Hazard anticipation and hazard perception are two distinct cognitive processes, and the term ‘perception’ emphasises mental awareness. In contrast, anticipation can be considered as having more to do with the visual aspects of expectancy and value (see the section, Hazard Perception and Visual Perception).

Some researchers, such as Horswill and McKenna (2004), consider that Hazard Perception is the awareness of danger nested within the broader construct of Situation Awareness, which was proposed and developed by Endsley (1995) that is represented in Figure 6. Situation Awareness involves “the perception of elements within an environment within a fixed volume of time and space, the comprehension of their meaning and the projection of their status in the near future”. In describing Situation Awareness, Endsley (1995) considered three levels, being 1) stimulus detection, and then 2) comprehension of essential elements, followed by 3) projecting how these elements might change over the course of time and space. In this conceptualisation, Situation Awareness involves detection, perception, and anticipatory components.

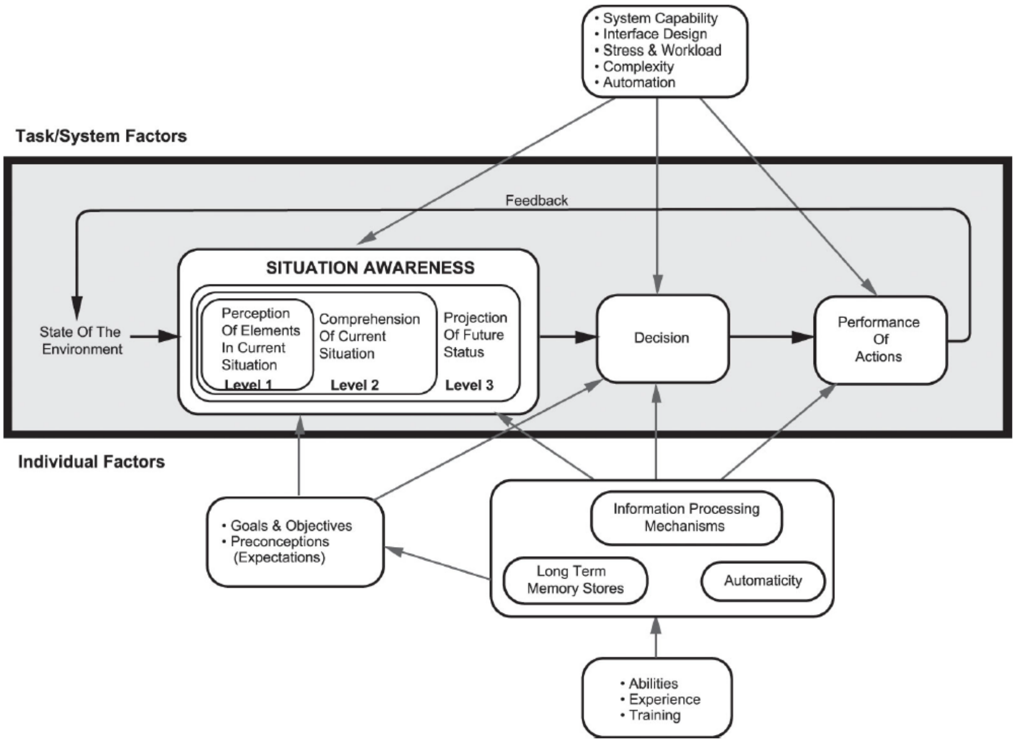

Figure 6*:* The conceptualization of Situation Awareness as a means of Dynamic Decision Making when driving (Endsley, 1995).

Endsley's (1995) conceptualisation of situation awareness allows for an expanded explanation of the role of hazard perception that can incorporate emotional states, or somatic markers, as feelings of risk. As drivers perceive, comprehend, and make projections, they can identify and experience the perceptions of risk accompanying these mentally simulated predictions and then act to reduce these uncomfortable somatic feelings (Kinnear, 2009; Vlakveld, 2011). It is also worth noticing that ‘Task/System Factors’ are those identified which influence drivers speed choice, while ‘Individual Factors’ can be broadly divided into categories of either driving skill or style.

One significant finding of relevance to this thesis is the relationship between hazard perception and risk perception. As discussed previously, speed choice is a drivers’ primary way of regulating situational risk. Thus, if a relationship between hazard perception and speed choice exists, drivers’ perception of risk is likely to be a key component. While it is uncertain why some researchers have discovered an association between hazard perception and risk (i.e., Renge, 1998), while others have found no compelling evidence for a relationship between the two (McKenna et al. 2004), the answer may rest in the way that risk is measured in the laboratory.

For example, Farrand and McKenna (2001) asked participants to complete a six-item questionnaire involving risk-related questions on a Likert scale ranging from 1 (“Very Risky”) to 11 (‘Not Risky’), and then to complete a video-based hazard perception task. The task required participants to press a button every time they perceived a hazard, while a computer recorded the number of button presses and response times. The results showed no statistically significant correlation between hazard perception performance and previous assessment of self-rated risk, driving ability, and crash likelihood.

In a second experiment using the same video-based task, participants were required to detect hazards. However, following each button press, the video was paused, and participants were asked to estimate the risk in the scene they had just viewed. Again, the correlation between hazard perception performance and risk ratings was not significant. One finding of note was participants who rated as having high self-rated driving ability reported lower levels of perceived risk.

While Farrand and McKenna (2001) conducted a valuable investigation, there are several potential methodological issues with their study. First, it may be difficult for participants to attach a subjective value to the level of risk they experience if the risk is perceived as a somatic feeling. Kinnear and Stradling (2011) found that drivers experience a somatic response when anticipating and perceiving that hazard. While this indicates a physiological response when perceiving hazards, it may remain outside of the ability of the driver to analyse consciously. Such a momentary sense of arousal may barely be perceptible unless it elicits a powerful emotional response – such a the fear associated with a near-miss with another vehicle. Moreover, measuring risk in a laboratory setting can be extraordinarily difficult due to the limitations in how realistic the simulated environment is to actual driving (Evans, 1991).

Another reason why it is reasonable to call these findings into question is that the study of risk-perception has shown that drivers experience risk at various subjective levels, even though the sensation may not be reflected in the objective level of risk. It has been noted that awareness of hazards is a critical source of information that influences the subjective perception of risk (Brown & Groeger, 1988). If hazards did not affect the perceived risk to at least some degree, an adequate alternative hypothesis would need to be formulated as to what signals a driver receives that causes them to experience risk while behind the wheel. However, research has revealed that drivers’ subjective rating of confidence can result in longer hazard detection latencies. There are also indications that the self-reported rating of risk is unreliable when drivers are under time constraints (Sun & Hua, 2019). This indicates that factors that influence the perception of risk also may operate on the hazard perception process.

Situational Awareness requires the driver to develop and maintain a mental representation of the road environment as they encounter a changing situation over time (Endsley, 1995). This sophisticated mental representation is dependent on sufficient cognitive resources, working memory, and the extraction of cues from the continual stream of visual and other sensory information (Horswill & McKenna, 2004; Owsley & McGwin, 2010). The second level in Endsley's model is the ability of the driver to distinguish hazardous from non-threatening stimuli. This skill presumably evolves as experience is accrued and differing traffic and road situations are navigated.

Naturally, some stimuli will be threatening without a heightened degree of expertise or experience (e.g., a pedestrian running in front of the vehicle). However, there is an advantage in having experience. Due to their automatized nature, well developed mental models bypass the limitations of working memory (i.e., scripts or schemata that come with practice). Horswill, Falconer, Pachana, Wetton, and Hill (2015) further elaborate on Endsley (1995) model by discussing the superiority of experienced drivers' perception, comprehension, and projection (anticipation) over that of young or novice drivers. As cognitive and perceptual processes change or are altered due to the maturation that accompanies adolescence, this naturally will influence hazard perception. The role of these changes will be discussed at a later stage (see the section, Developmental Factors).

In this thesis, the principal measure of hazard perception is that of immediate hazards, which are those hazards that are overtly presented, though they may materialise from cues that could be considered covert. Various methods to measure hazard perception have been developed over the past several decades ranging from verbally identifying hazards to the more commonly employed video and simulator-based tasks, which involve participants either using a mouse click or pressing a touch-screen when they identify a visually apparent hazard (Horswill et al., 2004; Isler et al., 2009).

Hazard perception time for immediate hazards is measured from the moment the hazard becomes visible until the point in time where the driver attends to it (known as a 'hazard window'), either through sustained visual attention or by indicating detection through some indication (which is usually a button-press or verbal signal). While hazard windows provide a functional value for the time that a hazard is within the threshold of perception, there are often cues that occur before the opening of that window that are purely contextual (i.e., the traffic situation, such as approaching a school zone). These contextual cues serve to prime perceptual and cognitive resources in anticipation of hazards and are of enormous value in understanding how drivers' make decisions. Experienced drivers are often more aware of these contextual cues than novice drivers, meaning that they often devote visual resources toward hazard rich regions of the visual scene. Many studies into hazard perception emphasize the readily apparent aspects of the scene and neglect the contextual indicators that can be observed through eye-tracking. Some hazards are more attractive to the attention of drivers with greater levels of experience (Crundall et al., 2012). However, this can lead to situations where drivers deploy an inappropriate schema in response to the context (Brouwers et al., 2018).

Covert hazards can be any situation wherein a hazard may or may not materialise given specific contextual cues. The key difference between immediate (overt) and covert hazards is that immediate hazards readily present themselves as visually apparent. In contrast, covert hazards are anticipatory based on the context where driving is occurring. For instance, covert hazards may be anticipated in the driver's mind, and their eye movements may indicate the active scanning for such potential hazards. However, this may only influence behaviour once the probability of emergence becomes sufficiently high, and the driver may slow down in anticipation of these hidden (covert) hazards when driving past parked vehicles during school recess. The presence of pedestrians on the sidewalk in the distance may provide foreshadowing, which alerts the driver of possible risk (Garay-Vega et al., 2007; Sagberg & Bjørnskau, 2006). Garay-Vega et al. (2007) provided an example of foreshadowing, where a pedestrian begins stepping ping out onto the road but is so far away as not to be a hazard, but this at least draws the driver's attention to the fact that another pedestrian might step out from the location as the vehicle driver approached.

As covert hazards are not readily apparent, both novice and experienced drivers have greater difficulty predicting whether a hazardous event is imminent than when the hazard cues are more apparent (e.g., overt). Research conducted by Pradhan et al. (2005) noted that young novice drivers have greater difficulty than older and more experienced drivers anticipating hazards that are not visible, and similar findings have been observed by Sagberg and Bjornskau (2006).

Measuring Hazard Perception in Laboratory Settings

Researchers frequently measure hazard perception in laboratory settings rather than during real-world driving. While measuring hazard perception in a naturalistic way is possible and has been successfully conducted by numerous researchers (i.e., Quimby & Watts, 1981) using both self-report measures. Video footage of the road and driver, the progression of technology has lent itself to laboratory-based tasks. From a research perspective, the primary reason for this is that experimenters have a high degree of control over the variety and frequency of hazard stimuli, consistent across participants. Laboratory tasks also provide a way for researchers to collect more precise data related to detection latency (time) and the spatial location of the hazards perceived by the driver (Moran et al., 2019). From an ethical and financial perspective, laboratory-based tasks do not expose participants to the risk associated with real-world driving and can be developed quickly while remaining reasonably cost-effectively.

Hazard Perception and Driving Experience

Researchers have indicated a clear relationship between driving experience and improvement in hazard perception (Isler et al., 2009; Velichkovsky et al., 2003), and there is much evidence from several studies that indicate that more experienced drivers respond more frequently to hazards and have shorter response times compared with novice drivers. Horswill and McKenna (2004) note that one method of demonstrating a hazard perception task's validity differentiates between drivers separated by a substantial degree of driving experience. As hazard perception is a skill that improves with practice (as well as through training), a laboratory-based task that can differentiate between novice and experienced drivers from their respective ability to distinguish different hazardous elements of the road and traffic situation can be considered reliable. This capacity to differentiate between drivers with different degrees of experience is recognized as a standard requirement in developing and validating hazard perception tasks (Horswill, 2016; McKenna & Crick, 1991).

As with any acquired skill, initially, the task requires the learners' full complement of mental resources, and the learner is fully conscious of the demands of the task. However, over time as the skill becomes more rehearsed, it can be carried out below the level of conscious awareness. Automaticity is the process whereby a certain activity ceases to require conscious mental attention or resources but occurs subconsciously. While lower-level skills become automatized relatively quickly, higher-level skills can take much longer to become fully incorporated into a catalogue of associated schemata (Isler et al., 2006; Salmon, 2013, 2016). Experienced drivers rapidly detect a more numerous variety of hazards compared to novice drivers (Crundall et al., 2012; Underwood, 2007; Geoffrey Underwood et al., 2002; G. Underwood et al., 2002). There is, therefore, good reason to assume Hazard Perception develops alongside Situation Awareness, and this is represented in Figure 7, taken from Endsley (2006):

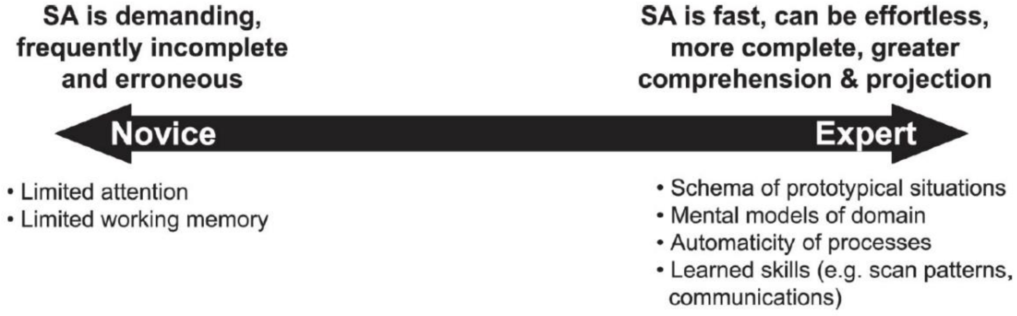

***Figure 7**:* The development of Situation Awareness Skills as driving experience increases, differentiating Novice from Experienced drivers (Endsley, 2006).

Altogether, these findings support the contention that increased experience plays an essential role in the acquisition of hazard perception skills and is in keeping with a broad cross-section of literature (Horswill & McKenna, 2004; Mayhew et al., 2003).

As the amount of driving experience accumulates, there are notable changes to how hazard awareness and perceived levels of risk may moderate speed choice. In a study employing pre-recorded video of various traffic environments in measuring risk and hazard awareness, Renge (1998) found that the amount of experience strongly influenced both hazard perception ability and speed preference between newly licensed, novice, and experienced drivers, including driving instructors. Renge (1998) identified a significant relationship between improved hazard perception, the perceived level of risk, and slower speed preferences. As driving experience increased, drivers had a greater ability to perceive hazards and selected slower speeds.

Although primary driving skills can be acquired in a relatively short amount of time, inexperienced drivers often lack developed perceptual skills and the executive processes that are required to process the sensory information needed to drive safely (Deery, 1999). Inexperienced drivers also tend to be less able to anticipate the behaviour of other road users and react accordingly (McKenna et al., 2006). Novice drivers scan the road environment less efficiently than more experienced drivers. They may not perceive subtle cues for hazards, only identifying nearby and visually salient hazards, and are therefore unlikely to detect hazards much further down the road (Brown & Groeger, 1988; Groeger, 2002). This suggests that inexperienced drivers who travel at high speeds may not detect a hazard until it is too late to respond safely[6]. At high speeds, they may overcorrect in manoeuvring the vehicle leading to an accident.

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[6] This leads to an interesting question: If drivers are speeding, visual cues pass by so fast they are barely perceived and thus hazard perception is degraded. On the other hand, if drivers are perceiving hazards and appraising risk, they choose a slower speed where they can detect more cues. So does speed choice effect hazard perception, or does hazard perception influence speed choice?

Hazard Perception and Visual Perception

Visual perception plays a critical role in driver behaviour, and there has been a long history of research into the visual aspects of driving (Crundall & Underwood, 2011; Owsley & McGwin, 2010). There is no doubt that disruption to visual attention is responsible for vehicle crashes and is considered a major contributing factor in crashes where distraction is involved (Recarte & Nunes, 2002). For example, using information gathered from the 100-car-naturalistic study, Klauer and colleagues (2006) found that some form of inattention caused approximately 78% of crashes and 65% of reported near-crashes (Klauer et al., 2006). Active visual attention is an essential skill that needs to be developed as part of any effective training intervention, given its strong influence on either the success or failure of the driving task (Konstantopoulos, 2009; Underwood et al., 2013).

Many studies have demonstrated that eye movements provide a useful means of understanding how experience influences hazard perception. Chapman et al. (2002) found that novice drivers tended to fixate largely on objects within the centre-field. In contrast, more experienced drivers had a much fuller ellipse of eye motions that included the peripheral field where hazards were most likely to be encountered. One significant finding was that novice drivers' were resilient to modifying their search strategy as road conditions changed, while experienced drivers tended to devote more time to scan the areas of the roadway where other vehicles were likely to intersect (Underwood et al., 2003; Underwood et al., 1999).

The breadth of visual search has been demonstrated across many studies to be associated with driver experience (Crundall & Underwood, 2007). However, a recent meta-analysis conducted by Robbins and Chapman (2019) found no significant difference between novice and experienced drivers' breadth of visual search or the number and duration of fixations. However, Robbins and Chapman (2019) caution how this finding is interpreted. Their analysis focused only on the quantitative aspects, not the expectancy or value of different drivers' visual behaviour (i.e., what information is gathered). While drivers may display a similar breadth of search, experienced drivers can likely extract more useful information for the driving task (Lemonnier et al., 2015).

Hazard perception skills involve having a continuously changing composite representation of current traffic situations, a feedback loop guided by the moment to moment perceptions, decisions, and actions of the driver (Baas & Charlton, 2005).

Effective hazard perception skills result in a holistic assessment of risk, which combines information from multiple sources in a continually evolving cycle of perceiving, processing, planning, and performing (Bellet et al., 2009). The process of perceiving hazards can be explained as a continuous loop. The driver needs to sequentially perceive, analyse, and then create a plan to respond given the drivers' goals, knowledge, and ability, and then carry out that planned action. As a consequence of action combined with the dynamic traffic environment, the driver must update their perception, conduct a new analysis, and create a subsequent response plan (Baas & Charlton, 2005). As with risk-appraisal as discussed earlier, vehicle performance, road and traffic conditions, and the drivers' mental well-being, cognitive demand, and awareness are all components that influence the performance of this feedback loop and the time taken to perform a complete cycle (Neisser, 1976). This theoretical mechanism is shown in Figure 8:

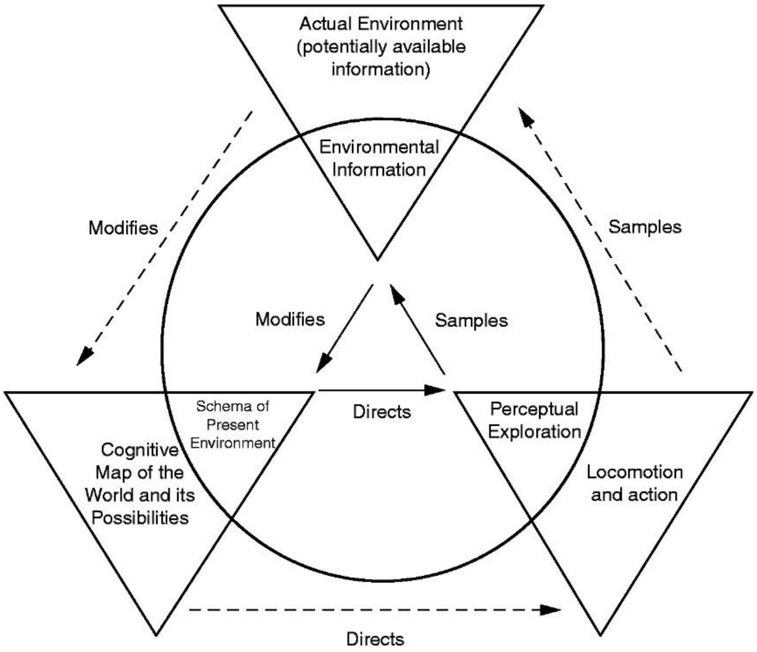

Figure 8: Neisser's (1976) Perceptual Cycle model, which represents the relationship between perceptual exploration, environmental information, and the schema that represents the environment – and how this directs behaviour.

Neisser (1976) conceptualised that information from the environment continuously modifies a corresponding 'map', or mental representation, from which actions are planned and directed. Acting on the environment introduces new information which feeds back into the 'map' and subsequent decision-making and actions, completing the loop. As drivers' attention and ability to process visual information are limited, only a small amount of the total information a driver encounters is used to make decisions. This cognitively economic process is known colloquially amongst cognitive scientists as thin-slicing (Gladwell, 2005; Schank & Abelson, 2013). For drivers with a high degree of experience, much of the decision-making is likely to be recognition-primed and habitual, using specific cues and drawing upon an available repository of highly-practised automatic responses, requiring little conscious attention from the driver. This allows experienced drivers to anticipate and predict traffic behaviour in the near future, enabling them to plan appropriate courses of action almost effortlessly (Bargh, 1992, 1994).

However, the degree to which hazard perception places a demand on cognitive resources is highly subject to the number of factors that the driver needs to consider at any given time (Wickens, 2008). It seems plausible that advanced hazard perception skills draw substantially on cognitive resources as they are considered to be conscious and effortful processes and are unlikely to become fully automated (Horswill & McKenna, 2004). Evidence of this lack of complete automatization has been presented by Mckenna & Farrand (1999), who found that experienced drivers may require more attentional resources to achieve a superior level of hazard perception, which does not appear to become more automated with practice. Additionally, in an analysis by McKenna and Horswill (1998), many driving behaviours which presumably become automatic with repeated practice do not load onto the same factor, suggesting that some behaviours may be automatic and others may involve conscious monitoring and attention. For example, some researchers have found that steering is not adversely affected by additional cognitive load, and there is evidence that steering may involve intentional and automatic processes that work in concert (Salvucci & Gray, 2004).

The idea that hazard perception may not be automatized with practice may seem counterintuitive at first, as experienced drivers have been shown to detect hazards more effectively than novice drivers even under the pressure of additional cognitive load, such as a secondary task. Groeger (2000) has argued that a reasonable explanation for this seemingly contradictory result is that hazard perception is similar to pattern-matching. It is reasonable that over many hours of driving, experienced drivers develop a rich store of hazardous scenarios in long-term memory and become more capable of perceiving non-hazardous traffic situations against hazardous ones, placing less demand on working memory. It is reasonable to assume that a driver with more experience is also likely to have a much larger repository of patterns to draw from. Consequently, when the traffic situation aligns with a stored mental pattern, experienced drivers become aware of hazards faster and can initiate an effective response more promptly than novice drivers (Groeger, 2000). In contrast, novice drivers continuously process non-hazardous traffic situations through working memory, which places an increased demand on immediately available cognitive resources and, consequently, reduces overall responsiveness or ability to plan and deploy evasive action.

In viewing hazard perception as a pattern-matching task, Ventsislavova et al. (2016) discussed the mechanism of hazard detection within the cognitive framework of Signal Detection Theory. They note that as experience is gained, there is increased sensitivity to stimuli accompanied by a reduced incidence of false positives (i.e., identifying non-hazardous stimuli as hazards) and more developed decision-making in responding to hazards. In this respect, hazard perception can be considered as a continually refined set of scripts that form more complex schemata (Salmon et al., 2014; Salmon et al., 2012; Walker et al., 2011). These schemata are automatic and proceduralised to the extent that they are performed without the interference of explicit control or conscious attention (Charlton & Starkey, 2011).

However, scripts or schemata can be underdeveloped, false, distorted, or faulty (Prabhakharan & Molesworth, 2011). An example of poor driving behaviour becoming automated might be frequent and risky over-taking that becomes reinforced when adverse consequences are not encountered. In many instances, these schemata are proceduralised and run subconsciously. When they are deficient, they can result in inefficient visual search, cognitive tunnelling, and “look but fail to see” incidences (Charlton & Starkey, 2011; Cole & Hughes, 1984; Hughes & Cole, 1986). Additionally, drivers can fail to identify hazards due to inattentional or change blindness. There is an inability to perceive a particular stimulus because it moves outside of our attentional range. (Galpin et al., 2009). Drivers can also be prone to ‘blind scanning’, where drivers scan the road environment without conscious awareness (Crundall et al., 2006).

Evidence suggests that when signal detection is heavily dependent upon proceduralised cognitive processes, there is the potential for individuals who are sensitive to non-relevant visual cues to become prone to errors involving the misdiagnosis of stimuli. This misdiagnosis may result in the misappropriation of schemata unrelated to the situation, degrading overall performance (Brouwers et al., 2018). When a cognitive process is inappropriately triggered by some salient ‘distractor’, this can draw resources away from making an accurate interpretation and subsequent response – an issue referred to as ‘miscuing’ (Rowe et al., 2009).

Despite the possibility that proceduralised behaviour may result in an error, there are undoubtedly significant advantages to the cognitively economic way that schemata assist the performance of experts and why automated mental processes are a desirable outcome of quality training. Additionally, despite the automatization of much of the underlying process of hazard perception, the interference of an additional workload can reduce the hazard perception skills of even experienced drivers to a level much lower than that of novice drivers (McKenna and Farrand, 1999). This finding indicates that even after many years of driving experience, these skills may place high demands on conscious attentional resources. For these reasons, drivers must attempt to ensure an optimum level of performance – such as by controlling fatigue and stress, avoiding substances that impair function, and reducing the potential number of distractions.

Hazard Perception: Where’s the Risk?

In examining the psychology of speed choices, a strong emphasis has been placed on the role played by drivers' perception of risk. Speed choice is one of the primary ways in which drivers balance their goals against the likelihood of being involved in a crash. While travelling at the speed limit might enable the drivers to arrive at their destination slightly earlier (e.g., the driver's goal), risks such as other road users or weather conditions may require a driver to reduce speed to remain safe. As has been previously mentioned, Farrand and McKenna (2001) observed no relationship between participants hazard perception skills and drivers ratings of risk. It was hypothesised that drivers who had more advanced hazard perception abilities would also have higher ratings for the level of risk in the road and traffic situation. However, Farrand and McKenna (2001) found a non-significant relationship between risk ratings and hazard perception latencies. This lack of an association was found both in response to videos from their Hazard Perception task and for risk-rating on images with a greater number of hazards.

This is not the only instance where a relationship between risk and hazard perception has not been found. Derry (1999) found that skin conductance did not correspond to drivers' subjective ratings of risk when there was increased danger. However, both Watts and Quimby (1979), and more recently, Kinnear (2010), found that drivers do appear to experience a physiological response to increased risk on the road in the presence of hazards, as evidenced in measurements of galvanic skin response.

Defining Hazard Perception in this Thesis

There is a considerable variation in both the conceptual frameworks and methodologies used to examine hazard perception in reviewing the available literature. The term hazard perception embodies many concepts that vary in their operational scope, limiting the reproducibility of research findings across multiple studies. Additionally, there is an interchange in the terminology used by researchers, such as hazard detection, hazard perception, and hazard anticipation. While a variety of definitions of the term 'hazard perception' has been suggested, this paper will use the definition proposed by Horswill, Waylen, and Tofield (2004), which defines hazard perception as "the ability to recognize and anticipate dangerous traffic situations" (p. 179). This definition provides a sufficiently broad scope for what constitutes a hazard (e.g., dangerous traffic situations), as well as the driver's ability to attend to the probable location of hazards (e.g., anticipation) and consider the importance of identified hazards (e.g., recognition). Most importantly, recognition can involve components that are both automatic as well as effortful.

The following diagram simply distinguishes how the author conceptualises the chain of events from automatic subconscious signal-detection of hazardous features against a set of cognitive templates (i.e., hazard detection) through to a conscious, effortful level of hazard perception, which is the intentional attending to the stimulus by the driver:

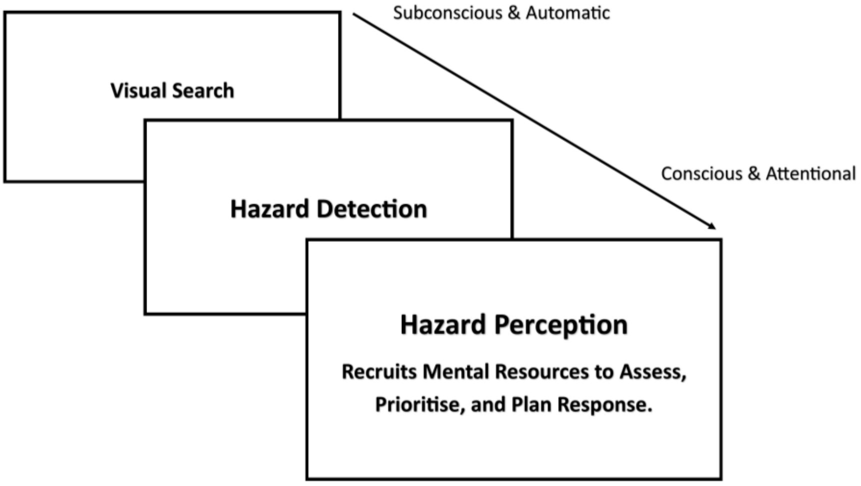

Figure 9: The conceptualisation of Hazard Perception used in this thesis, divided into three distinct mental processing stages. The first level involves a continuous subconscious and automated search for events that match known hazards. When this process matches knowledge against the situation, it can be considered Hazard Detection. The final stage involves awareness and cognitive resources in perceiving, evaluating, and then strategically planning a compensatory response to avoid or minimize risk.

Figure 9 above shows how information is processed through the course of detection through to perception. At a subconscious level, a visual search mechanism compares the current traffic situation against an extensive database of templates (e.g., schemata or scripts) for a novel scenario not previously encountered (Bellet et al., 2009). This process occurs entirely subconsciously, and the driver is not aware of this until a novel situation occurs. At this stage, the situation is determined to be either a hazard using existing patterns. It is sent to be prioritised into working memory if it is a hazard, where an evasive action must be planned and performed. This chain is prone to errors or lapses at various levels: from the inability to detect a signal visually, through to the level of detection where ‘look but fail to see’ accidents occur, through to hazard perception where a driver may fail to weigh the danger of a hazard adequately or produce an inappropriate response (Brown, 2002; Trick & Enns, 2009).

Critical Review of Previous Research

Much of the previous research that associates hazard perception with speed choice has been conducted within the context of driver education, as this allows for the measurements of speed choice concurrently with hazard perception while hazard perception is manipulated through some form of training. This section will briefly examine three studies that found evidence of a relationship between hazard perception and speed choice.

An Examination of Renge's (1998) Study

As previously mentioned, Renge (1998) conducted a series of studies that revealed a relationship between hazard perception and drivers speed choice. In an article published in 1998, Renge reported the results of two studies that investigated the inter-relationship of drivers' experience in hazard perception, self-rated confidence, and speed choice. In the first study, 24 traffic scenarios were selected from footage recorded from the driver's perspective, with an average duration of 10-15 seconds per clip. Twelve traffic scenarios were filmed during daytime and 12 during night-time conditions. Forty participants observed the series of traffic scenarios as a group and were asked to identify features considered hazards. When twenty percent of participants identified the same feature as hazardous, it was included in the final list, which consisted of twenty-two hazards. Two sham scenarios containing no hazards were included to ensure participants were engaged in the task. The list of hazards was grouped arbitrarily into two daytime clusters and two nighttime clusters – a total of four clusters containing six clips each, covering a range of hazards such as pedestrians, bicyclists, parked cars, preceding vehicles and merging vehicle lanes.

This coded list of hazards was then used in the second study, where a separate cohort of 129 participants was asked to watch each video clip presented on a projector screen. Following each traffic clip, participants were asked to answer four questions. The first question was how risky the viewed clip was using a 5-point Likert scale from *'Very Dangerous'* to '*Not Dangerous',* followed by a 5-point scale of how confident the participant would feel driving on the road shown in the clip. The third item required participants to rank order the hazards from most hazardous to least hazardous, using a scoring system where points were given for every 'correct' answer based upon hazards in the coding system developed in Study 1. Participants could receive a total of three points per trial, with two points given for the first correctly identified hazard and 1 point for a subsequent hazard. The final question involved how much faster or slower the participant would feel comfortable travelling using a 5-point Likert from -20km/h to +25km/h. The second study, which involved a larger group of 129 drivers. The time to complete the experiment was approximately 30 minutes for each group.

The findings of the two studies showed that as drivers' experience increased, there was a corresponding higher score in hazard perception performance. Additionally, experienced driver's had higher confidence levels, selected slower speeds, and observed higher risk. Renge (1998) notes in summary that the "more experience a driver has, the more correct he [sic] perceives hazardous objects/events, the higher he/she evaluates risks and the lower he chooses his driving speed" (p. 109).

One interesting and unexpected finding was that driver's perceived fewer hazards during night driving, which was interpreted as a consequence of diminished visibility. Paradoxically there was less of a reduction in speed choice on the night video clips than the day video clips. Drivers tended to notice fewer hazards in the night driving condition, which may explain why there was less of a reduction in chosen speeds compared with speed choice for the daytime condition. However, an analysis of the risk rating for night driving was not included, which encourages further research into how night driving is related to speed choice and how night driving influences visual search behaviour.

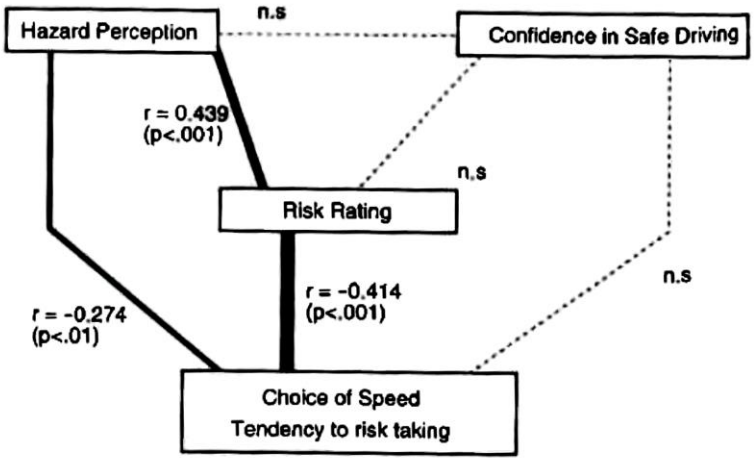

***Figure 10**:* The correlations between the Number of Hazard Perceived, Self-rated perception of Risk, and drivers' Speed Choice. More advanced Hazard Perception was related to both higher Risk ratings and slower Speed Choice. The self-rated risk rating is also related to Speed Choice (taken from Renge, 1998)

As shown in Figure 10, a highlight from Renge (1998) paper was that more advanced hazard perception skills appeared to be associated with slower chosen speeds, as well as higher ratings of perceived risk. Together, advanced hazard perception skills and higher ratings of risk were associated with slower speed choice. This finding supports the idea that risk-appraisal and speed choice are related, providing empirical support for Fullers (2008, 2011) risk-allostasis theory.

While Renge's (1998) study provided a good foundation for exploring the role of hazard perception, risk-appraisal, and speed choice, their design was reliant solely on Likert-based measurements in conjunction with film clips, which may lack the sensitivity that is found in a simulator. This is especially true concerning speed choice, which in Renge's (1998) study was calculated based upon questionnaire scores participants provided for each clip. This method of reporting speed is limited in several ways. Firstly, drivers are particularly poor at judging vehicle speed, and this can become exaggerated in using video-based measures, so ecological validity needed to be established. If the driver were to provide an estimated speed, it would be known how much faster or slower they were willing to accept in relation to the actual vehicle speed.

Secondly, the coding system for different identified hazards was based on what the majority of drivers with varying levels of ability were able to identify at a minimum of 20 per cent agreement. This could have inadvertently placed novice drivers at a disadvantage. Certain hazards that were not immediately apparent could be perceived less frequently by novice drivers, despite being easily identified by more experienced drivers. In the first study, where drivers provided the initial identification and classification of hazards, participants aged over 25 years old represented the majority, including skilled drivers such as instructors. In the results, Renge notes that experienced drivers perceived hazards more correctly. While this is a characteristic requirement of a hazard perception task, there is still the potential for an unintended bias favouring more experienced drivers.

Nevertheless, this innovative approach to coding hazards meant that the hazards drivers perceived were within the threshold of what the average driver might identify and allowed for the examination of both potential and 'obvious' hazards[7] between

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[7] In this thesis, the distinction Renge (1998) makes between potential and 'obvious' is covered entirely under the umbrella of immediate hazard. For instance, Renge lists a potential hazards, refered to as covert, are partially obscured objects "possible appearance of a pedestrian behind a car" as opposed to the overt "pedestrian standing in front of a car". Within our definition of immediate hazard, some hazards such as 'children playing on side of road' is covert, while 'boy standing to cross road' or 'car braking' are in the later overt category.

different groups of driver experience. However, Renge did not evaluate whether these different types of hazard influenced speed choices. Furthermore, there is potentially some issue in how participants were awarded points in their hazard perception ability. Drivers were required to rate the hazards they perceived from most dangerous to least in order, which is highly prone to the subjective appraisal of risk, and the ordering of hazards was not examined in detail. For example, novice drivers may have been less competent in ordering the danger inherent in a hazard compared to more experienced drivers. An analysis of this could indicate what hazards or dangers on the road attract the attention of drivers with differing levels of experience. This important consideration has been noted by Crundall et al. (2012).

Another aspect of the hazard perception measure used by Renge is the absence of a measure for hazard perception time. Hazard perception time, sometimes referred to as latency, has been identified as a critical component to drivers ability to detect and respond in an appropriate and time-sensitive way to danger in the traffic and road environment. Some researchers consider measures of hazard perception latency to be as important as the number of hazards that a driver perceives (Farrand & McKenna, 2001).

Renge (1998) provided the initial link in the chain of empirical literature suggesting a relationship between hazard perception and speed choice. Despite several limitations, his research contributes to this thesis's hypothesis, namely, that there is a relationship between hazard perception and speed choice and that an individual’s perception of risk may moderate this relationship.

An Examination of McKenna, Horswill, and Alexander (2006)

A study conducted by McKenna et al. (2006) involved designing a hazard anticipation procedure requiring the participants to listen to an expert verbal commentary on what hazards are presenting while watching video-based traffic situations and how they would deal with them to mitigate the risk. McKenna et al. (2006) measured drivers perception of risk, speed choice using a video speed task, and hazard perception using a video-based computer task. Additionally, they measured close-following and gap-acceptance using two additional video-based tasks. Three separate studies involving these measures are discussed in their 2006 paper, which presents an excellent case for the existence of a relationship between hazard perception and speed choice. The first study focused on the development of a method for hazard anticipation training.

In the second study, McKenna et al. (2006) created a video-based speed choice task that presented drivers with six scenarios involving the absence of hazard accompanied by six identical traffic scenarios where a hazard was included. This design was to rule out non-specific effects from the training against an actual improvement in hazard perception ability. They reasoned that drivers who were trained should respond with a more significant reduction in speed to the hazardous scenes than for less hazardous scenes. The presence of non-specific effects related to changes in safety awareness would result in an equivalent reduction in speed to both situations.

The results of this second study were that drivers who had received the training showed a greater reduction in speed as a response to hazardous scenes when compared with non-hazardous scenes. They concluded that the training method successfully improved hazard perception, rather than merely increasing safety awareness, and that drivers with more advanced hazard perception reduced speed in response to hazardous situations. The final study of the training involved testing police officers with differing degrees of experience, who were grouped into drivers with advanced and non-advanced driving ability.

The purpose of this third experiment was to determine whether advanced hazard perception skills would be associated with a greater reduction of speed on hazardous roads as to roads without hazards, in a similar way to the training in the previous study. McKenna et al. (2006) found that police officers with advanced training selected significantly slower speeds on the hazardous scenarios as opposed to the non-hazardous scenarios. In contrast, the non-advanced officers showed less of a difference in their choice of speed between hazardous and non-hazardous roads. They concluded that this provided good evidence that it was the drivers' ability to perceive hazards that influenced their speed choices, rather than advanced drivers' being more cautious in general (p. 7, McKenna et al., 2006).

While McKenna et al. (2006) developed a robust series of experiments to demonstrate that training did not merely reduce risk-taking, but improved hazard anticipation, the assumption that a nonspecific increased vigilance for safety, as opposed to increased hazard anticipation, cannot entirely be sustained. Firstly, it cannot be determined from their study whether the anticipation training primed drivers to reduce their speed choices. McKenna et al. (2006) suggested that if the training produced a non-specific reduction in risk-taking, there would be a similar reduction in speed for both hazardous and non-hazardous situations. However, drivers who generally are risk-averse with increased vigilance could reduce speed in the presence of increased visual noise, as visual distractors have been shown to make traffic situations appear riskier.

The use of an eye-tracker could show that the specific search for hazards was occurring, rather than the addition of more visual clutter, making the road appear riskier. In extending their research, the use of an eye-tracker will provide valuable clues as to what hazards or features of the road influence drivers speed choices, as it has been shown that there is a need to identify those hazards which discriminate between safe and unsafe drivers (Crundall et al., 2012). McKenna et al. (2006) introduced hazards that were both overt (e.g., car exiting a partially concealed driveway) and covert (i.e., cars obscuring the view around a corner). However, the effect of these hazards on speed choice was not examined.

McKenna et al. (2006) present a strong and robust case for the relationship between hazard perception and speed choice within the context of validating a driver training tool that has significant applications for improving road safety. Their contribution provides the foundational evidence that this present thesis will extend by further examining the relationship between hazard perception and speed choice through the use of commentary protocol and eye-tracking measures.

An Examination of Edquist, Rudin-Brown, and Lenné (2011)

One reviewed research paper examined drivers' role in different road and traffic settings, which feature increased crash risk, focusing on how visual noise influences drivers speed behaviour and hazard perception. In a conference proceeding, Edquist et al. (2011) introduced eye-tracking to accompany a speed-choice task. Twenty-nine participants drove in a simulated urban commercial route with no parking bays, empty parking slots, and parking slots that were occupied by cars. Participants also drove on a less complex ‘arterial’ road with no parking skirting the road. Participants were required to identify an unexpected event where a pedestrian would suddenly appear in front of the participant's simulated vehicle, to which drivers were required to identify by pressing a button. Participants were free to modify their driving through the use of a steering wheel and electronic pedals, which provided a real-time update to the simulator.

As hypothesized, drivers' simulated vehicle speeds were slower in the presence of occupied on-street parking bays compared to the other two environments. Drivers reduced their speed and drove further from the curb in response to the presence of vehicles parked on-street in the complex, urban environments. Additionally, drivers reacted more slowly to a peripheral target and had reduced responsiveness to the pedestrian unexpectedly crossing the road when driving in the more complex fully occupied car-park as opposed to when there were no occupied car parks.

Although there was evidence of some compensation by drivers in response to the changes in the complexity and visual-clutter in the road environment, it was determined that these behavioural changes were not sufficient to protect drivers from an increase in crash risk as measured by response to the unexpected pedestrian. Even with the reduction in speed, this alone was not sufficient to offset the decreased reaction times. Increased visual complexity, accompanied by the presence of parked cars, while resulting in a reduction in speed, also resulted in longer response times. The increased environmental complexity and cognitive workload significantly reduced their time releasing the accelerator and applying the brakes, with greater pressure being applied to the brake pedal. The minimum safe distance was also influenced by parked cars, with shorter stopping distances and reduced reaction times increasing the likelihood of colliding with the pedestrian. These findings have strong safety implications, especially concerning spaces shared by pedestrians and vehicles, such as parking buildings. Their research outlined the need for employing markings that can act as traffic calming measures, as well as a continued emphasis on maintaining slower speeds in complex environments. Furthermore, even though Edquist et al. (2011) identified this as a limitation, their findings presented a good case for using low-fidelity simulators to measure drivers' visual behaviour and speed choice. This preliminary proceeding provides some compelling findings for future road safety research and practice.

One area which would have been interesting is investigating how age and experience influenced the behavioural responses of drivers in this study. This was not examined in their analysis. Experienced drivers may be more responsive to certain cues, such as the markings and presence of other vehicles, which could have influenced their behaviour. Examining drivers hazard perception across a range of stimuli, rather than a single pedestrian event, would have provided a more robust measure of drivers ability to detect hazards, and this has the potential to look at using training, much like that of McKenna et al. (2006) study to determine whether improving drivers hazard perception skills could help to mitigate the effect of increased visual noise and mental workload on drivers choice of speed. This would be a significant advancement in understanding how training hazard perception may influence drivers speed choice. In this thesis, we will attempt to overcome this limitation through the use of eye-tracking and a range of different stimuli over different road types and under different conditions.

Additionally, increasing visual noise while simultaneously increasing drivers mental workload can be overcome through well-developed hazard perception abilities, which employs greater top-down visual search for hazards. Advanced hazard perception may circumvent the limitations inherent in bottom-up visual search, which is far more likely to be influenced by the load created by excess visual information that competes for cognitive resources (Beck & Kastner, 2009). This bottom-up search method in drivers with poor hazard perception is a critical point at which novice drivers are disadvantaged (Konstantopolous, Chapman, & Crundall, 2010).

Summary of the Existing Gap in Knowledge

In reviewing the literature, overall, there was surprisingly little research regarding a link between hazard perception and speed choice. However, there appears to be evidence that indicates hazard perception might be associated with speed choice (McKenna et al., 2006; Renge, 1998). Combined, these studies each present valuable insights into various aspects of the role of hazard perception in speed choice, indicating that an interrelationship may well exist. Despite these initial findings, however, there remains a substantial gap in our knowledge of the relationship between speed choice and hazard perception.

Many previous studies have relied heavily upon the use of questionnaire-based measures rather than reliable and validated laboratory measures of speed choice, which means that it is difficult to determine whether driver behaviour is representative of actual real-world behaviour. Furthermore, these methods are limited in determining how drivers adjust their speed choices in response to changes in the road and traffic situation, which is part of everyday driving.

This thesis will build upon the existing research by investigating the relationship between hazard perception and speed choice through the use of validated laboratory-based methodologies. This thesis will examine how different hazards influence speed choice and how this relationship may be mediated through eye-movement behaviour and moderated by age and experience.

The Vulnerability of Young and Novice Drivers

Young drivers are over-represented in crash and traffic fatality statistics, particular during their first year of unsupervised driving (Preusser & Leaf, 2003; Williams, 2003). Worldwide, road crashes are the most significant cause of death for men aged 15-29 and the second greatest for 15-29-year-olds overall, according to the World Health Organization (WHO, 2007) figures. New Zealand has the second-highest per-capita crash fatality rate for young drivers (OECD, 2006), with young drivers in the 20 to the 24-year-old age group being approximately three to five times more likely to crash than the lowest risk 55 to 59-year-old drivers of the same gender (for a more comprehensive review, see Appendix 6).

In New Zealand, young inexperienced drivers are more than two and a half times as likely to have speed as a contributing factor in crashes than drivers over the age of 25 years (Stradling et al., 2000). Crashes involving drivers losing control of their vehicles are common in crashes involving young drivers, in which inappropriate speed plays a significant role. Thirty-nine percent of 15 to 24-year-old drivers involved in fatal crashes were in single-vehicle loss-of-control or run-off-road crashes, compared to twenty-one percent for older drivers. In addition, many head-on crashes also involve drivers losing control of their vehicles (Ministry of Transport, 2009).

Mayhew et al. (2003) were able to show that the crash likelihood is greatest in the month immediately following licensing for all drivers regardless of age and then decreases substantially over the following six months (Figure 11). During the learning stage of driving, crash risk is quite low, though once a driver migrates to a restricted licence, the likelihood of being involved in a crash dramatically increases. Gregersen et al. (2003) have suggested that the risk of being involved in a crash is 33 times greater for drivers once novices begin solo driving – thus, the transitional period between supervised and unsupervised driving appears to be a period of considerable concern.

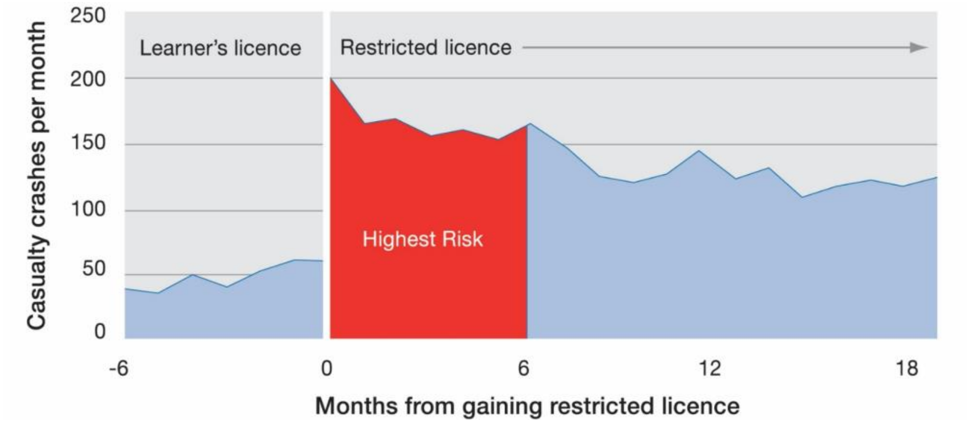

Figure 11: Crash profile of drivers as they move from supervised (Learner licence) to unsupervised driving, indicating a substantial increase in crash likelihood directly after transitioning to solo driving on a Restricted Licence (Ministry of Transport, 2009)

Groeger (2000) suggested that this increase in crash likelihood[8] may be attributed to the lack of developed higher-level driving skills, and this suggestion is supported by research conducted by Mayhew and Simpson (2002), which showed that the amount of supervised experience young drivers receive is insufficient to allow for the acquisition of competencies such as visual search and appropriate hazard perception abilities. Renge (1998) found that driving experience had a strong influence on hazard perception ability, risk perception and speed preference between newly licensed novices contrasted with experienced drivers, as well as driving instructors.

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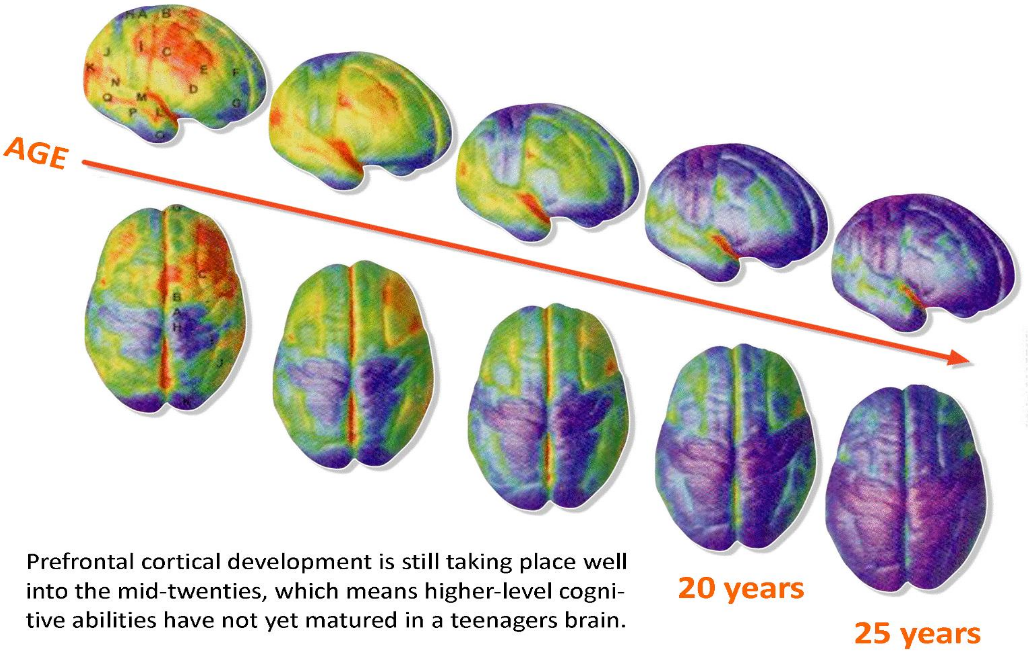
[8] Internationally, it has been highlighted in the literature that crash involvement of young drivers is greatest immediately following provisional (or restricted) licensure, and this increased crash risk is also reflected in New Zealand crash statistics (Ministry of Transport., 2009).

Developmental Factors

One of the most noteworthy considerations gained over the past two decades is that the adolescent brain has differing visual and cognitive processing capabilities compared to adults. A review of the literature gives evidence that limitations in visual processing (i.e., the frontal eye field) and limited cognitive resources and working memory are due to the lack of fully developed frontal lobes in young drivers, which may be associated with poorer hazard perception abilities. Adolescence is marked by significant changes in the brain, which are related to cognition and emotion. Increasingly so, contemporary research into risk-taking has emphasized the biological substrates of behaviour which involve the maturation and fine-tuning of the prefrontal, temporal, and cortico-limbic brain circuitry related to executive functions and emotional regulation (Albert & Steinberg, 2011; Dahl & Spear, 2004; Gogtay et al., 2004; Marcovitch & Zelazo, 2009; National Research Council, 2011; Steinberg, 2005). Figure 12 shows the progression of grey-matter maturation in five-year intervals from childhood to adulthood:



Prefrontal cortical development is still taking place well into the mid-twenties, which means higher-level cognitive abilities have not yet matured in a teenagers brain.

Figure 12*:* The development of grey matter in the cortex during maturation, showing changes in 5-year increments from Childhood through to Adulthood (from Gogtay et al. (2004)). Grey matter is where the bulk of mental processing occurs. It includes regions of the brain involved in sensory perception, decision making, behavioural regulation, memory, emotion, speech, muscle control and motor planning.

Executive functions are primarily performed by the prefrontal cortex (PFC) and are associated primarily with planning, regulation of behaviour and decision making, as well as divided and sustained attention (Sarter et al., 2001), precession speed, and cognitive flexibility, amongst others (Kurzthaler et al., 2005). Each of these cognitive functions has relevance to driving behaviour (Isler & Starkey, 2008). Research suggests that it takes young drivers longer to develop risk assessment skills and that young drivers' detect and assess hazards more slowly, especially during the early stages of learning to drive (Deery, 1999; Fisher et al., 2006; McKenna & Crick, 1991; McKenna et al., 2006). Importantly, among adolescents, the areas of the prefrontal cortices that are activated during exposure to social stimuli overlap considerably with other parts of the brain shown to be sensitive to reward stimuli (Casey et al., 2016; Sunstein, 2008). These changes are thought to be a principal contributing factor to socio-emotional development throughout adolescence. However, this heightened reward when engaging with peers may make teens more susceptible to unfavourable peer influence.

Hazard perception and visual tracking are also affected by the maturation of executive processes. This may predispose young and inexperienced drivers to misjudge road conditions or poorly respond to hazards (Chapman et al., 2002; Deery, 1999; Rosenbloom et al., 2008). Additionally, these refinements of the cognitive architecture of the brain that gradually lead to improved attention and awareness may explain why inattention (or focus on visually salient cues irrelevant to the driving task) frequently precipitate crashes involving young novice drivers (Keating, 2007; Underwood, 2007).

Young novice drivers find themselves in the dilemma that they need to increase their driving experience to reduce the risk of crash involvement, but the more they drive, the more they are exposed to high risks. Given all the facts about the high risks of young drivers for over half a century, many countries across the developed world have introduced some form of driver training or education to address this problem (Hatakka et al., 2002).

As previously discussed concerning risk-appraisal, drivers may maintain a stable level or target of acceptable risk, which can defeat the introduction of safety measures (McKenna, 1987; McKenna, 1990). In theory, Graham (1998) notes that risk-homeostasis will undermine all non-motivational countermeasures, as drivers will continually adjust their behaviour to accommodate reductions in situational risk by increasing personal risk behaviour. Wilde's (1994) response to these criticisms is that drivers can be encouraged to assume smaller target risk by promoting the consideration of long-term wellbeing; however, this requires that drivers can contextualise current risk targets within long-term goals. The lack of foresight can obscure this ability to project long-term outcomes - the 'myopia to future consequences' - that young people experience in their process of making decisions (Cauffman & Steinberg, 2000; Steinberg et al., 2009).

The study results by McKnight and McKnight (2000) indicated that young drivers had crashes not so much because of deliberate, reckless driving, but because of poor hazard anticipation. This is to say that, in general, novice drivers did not recognize the presence of hazards and consequently may not have perceived the risks associated with those hazards. McKnight and McKnight's (2000) conclusion that the heightened crash risk for young drivers is the result of deficient risk assessment and poor hazard anticipation was confirmed in a more recent study by Curry et al. (2011).

In an extensive American interstate survey involving over three-hundred thousand teen-related crashes, Curry et al., (2011) found that inadequate driving skills, such as recognition errors (e.g., inadequate surveillance), failures in decision-making (e.g., driving too fast for the conditions), and errors in performance (e.g., loss of control) accounted for the overwhelming number of crashes. Driving style, such as aggressive driving, was less commonly cited as the cause for speed-related crashes. As an outcome, they recommended that prioritization in driver training should be focused on improving hazard perception and visual surveillance while avoiding driver distraction. While essential to robust driver education, these higher-level driving skills ought to be accompanied by maintaining the existing broader educational approach targeted at societal-level changes involving norms and values (which are generally more directed to adjusting driving style).

Experiential Factors

Age has been found to be a very significant predictor of crash involvement, with several studies finding age apart from experience serving as a contributing factor in determining crash involvement before the age of 25 years. This is not to diminish the significance that quality driver experience plays in road safety but rather to highlight the vulnerability of adolescents due to functional changes that occur as a consequence of neurological development. For instance, according to a study by Mayhew et al. (2003) which examined the collision rate amongst novice drivers during the first months of driving, 16 years olds are involved in more crashes than recently licensed older drivers (age 20 or older). A study in Sweden in 2001 showed that drivers aged between 18 and 19 years old were five times more likely to be involved in a fatal crash than drivers aged between 35 and 50 years old (Gregersen et al., 2003). At that time, the prevailing view was that novice training programs should focus on acquiring lower-level driving skills, such as traction control and lane management.

The assumption was that if drivers were more competent in managing their vehicle control, especially in hazardous circumstances, then there would be fewer crashes. If crash statistics demonstrated a high rate of skid-related crashes, then presumably this points to a deficiency in skid management, and increased training should, in theory, reduce crash rates. However, following the widespread implementation of one such large-scale training program that emphasised basic car handling skills (such as the skid-training as mentioned above), novices drivers were being involved disproportionately represented in skid-related crashes. Gradually it was discovered that increased self-confidence coupled with an incomplete mastery of driving skills could increase the likelihood that young drivers would engage in dangerous driving – resulting in a dramatic increase in crashes.

The unexpected consequence of concentrating driver training on low-level skill acquisition was that it led to increased risk-taking and, subsequently, higher crash rates. Gregersen (1996) studied this phenomenon and discovered that drivers might develop a false sense of superiority in their driving ability, encouraging them to engage in greater risk-taking. This idea of inflated confidence conjoined with poor actual driving skill is known as miscalibration (Havârneanu & Popusoi, 2015; Kuiken & Twisk, 2001). Calibration refers to the internal balancing of task demand to task competency. Conceptualised within Fullers (2011) risk-allostasis theory, poor calibration results in a lower appreciation of risk factors, leading to drivers engaging in dangerous driving where the driver believes they can perform a risky manoeuvre without consequence. Miscalibration (or poor calibration) refers to a situation when task demands exceed task competency, allowing accidents to occur from loss of control in the inability to regulate the crash factors within the system (Fuller et al., 2007).

It became increasingly clear that basic training that focused solely on car handling skills was inadequate in creating competent drivers. This was the turning point where attention shifted to include other skill sets to complement existing training. There are many skills that drivers are required to develop throughout their on-road experiences, such as maintaining lane position, steering and vehicle control, and a plethora of rules governing safe interactions with other road users. While there are many situations where low-level training may prove helpful, these skills need to be blended in gradually with those skills that function at higher levels.

Most of these driving skills can be classified within a categorical hierarchy, composed of four levels ranging from the most basic (e.g., braking) to the more demanding and complex (e.g., situational awareness). This hierarchy of driver competencies is known as the Goals for Driver Education (GDE) matrix and was first proposed by Hatakka, Keskinen, Gregersen, Glad, and Hernetkoski (2002). The GDE matrix provides a framework to guide the licencing process by ensuring that novice drivers acquire all the necessary skill-sets before progressing from supervised to unsupervised (or 'solo') driving. The cornerstone of this hierarchy is the higher-level skill of hazard perception.

As stated previously, driving can be considered as a hierarchical process involving strategic, tactical, and operational levels (Salvucci & Taatgen, 2011), all of which depend on executive functions related to cortical maturation (Dahl & Spear, 2004; Spear, 2000) – and this has increasingly become the target of research into driver education. One such project, the 'Frontal Lobe Project', was conducted in New Zealand to investigate the relationship between executive functions and driving behaviour.

This two-week study provided invaluable scientific evidence that executive functions, especially working memory and cognitive switching, are associated with higher driving performance and more accurate self-appraisal of driving skill (Isler, Starkey, Drew, et al., 2008). Furthermore, following a brief but intensive training program of higher-level driving skills, it was demonstrated that improvements could be obtained in both driving ability and visual search behaviour. Using a specific higher-order training method based upon road commentary, the number of hazards perceived and the number of actions in response to perceived hazards was improved within a relatively short period (Isler, Starkey, Drew, et al., 2008; Isler et al., 2009). Similar training using road commentary has provided promising results in developing the hazard perception ability of older and more experienced drivers within a short period (M. Horswill et al., 2013).

In the literature, evidence of relevant factors at the level of individual-differences are frequently observed to be related to crash likelihood, such as gender (e.g., Laapotti & Keskinen, 2004) and personality traits such as sensation-seeking or need for control (e.g., Dahlen et al., 2005; Jonah, 1997). It is well known that males tend to take more driving-related risks than females. Lee (2007) pointed out that young male drivers, in particular, are more sensitive to peer influence in adopting inappropriate norms (e.g., Lin & Fearn, 2003; Simons-Morton et al., 2005). Renge (2000) found that young drivers are at higher risk to get involved in a traffic accident since they tend to misunderstand common traffic signals (e.g., indicators, headlights, or hand gestures). Furthermore, young novice drivers tend to demonstrate an inefficient pattern of visual search (e.g., Chapman et al., 2002; G. Underwood et al., 2002) and are less competent when adjusting their speed and following distance in keeping with the driving conditions (Clarke et al., 2005).

Similar differences in visual search behaviours between novice and experienced drivers were observed when drivers encounter multiple-lane carriageways, where hazards ought to be anticipated from both sides of the vehicle. In such situations, novice drivers focused on the centre of the carriageway, while experienced drivers increased scanning of the peripheral field where hazards are likely to intercept, such as vehicles transitioning between lanes. The maturation of the prefrontal cortex has been found to affect the performance in saccadic eye movement tasks, and in young people, performance deficits could be attributed to this ongoing process of maturation (Munoz et al. (1998), cited in Isler et al. (2009). Isler et al. (2009) noted that:

> … young drivers may be disadvantaged in their search behaviour by not being able to move their eyes fast and frequently enough to fixate on all important traffic information… However, the inefficient eye scanning behaviour of novice drivers may also stem from the fact that they have not encountered a sufficient number of hazardous situations, to allow them to

> draw on a broad knowledge base, or a mental map that could assist them in determining what to look out for in different traffic situations… (p. 12)

Crundall and Underwood (2010) found that young novice drivers possessed a smaller spread of visual search and devoted less attention to the periphery and mirrors when compared to more experienced drivers. Hazard perception, in part, could be considered a function of attentional resources being dedicated more broadly across the visual field, including the peripheral regions of the carriageway - with more rapid fixations across the visual field being associated with greater driver performance.

For example, while visibility was not found to be a factor differentiating eye movements between experienced and novice driver groups, Konstantopoulos et al. (2010) found significant differences in visual search behaviour between groups, and this is depicted in Figure 13:

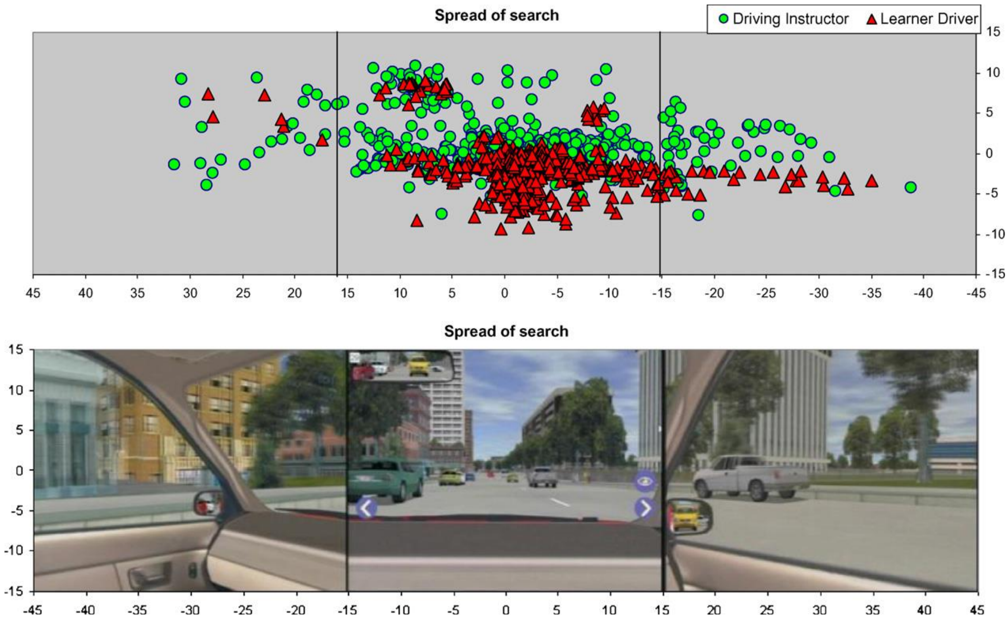


***Figure 13**:* The differences in visual search behaviour between Experienced and Novice driver groups on a simulated motorway scenario (Konstantopoulos et al., 2010)

The findings made by Konstantopoulos et al. (2010) indicated that novice and experienced drivers differed significantly in search behaviour. Konstantopoulos' (2010) research confirmed the previous findings made by Crundall and Underwood (1998), with experienced drivers having a more significant number of short fixations distributed across the entire horizontal field of view. Experienced drivers also displayed higher sampling rates across several road scenarios compared with novice drivers, with a higher number of fixations and shorter fixation times – suggesting experienced drivers collected more information pertaining to the road environment and salient hazards (Desimone & Duncan, 1995; Konstantopoulos, 2009; Konstantopoulos et al., 2010). Konstantopoulos (2010) suggested:

> [This] strategy of deploying frequent short fixations can be considered crucial in hazardous situations when the driver has to be able to anticipate dangerous on-road behaviours by maintaining awareness of many potential sources of hazard without becoming overly focused in any one source. Driving instructors spread their fixations on the horizontal axis significantly wider than learner drivers, irrespectively the visibility of driving conditions. (p. 831)

Konstantopoulos et al. (2010) suggested that driving instructors can shift their locus of visual attention across a broader visual range at a greater speed than novice drivers, as illustrated by the deployment of rapid fixations with a short duration.

Crundall and Underwood (1998) showed that young drivers have difficulties gathering relevant visual information while driving, especially when driving conditions become more complex, which is supported by Whelan et al. (2004). These themes are essential for understanding how drivers allocate their visual attention, and a modestly extended discussion can be found in Appendices 11, 14, and 17. Konstantopolous et al. (2010) recommend this implication be the subject of future research, with obvious practical applications to the development of new driver training methodologies, which will be a consideration toward the end of this thesis.

The Aim of this Thesis

In summary, this literature review has revealed the need for more research examining the relationship between hazard perception and speed choice and the potential role of eye movements to mediate such an anticipated relationship. The central focus of this thesis was to fill this gap in the road safety literature by examining in depth the role of hazard perception in speed choice, and to thoroughly and systematically test any observed relationship for its strength and causality, while taking eye movement patterns and driving experience into account as potential mediators and moderators.

In order to fulfil this aim, a series of experiments have been designed. Experiment 1 will test a laboratory-based speed choice task for ecological validity and measure the efficiency of eye-movement behaviour in novice and experienced drivers. Experiment 2 will examine if hazard perception skills relate to speed choices when the two tasks (hazard perception and speed choice) are separate and unrelated. Experiment 3 will merge the two tasks into one, requiring the participants to select the most appropriate (i.e., ideal) speed after each hazard perception trial. Experiment 4A will try to improve the hazard perception skills of the participants (particularly in young drivers), while Experiment 4B will examine if improved hazard perception relates to slower speeds. Each experiment will have a set of research questions and hypotheses, serving to fulfil the aim of this thesis.

Experiment 1

Introduction

One of the most challenging issues when measuring drivers' behaviour in a laboratory setting is determining ecological validity. This issue plagues the earliest 'low fidelity' simulators and video-based tasks to the more true-to-life and immersive simulators. Generally speaking, it is difficult to determine whether findings based in the laboratory correspond to real-world driving without observing real-world behaviour. Validating laboratory tasks frequently involve proxy measures of crash likelihood, such as questionnaires related to dangerous attitudes or beliefs and the self-reported number of crashes or traffic infringements. However, this approach requires a large and generally heterogeneous group of participants, as crashes and near-misses are relatively infrequent.

Regardless, simulators have become a ubiquitous tool in driver research, as experimenters can efficiently study drivers' behaviour by presenting participants with identical traffic situations under near-identical conditions, reducing the number of confounding factors that occur in naturalistic settings. While there are many benefits to using a simulator, there is always the concern that experimental findings may not be transferable to drivers in the real world. For example, it is questionable whether participants are motivated to behave in a simulator in the same way as they would in the real world (Carsten & Jamson, 2011).

One issue is that young drivers tend to view simulated driving as similar to a computer or video games (Kuiken & Twisk, 2001). Hence, they may view the task less seriously than they would if they were under real driving conditions. Evans (1991; 2004) noted that it is exceedingly unlikely that simulators can provide useful information on a participant's tendency to speed, as simulators lack the element of fear (e.g., risk of injury accompanying a potential crash), which elicits realistic 'absolute' validity. Participants' possible lack of fear makes the validation of laboratory measures of risk-based driving behaviour challenging, as participants have no real concern that a simulated crash will result in actual injury. While this is an important consideration, researchers believe that 'relative' validity can still be inferred by demonstrating that driver behaviour in a simulator reflects real-world observations (Blaauw, 1982; Carsten & Jamson, 2011). For example, Liu et al. (2016) found that drivers chose faster speeds on wider roads compared to narrow roads in a simulator, which confirmed similar naturalistic observations made by Fitzpatrick et al. (2003). The criteria for a simulator to have relative validity are met when the differences between real-world and simulated driving are of the same order and direction. When the values are identical between real-world and simulator-based experiments, the system is defined as having absolute validity (Blauw, 1982).

The first experiment aims to test the relative ecological validity of the video-based speed choice task used throughout this thesis, by determining whether drivers would choose similar speeds in the laboratory task compared with speed choices anticipated from data from drivers behaviour in a real-world setting. The speed choice task is a modification of the task developed and validated by Horswill and McKenna (1999). Their speed choice task was predictive of drivers' previous involvement in speed-related crashes and corresponded to questionnaire measures of riskier attitudes towards speeding. Horswill and McKenna's (1999) experiment was replicated in Australia by Thornton and Rossiter (2003). Cantwell (2010) then further adapted it for a New Zealand context, with several modifications, including the additional requirement that participants estimate the vehicle speed. Thornton and Rossiter (2003) and Cantwell (2010) found that their video-based tasks revealed differences in the speed choices of drivers with differing amounts of age and experience, with young novice drivers choosing significantly faster speeds compared with older and more experienced drivers. Cantwell (2010) found that these faster speed choices also corresponded to riskier attitudes and were predictive of higher self-reported traffic violations or fines (Cantwell, 2010). This ability to differentiate between novice and experienced drivers is one of the crucial requirements of validating hazard perception tasks (Horswill, 2016) – and in similar regard, the ability to differentiate between experience provides support for the validity of the video-based speed choice task.

One of the shortcomings of previous video-based speed tasks is that participants were required to provide their speeds, without reference to the perceived speed of the vehicle or the road limit, but simply to suggest how much faster or slower they would choose to travel. The potential drawback to this approach is that researchers cannot see necessarily how close to the road limit a driver would choose the speed, or whether over or under-estimating the vehicle's speed based on the video-based method influenced subsequently chosen speeds. Cantwell (2010) asked participants to estimate the vehicle's speed and then asked participants to select their ideal speed based on their previous estimate for that clip. Additionally, the roads were filmed using different vehicle speeds, requiring drivers to actively engage with the task rather than select a ‘default’ speed for all scenarios (e.g., selecting the same speed they had estimated the vehicle was travelling).

Cantwell (2010) noticed that experienced drivers adapted their chosen speeds to the differing filmed road scenarios in a previously developed task. In contrast, novice drivers seemed to choose speeds consistent with the posted speed limits for those roads. The filmed road scenarios ranged from open roads to arterial commercial, industrial, and urban roads. Suburban roads were the only road scenario where both novice and experienced drivers chose similar reduced speeds. This finding could potentially be explained by the greater visual complexity of suburban roads, which has a notable effect on drivers speed (Edquist et al., 2011; Oviedo-Trespalacios et al., 2017) – a hypothesis for which eye-tracking may provide further insight.

Wang et al. (2010) tested the hypothesis that one of the most sensitive measures of validity was eye-movement behaviour. It was argued that if drivers’ visual behaviour were consistent across different experimental settings, this would indicate a high degree of correspondence to real-world behaviour. Wang et al. (2010) compared drivers' behaviour in simulator versus on-road driving and found a high degree of both absolute and relative validity in drivers visual behaviour. Notably, they considered that eye movements demonstrate sensitivity to changes in the physiological arousal associated with mental workload (Wang et al., 2010).

Visual complexity presents drivers with more factors to consider, which subsequently increases the demand on drivers’ attentional and cognitive resources, as well as the level of perceived risk (Charlton & Starkey, 2011; Edquist et al., 2011; Weller et al., 2008; Wilmot & Khanal, 1999). Fuller, McHugh, and Pender (2008) propose that factors likely to increase drivers’ subjective workload and perceived task difficulty moderate drivers chosen speeds when controlling for changing risk on the road (Charlton et al., 2014; Wilmot & Khanal, 1999).

Another significant observation between novice and experienced drivers’ visual search was differences in the role of expectancy and value, which refers to the visual sampling strategy that maximizes the amount of useful information a driver retrieves from the visual scene (Lappi, 2014; Lemonnier et al., 2015). Expectancy refers to the driver’s anticipation of certain specific cues (i.e., it is reasonable for a driver to expect to encounter children) when driving past a school. Value refers to the significance that such cues play in influencing drivers behaviour (i.e., a ball rolling onto the road is of high value, as a child will likely follow it). As expectancy and value is a product of knowledge (i.e., schemata) that develops with experience, novice drivers may not have an efficient visual search strategy and fail to detect valuable cues about the road or traffic situation leaving them more vulnerable to making incorrect judgements (Konstantopoulos et al., 2010; Wickens & McCarley, 2008).

For instance, extensive research has found specific fixed road characteristics (e.g., the presence of a median strip and barriers) influence drivers' perception of risk and consequent speed choice (Elliott et al., 2003). Additionally, road markings have been found to influence driver's behaviour. Novice drivers fixate more on lane-markings in order to determine vehicle position and adjust steering than experienced drivers (Mourant & Rockwell, 1972), even though markings still inform experienced drivers of relative position through peripheral vision (Land & Horwood, 1995). As noted in the reviewed literature, many aspects of the road environment may influence drivers' speed choices, with weather and visibility conditions, as well as the roadside activity being a strong determinant of speed choice (Bella et al., 2014; Chinn & Elliott, 2002). This is a point of concern, as novice drivers, in particular, may fail to notice these factors and adjust driving behaviour, which may potentially lead to a crash (Chapman et al., 2002; Konstantopoulos et al., 2010; McKnight & McKnight, 2000). Hence in developing a test for speed choice, it is important to carefully choose roads that should differentiate between sensitive and insensitive drivers.

Despite research that has examined the role of certain factors on drivers' speed choice in general, there is relatively little research into how such characteristics influence drivers' chosen speeds under different road conditions in particular. This question was raised in the study by Cantwell (2010), where novice and experienced drivers made different speed choices that appeared to be related to the amount of perceived risk (i.e., calibration). The use of an eye-tracker would provide valuable information into the characteristics that drivers visually attend to in relation to their speed choices. Considering that personal perception and judgements influence speed choice, examining the influencing factors is a critical avenue of research and may help improve the way novice drivers can be trained in making speed judgements and provide information supporting the use of certain perceptual countermeasures.

While considering these areas for the advancement of knowledge, the ability of this new task to differentiate between novice and experienced drivers will indicate the relative validity of this task for further research. Furthermore, investigating the visual behaviour of novice drivers compared with more experienced drivers may reveal what specific cues drivers utilise in making speed judgements. This could help explain the differences in speed choices observed across road conditions between Novice and Experienced drivers found by Cantwell (2010). It is expected that novice drivers will choose faster speeds and be less sensitive to changes in road condition. Differences in speed choices between road types and conditions could potentially support the validity and sensitivity of the task as a laboratory measure of drivers' speed behaviour.

Research Questions

Following the reviewed literature, the following questions were addressed in relation to road environment, type, and condition in this experiment:

1. ***Does the video-based laboratory-based speed choice task show ecological validity?***

   Can the ecological validity of the video speed task be inferred by examining the chosen speeds that drivers of different age and experience make in the laboratory compared to expected real-world behaviour?

   It is possible to infer that the laboratory speed task is ecologically valid if, as expected based on previous research by Horswill and McKenna (1999) and Cantwell (2010), young novice drivers choose significantly faster speeds than more experienced and experienced drivers and that the choice of speed overall corresponds to observed speeds measured in the real world.

   Are the speed choices of all drivers dependent on the level of the driving risk (wet versus dry road, day versus night-time driving, no road markings versus road markings)?

   The hypothesis drawn from the literature is that drivers will slow down under more difficult conditions. In response to increased driving task demand, and as the risk present in the situation increases, there should be a subsequent reduction in speed. This, in turn, could demonstrate the ecological validity of the laboratory speed choice task, according to the various theories of risk, such as homeostasis theories (e.g., Wilde, 1982, 1994; Fuller 1992). It is expected that as the traffic environment becomes more complex, drivers will reduce their chosen speed

(Edquist et al., 2011), consistent with their perception of risk (Elliott et al., 2003; Lewis-Evans & Rothengatter, 2009). The use of eye-tracking may provide insight into the factors during night driving that contributed to the faster speeds observed by Renge (1998). Additionally, a reduction of speed on the more demanding roads will demonstrate the sensitivity of the video speed task measure.

2. What visual cues do novice and experienced drivers focus on when making speed choices?

The hypothesis is that novice drivers will scan the road less broadly than experienced drivers and potentially fail to identify cues that assist in making appropriate speed judgements. In real-world driving situations, inexperienced drivers have longer fixation times accompanied by fewer fixations (Crundal & Underwood, 1998; Underwood et al., 2013), with a narrow spread of visual search compared to experienced drivers (Konstantopolous et al., 2010; Vlakveld, 2011). Eye movements are expected to reflect differences in visual expectancy and value between novice and experienced drivers (Lappi, 2014). If the same differences can be found in a laboratory speed choice task, this provides stronger support for the task's validity based upon Wang et al. (2010), and further examination of the effect of eye movements on chosen speed is worthwhile considering.

Method

Participants

This research was conducted in line with the University of Waikato Ethical Guidelines concerning human testing (the University of Waikato Handbook on Ethical Conduct in Research, 2001). Participants' eligibility criteria were that they held a valid New Zealand driver's learner, restricted, or a full license, and had corrected to normal or close to normal vision. Participants were recruited from the School of Psychology at the University of Waikato (Hamilton Campus) using posters and online-course advertisements. Eligible students received course credit for participating. Due to a teaching recess, participant testing occurred in two batches over approximately two months. Based on previous research conducted by Cantwell (2010) and the effect size given the number of participants in that study, a sample of 42 participants was determined to be appropriate for this first experiment.

Given the significant age difference, as well as referring to previous research related to age and the development of the prefrontal 'executive' systems of the brain (Isler, Starkey, Drew, & Sheppard, 2008; Dahl & Spear, 2004; Steinberg, 2005, 2008, 2009), as well as the significance of age as a predictor of crash involvement, drivers were assigned to one of two driver age and experience groups, with participants aged younger than 25 years old assigned to the "<25 <" driver group (referred to as novice), and participants aged 25 years and older assigned to the "> 25 and older" driver group (referred to as experienced). A total sample of 42 participants (22 males, 20 females) participated in this study. The mean age of drivers in the Novice group was 19.3 years (*SD* = 0.68), and for the Experienced driver group was 29.5 years (*SD* = 4.19).

Novice drivers had driven an average of 3.5 years (*SD* = 0.69) and reported driving an average distance of 198km (*SD* = 64.43) per week. Twelve of the young drivers had full licences, seven held restricted licences, and two held learner licences. Experienced drivers all had full NZ driver licences, had driven an average of 14.8 years (*SD* = 2.60), reporting a distance of 135km (*SD* = 29.12) driven per week. Measures of self-reported incidences of crashes/collisions, near misses and vehicle fines in the past 12-months, are presented in Table 1:

Measures of self-reported incidences of crashes, near misses and vehicle fines in the past 12-months, distance driven in the average week, and participant age are presented in Table 1:

Table 1:

The Demographic Information and Driver History of Participants. Total (T) are shown, followed by Means (M) with Standard Deviations in brackets.

Driver Group	**N**	**Age (years)**	**Distance Driven (km/h)**	**Years Driving**	**T / M Crash Rate**	**T / M Near-misses**	**Mean no. of Fines**
Novice	21	19.3 (0.68)	198 (64.43)	3.5 (0.69)	3 / 0.04 (0.200)	48 / 1.76 (2.471)	7 / 0.24 (0.523)
Experienced	21	29.5 (4.19)	135 (29.12)	14.8 (2.60)	1 / 0.21 (0.535)	8 / 0.89 (1.696)	2/ 0.21 (0.535)
Total	42				4	56	9

The number of near-misses was very high for the novice driver group. Given this disparity, it is unknown whether the reported ‘near misses’ are genuine, potentially indicating that the question was worded without enough specificity. Hence, near misses will not be used as a measure of driver history, while crashes will be used. Self-rated skill as a driver was found to differ significantly between driver groups $t(41) = 2.457$, $p< 0.05$, with young drivers rating “somewhat better than the average driver” and experienced drivers rating “about the same”.

Research Design

The experiment was designed as a within and between-subject study with multiple repeated measures. The independent variables being examined are the road environment (urban or rural), road type (i.e., with or without shoulders/markings), and condition (i.e., day or night, dry or wet). The dependent variable was the driver's choice of speed for each of the clips, measured in km/h. This design allows for comparison between driver age groups for different road environments (rural and urban), conditions (dry or wet, day or night), and various road types (e.g., presence of shoulders; width and visual distance).

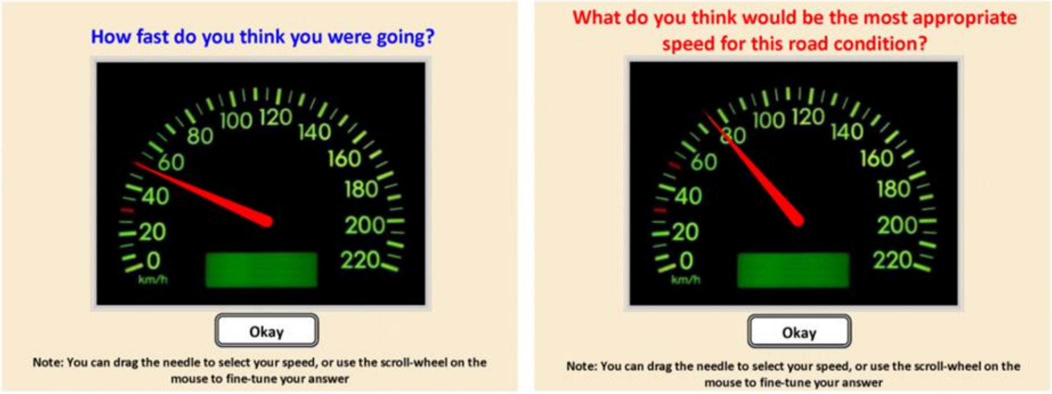
In this experiment, the examination of the differences in speed choice between the two driver age groups was important in determining whether the task was ecologically valid by differentiating between Novice and Experienced Drivers. Secondly, to demonstrate task sensitivity, the speed choices of drivers was examined under different weather conditions and different road types. It was expected that if the task was valid, drivers would choose slower speeds on wet roads as opposed to dry roads, and slower speeds during the night compared to daytime. Different roads with marking should also affect drivers' behaviour, with drivers selecting faster speeds on roads that are perceived to be less risky.

Video Speed Task (VST)

The Video Speed Task (VST) was used to examine drivers' ability to estimate the speed of the camera vehicle in the video clip and determine appropriate speeds for the road conditions. Video clips covered several different traffic environments (Rural and Urban) and road conditions (Wet or Dry, Night or Day) and were recorded at different speeds. Participants watch a total of 30 video clips with a duration of 6 seconds each, showing the different traffic environments (Urban and Rural roads) and road traffic/weather conditions (e.g., Wet and dry).

The clips were carefully selected as not to include speed signs or other roadside signage that might influence drivers speed choices, in keeping with the general guidelines established by Horswill and McKenna (1999). Although some road environments contained few static or dynamic hazards (e.g. rural roads), urban situations almost invariably include hazards that a driver ought to be mindful of when making speed judgements. As real-world drivers rarely seem to consult their speedometers while engaging in speed-related behaviour (Mourant & Rockwell, 1972), there was no speedometer displayed during the clip. This ensured participants relied on their own perception to inform their speed choice and estimates.

Participants could select the speed they felt was most appropriate by moving the needle on a speedometer styled menu (Figure 14).



How fast do you think you were going?

Note: You can drag the needle to select your speed, or use the scroll-wheel on the mouse to fine-tune your answer

What do you think would be the most appropriate speed for this road condition?

Note: You can drag the needle to select your speed, or use the scroll-wheel on the mouse to fine-tune your answer

***Figure 14**:* The Speedometer display presented in the Video Speed Task. Participants were presented with a speedometer. Initially, participants were to estimate the vehicle speed, and then they could choose their 'ideal' speed by moving the needle. In this example, the needle is set to 75km/h.

Road Conditions and Types

There were two different traffic environments used in this task, rural/open and urban roads. For example, urban road environments were differentiated into two types based on their fixed features and then according to the road condition (e.g., day or night). Video footage was collected for both day and night road conditions at camera vehicle speeds of 50, 30, and 10 km/h. The filming occurred during the mid-late afternoon (1-3 pm) for the day condition, and then again after 'nautical' sunset (9-10 pm) for the night condition. This is illustrated in Figure 15:

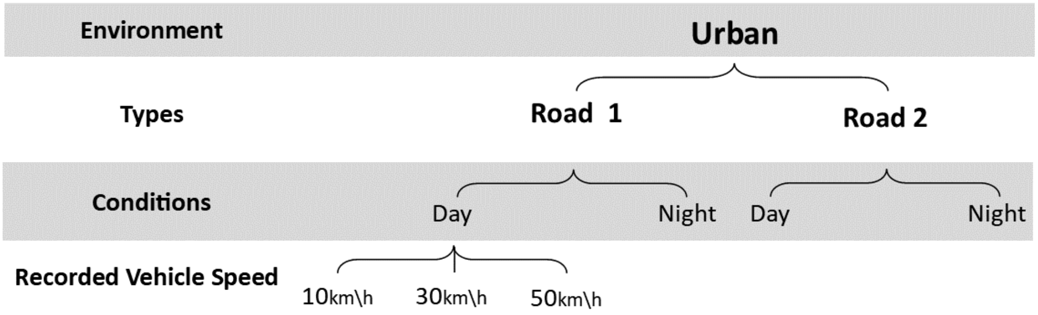


Figure 15: A diagram showing the arrangement of the Urban Road Environment, Type, Condition, and then finally, the vehicle speed when the video was filmed. For example, Urban Road 1 Day (UD1) is the Urban Environment, the Type being Road 1, filmed during the Day condition.

Urban roads (see Figure 16), with a legal speed limit of 50km/h, were filmed under the road conditions of day and night, with numerous hazards, including stationary hazards (e.g., parked cars) and moving hazards (e.g., pedestrians). Urban Road 1 was narrow with a sharp turn approximately 50m ahead. Urban Road 2 had a centre lane, was straight and extended into the visible distance with reasonable clearance to the left-hand side of the vehicle (roadside).

***Figure 16**:* Urban Road Conditions (Day/Night) with Road Markings and Centre and Edge Medians either Absent (Road 1) or Present (Road 2).

Rural roads with a legal speed limit of 100km/h (see Figure 17) were filmed with the wet and dry road conditions and with and without lane markings and shoulders. In the New Zealand context, frequently rural roads feature median-strip markings and reflective 'cat's eyes' at the centre of the road, with reflective batons skirting the shoulder at spaces of approximately 50 meters increasing in frequency on approach to corners.

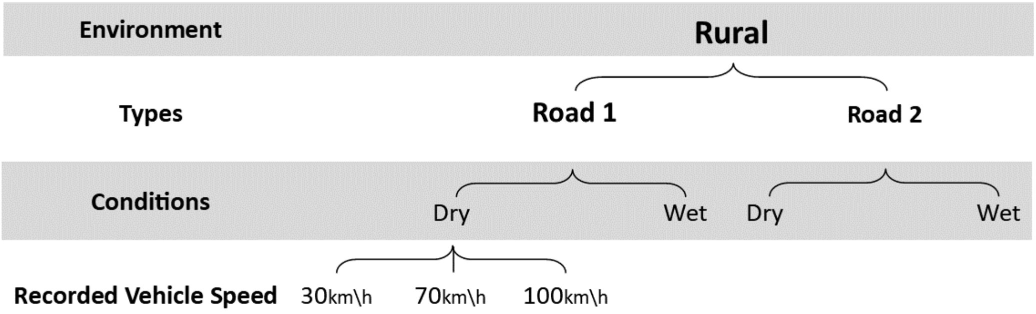


Figure 17: A diagram showing the arrangement of the Rural Road Environment, Type, Condition, and then finally, the vehicle speed when the video was filmed. For example, the figure shows Road Type 1 under the Dry Condition.

Rural Road 1 had no markings, no shoulder and was approaching a corner, and Rural Road 2 had clear markings, a wide shoulder, and ran level and straight. For the conditions in rural road environments, the footage was obtained in wet and dry conditions, with camera vehicle speeds set at 100, 70, and 30 km/h. Rural roads with different type and condition are shown in Figure 18:

Figure 18: Rural Road Conditions (Wet/Dry) and Types, where lane-markings and shoulder lines are absent (Road 1) or present (Road 2).

The experiment was conducted in a quiet, air-conditioned room measuring approximately 16m^2. The participant was seated in a recliner chair facing the display monitor. The participant was one metre away from the screen (giving a viewing angle to screen edges of ~60°). The participants used a mouse placed on a small platform to their preferred side of the chair. The room was illuminated during testing, as shown in Figure 19.

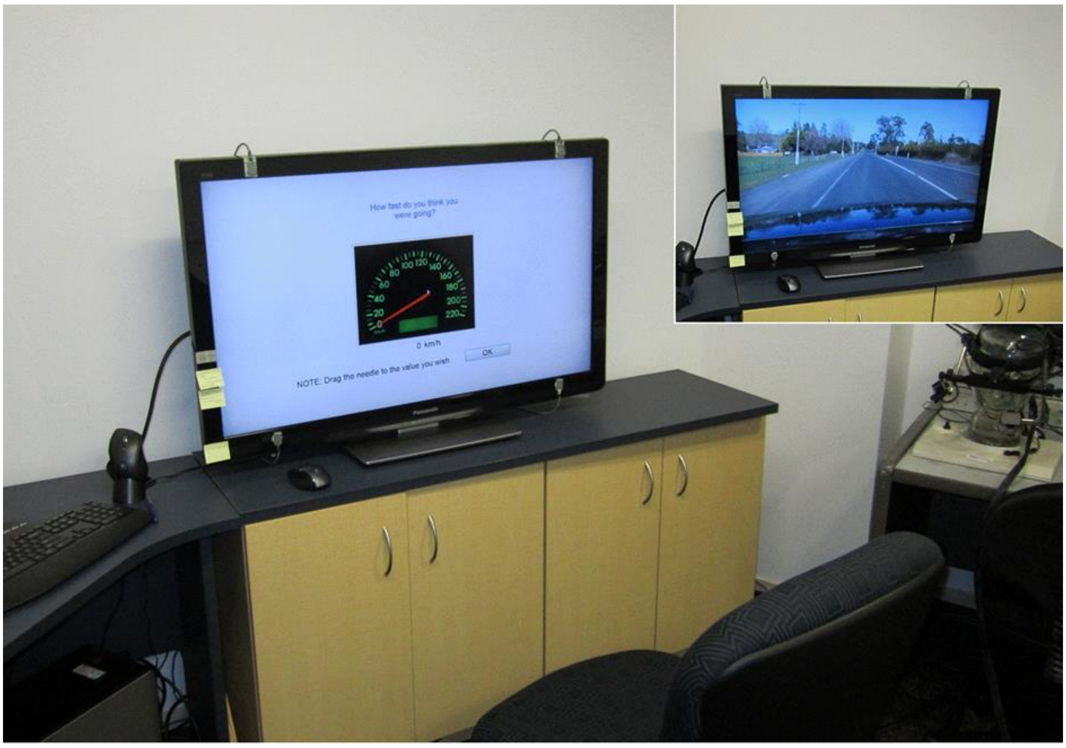


Figure 19: The laboratory setting demonstrating the task display and participant seating. The inset to the upper right shows one of the Video Speed Task clips.

The computer screen was initially blank before the videos were presented. A mouse click on the button in the centre of the screen labelled "Start Video" began the task. Following a three-second countdown, a six-second-long video clip was shown of a car travelling along a section of road without sound. After viewing each video clip, a new screen was presented, which asked participants to answer two questions:

> a) How fast do you think you were going? Using the mouse, the participant could either drag the needle or click on the speed they wanted to select, to position an on-screen speedometer needle. Once the participant was happy with the speed they had selected, they clicked the "Okay" button move to the next screen
>
> b) The participant was then asked, "What do you think would be the most appropriate speed for this road condition?" and as in the previous screen, the participant was able to select the speed that they preferred driving in that road condition using the on-screen speedometer.

The speedometer was based on a conventional vehicle display (ranging from 0-220 km/h) with the starting position set to zero. This process was used across all trials of the VST.

Once participants had selected their estimated and preferred speeds, the original blank screen would reappear with the prompt "*Next Video*" began the three-second countdown for the next video trial in the sequence. The process for each trial was the same, and it was repeated until all video clips were shown (30 trials, two practice, and four repeated trials). Once all the video trials were completed, the program ended.

To ensure that participants were making consistent speed estimates and choices, the task contained four repeating video trials (2 Urban, 2 Rural). These repeated video trials were correlated to determine the test-retest reliability for speed estimates and choices.

Eye-tracking for Validating Video task

Eye-tracking is a technique that measures changes in the relative position or movements of the eye(s) in relation to stimuli presented in the visual field. In this experiment, an eye-tracker will be utilised to examine any differences between novice and experienced drivers in how they view and use visual information related to speed choice and the different road environments/conditions. As different groups of drivers have been examined extensively, there is a good amount of information that can be used to compare and validate the speed choice task. If there are behavioural differences between the road conditions and type, this can be used to confirm the validity of the task. A more comprehensive discussion of eye-tracking can be found in

Appendix 9.

The eye-tracker measures such factors as the spread and number of fixations, the amount of gaze devoted to particular on-road features, and the amplitude and pattern of saccadic movements. These measures can be used to infer what drivers are using to create a mental representation of the road environment (Horsley et al., 2013).

The primary eye-tracker used in this thesis is the EyeLink II™. This head-mounted binocular eye-tracker allows the participant freedom of head movement while still recording eye movements with a high degree of accuracy. Participants have a greater degree of freedom to move with the head-mounted eye tracker; however, they were instructed to remain as still as possible throughout the experiments after being comfortably seated until the validation and calibration procedure was complete. Experiments using the EyeLink II™ were conducted using a Samsung high-resolution 48” display, with a Dell Optiplex 780 to record the eye-movement data, and a Dell Minitower (Intel i5, 2.8GHz, 4Gb RAM, 4Gb Graphics Card) running Windows 8-10. Eye movements were sampled from both eyes at a rate of 250-500Hz.

Eye-tracking Calibration and Validation

In order to ensure that data collected by eye-tracker equipment is accurate it was calibrated for each participant. This procedure is identical for the EyeLink II and the EyeLink 1000 used in this thesis. The eye-tracker was securely fastened to the participants head, and the two cameras were positioned to allow for a clear view of both the pupil and reflected corneal light (see Figure 20).

Figure 20: The binocular eye-tracker used throughout this thesis (EyeLink II ™, SR Research). . As displayed, the Eye-tracker was secured to the participants head using three fastener straps, and two IR-cameras with IR-LEDs were used to record Binocular eye movements.

For calibration, a matrix of 9-dots appeared one at a time at points about the screen (to map the edges and centre of the screen. Participants were instructed to focus on each point as they appeared. This procedure was conducted twice to enable validation before the start of each experiment. Using a 9 point calibration grid with an error threshold of +-2 degrees was the threshold for proceeding with the experiment. The initial calibration procedure took approximately 20 seconds and was followed by validation, which followed the same sequential target dot display. Where possible during the experiment, drift correction was conducted between each trial. Drift correction involved participants focusing on a single dot that appeared between trials, located in the centre of the screen, to ensure consistency in fixation location across the course of the task. The eye-tracker was able to use any variation to recalibrate if any drift was identified. If the participant's head position shifted during the experiment, or participants altered position noticeably between trials during an experiment, a calibration and validation procedure was conducted to correct for any potential error.

Measuring Saccades and Fixations

The essential measures of eye movements are fixations and saccades. Saccades can be defined simply as rapid eye movement with direction and acceleration, typically varying in duration from 10ms to 100ms (Duchowski, 2003). The perceptual system uses saccades to direct the eye from one point of interest to another. A fixation occurs when eye gaze is directed and is usually representative of mental processing. Fixation durations vary and are task-dependent. For example, the mean fixation duration on a reading task is 225ms, while for scene perception, it is 330ms (Rayner, 1998). Fixations and Saccades are shown in Figure 21, superimposed over Urban Road 2 during the Day Condition:

Figure 21*:* Fixations and Saccades, as shown in DataViewer™ (SR Research). Fixations are shown (top) as circles, with the diameter representing the duration. Saccadic eye movements (bottom) are presented as orange lines connecting fixations. The pattern of saccades, or 'jumps', between fixations can be used to determine the visual search strategy used.

In this research, fixations that were shorter than an interval of 80ms were excluded, as these often preceded multiple short saccades that were considered corrective eye movements unrelated to the acquisition of visual information (Duchowski, 2004).

Fixations with a duration longer than 140ms were considered to relate to sustained focal processing (Holmqvist et al., 2011), indicating where drivers' visual attention was orientated. This criterion was used to distinguish cognitive-process related fixations from non-cognitive fixations (e.g., Crundall & Underwood, 1998). In this research, the default SR Research DataViewer™ settings were used to calculate fixations and filter out micro-saccadic and tremor noise.

Fixation durations ranging from 200ms are typical for the early stage of perceiving hazard-related stimuli within a driving-related context (Velichkovsky et al., 2002; Pollatsek & Rayner, 1982). Crundall and Underwood (1998) found that fixations associated with perceiving hazards range from 325 ms to 395 ms given the driving demands. Following on from this early research Geoffrey Underwood et al. (2002) found that novice drivers average gaze ranged from 836 ms on rural roads to 512 on urban roads. Experienced drivers gaze was found to range from 822 ms to 509 ms under the same conditions. Based on this previous research, it was anticipated that novice drivers would have longer fixations when perceiving hazards, while experienced drivers would have shorter fixations when perceiving hazards.

Fixations provide a means of determining where a driver has gained visual information about the road or internal vehicle instruments. The duration and distribution of these fixations is an essential measure of both the total time spent assessing the importance of features in the visual field to the driving task and the efficiency of a person's visual search strategies (Vlakveld, 2014). These measures can be used to differentiate between novice and experienced drivers effectively[9] as it is generally assumed that novice drivers require more sustained fixation time than experienced drivers to extract relevant driving-related information from the environment. Research also suggested that experienced drivers will make more saccadic movements across a broader area of the visual field and that the time between their saccades will be shorter. For more information, refer to

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[9] Konstantopolis (2011) focused his thesis on the effeciancy of visual search and the importance of driver education and the development of training interventions.

Appendix 9.

Computer and Display Settings

The video scenarios for the Video Speed Task (VST) were presented on a Panasonic 48" high definition LCD at a resolution of 1920 x 1080i pixels (16:9 aspect ratio). The display settings were set to factory standard. Participants were seated in a desk chair positioned 1 meter from the display, giving a viewing angle of 54°. The experiment ran on a Dell OptiPlex 780 Minitower desktop computer (3.2GHz processor, 4GB RAM, Nvidia GeForce 360) running Microsoft Windows 7 Enterprise.

Participants were tested using a head-mounted eye-movement tracker (EyeLink II, 500Hz sampling rate) to collect eye-movement data. The participant setup and briefing, calibration and validation procedure was conducted. In this experiment, between-trial drift correction was performed in this speed choice task when required; however, the three-second countdown provided a reference for post-hoc drift correction.

The need for drift correction or recalibration was determined by the real-time observation of drivers visual behaviour as fixations were superimposed in real-time over the video clip as it was played. This provided a unique view of where participants were focusing on a separate display, allowing the experimenter to determine when drift correction or recalibration was required (e.g., when gaze shifted from the count-down between trials).

Procedure

Participants were provided with an overview of the experimental setup and the task requirements, including how the eye-tracker was attached. Participants were given an information sheet and ethics consent form (Appendix 2). After providing consent, participants were seated in front of the display, approximately one meter from the screen. The eye-tracker was placed on the participant's head. Participants were asked to look at each edge of the display, and the cameras were adjusted to ensure the cornea and pupil were correctly measured. Once the eye-tracker was configured, participants were given a mouse and mouse-pad to select speeds. The eye-tracker was configured using a 9-point calibration and validation grid, with an acceptable threshold of 2 degrees.

The speed choice task began with two practice trials followed by 28 video clips representing different road scenarios. Four of the video clips are repetitions of previous clips to measure consistency across the experimental trials. The task consists of 24 video scenarios, covering the urban and rural road environments and type/conditions presented in a predetermined randomized order that was consistent for all participants. Participants were then asked (for each clip) to estimate how fast the vehicle was travelling (estimate measure) and what the appropriate speed would be for the road they were just shown (choice measure). Once the experiment concluded, participants were provided an informal debrief and thanked for their participation.

Results

Speed Choices and Estimation

Initial analysis was conducted on the raw data to test for validity and to determine what form of analysis would be the most appropriate. Statistics related to this initial analysis of the normality and descriptive information are found in Appendix 3. The speed choices for the different roads were grouped according to their primary characteristics (type, i.e., with and without markings) and road conditions (i.e., day or night, wet or dry). As the differing camera vehicle speeds (e.g., 10, 30, 50km/h) were not found to influence participants' speed choices. The total mean speed choice for the two urban and two rural road types was calculated for each condition. This provided the dependent variable 'speed choice' measured in kilometres per hour (km/h).

Aggregated Road Speed Choice and Driver Age Group

In order to demonstrate ecological validity, it was anticipated that the video-based speed choice task would differentiate between Novice and Experienced drivers choice of speeds, as had been observed in the reviewed literature and previous research using video-based tasks. The differences in speeds between Driver Groups were of fundamental interest, as speed choice between Novice and Experienced drivers have been found to vary significantly in the literature (e.g., Cantwell, Isler, & Starkey, 2013), and the road condition is likely to have a powerful effect. The mean speed choices from the two different road types for each road environment were calculated to provide an overall measure of speed choice between conditions.

For an analysis of the two driver groups, one being provided with the camera vehicle speed and the other having to estimate the camera vehicle speed before making speed choices, refer to Appendix 7.

A graphical representation comparing Novice and Experienced Drivers is shown in Figure 22. From inspection of the figure, it appears that Experienced drivers choose slower mean speeds than Novice drivers:

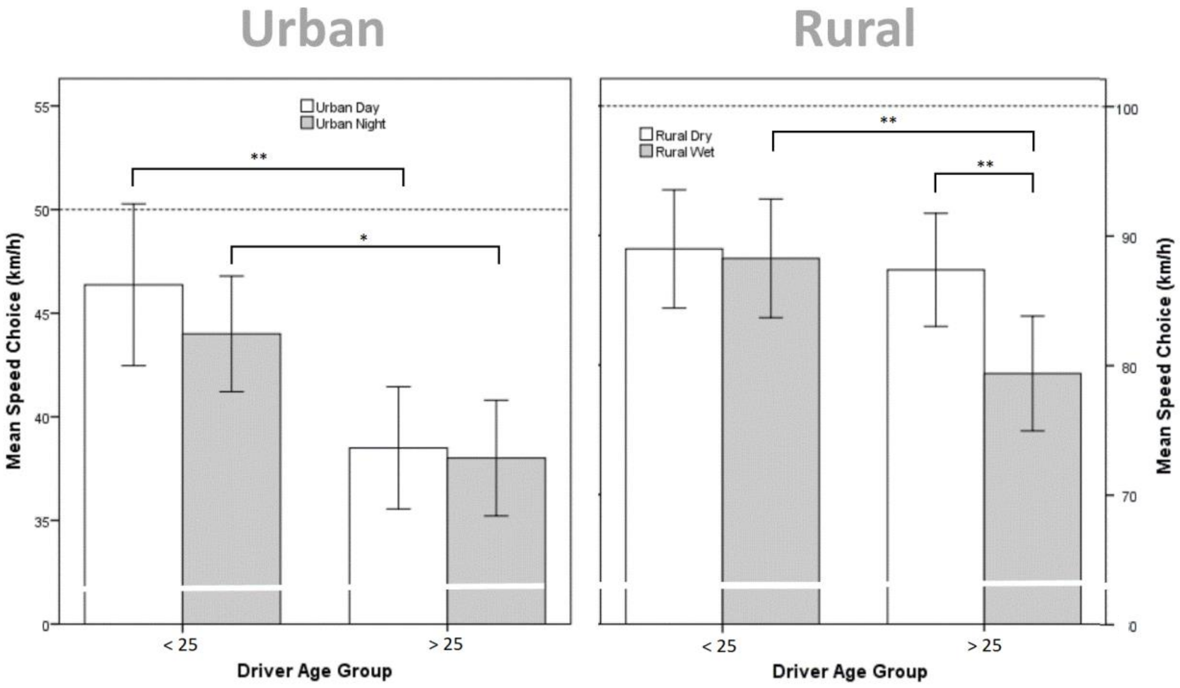

***Figure 22**:* The Mean Overall Speed Choice for both Urban (left) and Rural (right) Road Conditions, by Driver Age Group. Speed Limit is indicated by the horizontal dotted line. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p< 0.05$ *, and $p< 0.01$ **

Figure 22 indicated that there were differences in the speed choice between Driver Groups. Novice drivers, overall, chose faster mean speeds than Experienced drivers under both the Day and Night conditions for the Urban Road Environment and faster speeds for the Wet condition on the Rural roads. Both Driver Groups chose similar speeds for the Dry Condition on Rural roads. There appears to be a within-subject effect for Experienced drivers, who chose slower speeds under the Wet condition when compared to the Dry condition, while no within-subject differences can be seen for Novice drivers

A mixed, two-way 2 (Driver Group, <25 years vs ≥25 years) x 2 (Road Condition (Urban Night vs Urban Day, repeated measures) ANOVA was conducted on the speed choices. The ANOVA was significant, Wilks Λ= 0.940, $F_{(1,41)}$= 4.975, p< 0.05, η_p^2= 0.06, with a significant main effect for Driver Group, $F_{(1,41)=}$ 35.50, *p*< 0.01, η_p^2= 0.307, and no significant main effect for the Urban Road Condition, $F_{(1,41)}$= 0.99, *p*=.331, η_p^2= 0.012. No significant interaction between Driver Group and Urban Road Condition was received, $F_{(1,41)=}$ .451, *p*= 0.51, η_p^2= 0.006.

A similar, mixed two-way ANOVA was conducted for speed choices in the rural Road Condition (Rural Wet vs Rural Dry), revealing a statistically significant effect, Wilks Λ= 0.891, $F_{(1,41)}$= 9.497, p< 0.01, η_p^2= 0.109, with a significant main effect for Driver Group, $F_{(1,41)}$= 5.613, p< 0.01, η_p^2= 0.06, and a significant main effect for rural Road Condition, $F_{(1,41)}$= 36.86, p< 0.01, η_p^2= 0.315. No significant interaction between Driver Groups and rural Road Condition was received, $F_{(1,41)}$= .625, p= 0.43, η_p^2= 0.008.

A series of post-hoc one-way ANOVAs were conducted for the Driver Groups' speed choices for each road condition (Table 2:

Table 2:

Comparing the Mean Speed Choices (post-hoc ANOVAs) between Novice and Experienced Drivers for each Road Condition

				Driver Group			
				Novice		***Experienced***	
	F-value	Sig	η_p^2	M	SE	M	SE
Urban Day	17.463	0.01**	0.304	46.4	1.88	38.5	1.04
Urban Night	18.852	0.05*	0.149	43.9	1.34	38.0	1.03
Rural Dry	1.114	0.58	0.027	88.9	2.16	87.3	2.76
Rural Wet	25.465	0.01**	0.309	88.2	2.21	79.3	2.11

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Speed choice was significantly different between the Driver Groups on Urban roads for Day and Night driving conditions. The Novice driver group chose faster mean speeds in the Urban Day and Night road conditions than the Experienced driver group.

Speed choice was also significantly different between the Driver Groups for the Wet driving condition on Rural roads, with Novice drivers choosing faster speeds than Experienced drivers. There was no significant effect found between Driver Groups in the Rural Dry condition, with both groups of drivers choosing similar speeds.

Road Environment, Type, Condition, and the Effect on Speed Choice

Another way to demonstrate ecological validity is to focus on the different Road Types within each filmed Environment. This would demonstrate that drivers were sensitive to the differences in road width and markings, which have been shown to influence speed choices in the real world. The initial analysis focused on the differences between the Driver Groups responses to Road Environments and Conditions. Potential differences in the mean speed choices of novice and experienced participants according to differing road Conditions were anticipated by previous literature (Cantwell et al., 2012; De Craen et al., 2011). The following analysis determined whether there were overall effects between road conditions (Day/Night, Dry/Wet) and between road types that had different characteristics.

The mean speed choice was calculated for each road type and condition, as shown in Figure 23. Overall differences were calculated first, followed by the analysis of Driver Group effects (see Table 3). For context, Urban Road 1 and Rural Road 1 had narrow shoulders and limited markings, whereas Urban Road 2 and Rural Road 2 had wide margins and clear road markings.

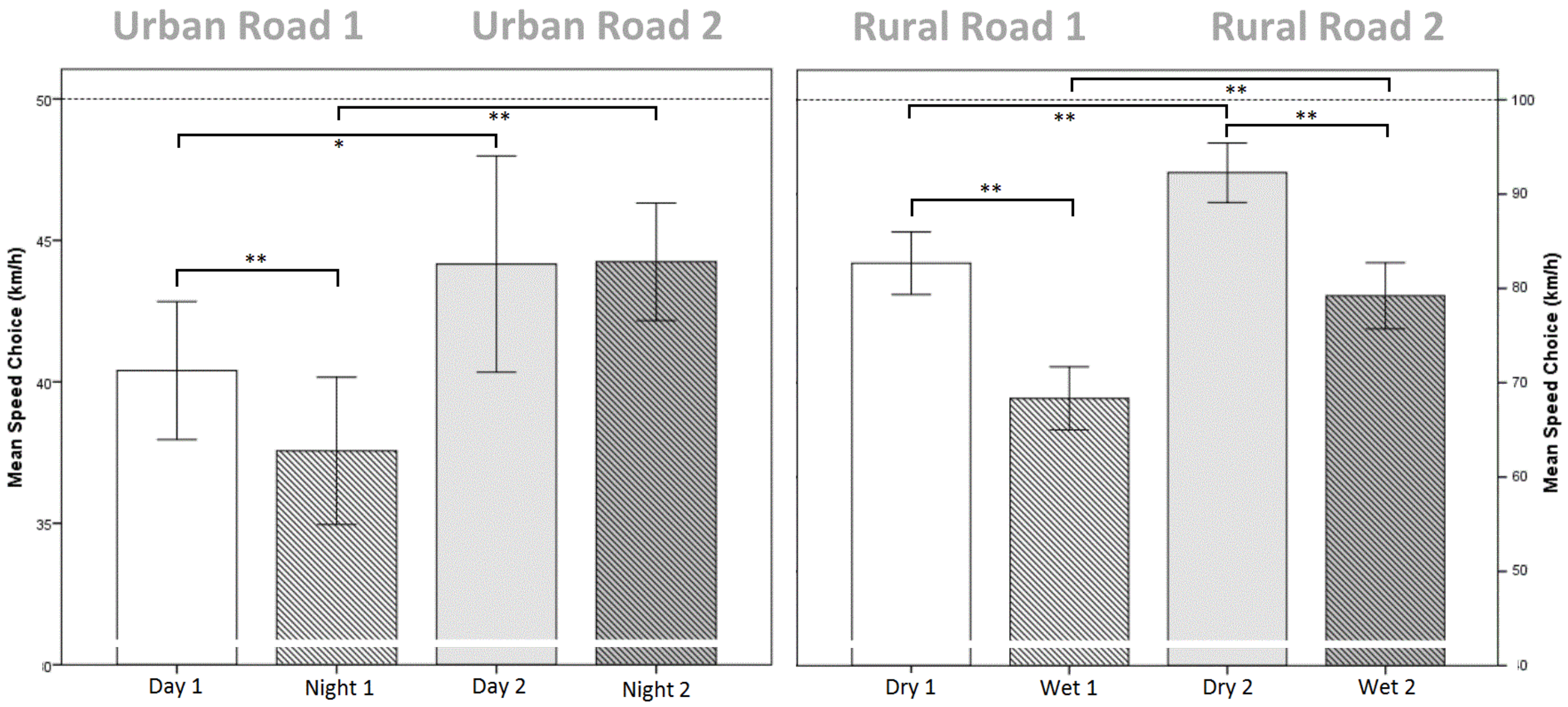

***Figure 23**:* The difference between Urban (left) and Rural (right) Road Type and Condition. The stripes indicate Road Condition: Night for Urban (left pane) and Wet for Rural (right pane). The horizontal dotted line indicates the road speed limit. Error bars represent 95% CI. Significance values are indicated, $p< 0.05$ *, and $p< 0.01$ **

Examining the Between and Within-subject effects for Road Condition and Types

Visual inspection of Figure 23 indicates that road condition and type influence all participants' overall speed choices. Both groups of drivers selected slower speeds for Night than for Day conditions for Urban Road 1. There are substantially lower chosen speeds on Urban Road 1 (no markings) than Urban Road 2 (markings) when comparing urban road types. Participants chosen speeds were similar irrespective of the condition by choosing roughly the same speeds for both Day and Night conditions.

Figure 23 also clearly showed that both road type and condition influenced drivers' speed choices. Overall, participants selected slower speeds for the Wet when compared with the Dry condition. There were differences between Road Type, with Rural Road 1 (no markings) having lower speeds than Rural Road 2 (markings).

Table 3:

Comparing Speed Choices for each Road Condition (post-hoc ANOVA) for Urban and Rural Road Types

Environment	**Type**	**Condition**	**F-Value**	**Sig.**	**η_p^2**
Urban Roads	1 (no markings)	Day	15.875	0.01**	0.284
	-	Night	-	-	-
	2 (markings)	Day	0.002	0.962	0.001
	-	Night	-	-	-
Rural Roads	1 (no markings)	Dry	156.41	0.01**	0.796
	-	Wet	-	-	-
	2 (markings)	Dry	94.648	0.01**	0.703
	-	Wet	-	-	-

A two-way ANOVA was conducted for Urban speed choices, with Road Type as the within-subjects factor, and Condition as the between-subjects factor. The ANOVA showed that speed choices differed between condition, Wilks $\Lambda= 0.553$, $F_{(1,39)}= 31.55$, $p< 0.01$, $\eta_p^2= 0.447$, but not between road type, Wilks $\Lambda= 0.955$, $F_{(1,39)}= 1.855$, $p= 0.181$, $\eta_p^2= 0.45$. A significant interaction between Type and Condition was identified, Wilks $\Lambda= 0.915$, $F_{(1,39)}= 13.249$, $p< 0.01$, $\eta_p^2= 0.254$. Post-hoc ANOVAs between condition are shown in Table 3, and between types are shown in Table 4.

A post-hoc ANOVA confirmed that, overall, participants chose significantly faster speeds on Urban Road 1 (no markings), with faster speed choices in the Day compared to the Night condition. There was no significant difference in speed choice on Urban Road 2 (markings) between the Day and Night condition.

A similar two-way ANOVA was conducted on Rural speed choices with Road Type as the within-subjects factor and Condition as the between-subjects factor. The ANOVA showed that speed choices differed between condition, Wilks Λ= 0.173, $F_{(1,40)}$= 191.663, p< 0.01, η_p^2= 0.827, and between road type, Wilks Λ= 0.309, $F_{(1,40)}$= 89.421, p< 0.01, η_p^2= 0.691. No significant interaction between Type and Condition was identified, Wilks Λ= 0.983, $F_{(1,40)}$= 13.249, p= 0.406, η_p^2= 0.017. Mean speed choice was significantly slower on Rural Road 1 (no markings) in the Wet compared to Dry condition. Similarly, mean speed choices were slower in Wet condition on Rural Road 2 (markings) than the Dry condition.

The main effects of a post-hoc ANOVA between the different Road Types are shown in Table 4. Figure 23 clearly indicated differences between Urban Road 1 and 2, and Rural Road 1 and 2, with drivers selecting faster speeds on the roads with markings and shoulders (Urban Road 2, Rural Road 2).

Table 4:

Comparing Speed Choices for each Road Type (post-hoc ANOVA) for Urban and Rural Road Conditions

Environment	**Condition**	**Type**	**F-Value**	**Sig.**	η_p^2
Urban Roads	Day	Urban 1 (no markings)	5.038	0.05*	0.112
	-	Urban 2 (markings)	-	-	-
	Night	Urban 1 (no markings)	43.54	0.01**	0.521
	-	Urban 2 (markings)	-	-	-
Rural Roads	Dry	Rural 1 (no markings)	48.448	0.01**	0.548
	-	Rural 2 (markings)	-	-	-
	Wet	Rural 1 (no markings)	74.028	0.01**	0.649
	-	Rural 2 (markings)	-	-	-

There were differences in speed choices between road environments, with apparent differences between the Urban and Rural Road Types under different driving conditions. Statistically significant differences in speed choice were found between Road Types using repeated mixed ANOVAs on both Urban roads for the Day and Night driving conditions. Participants chose slower speeds for the Day condition on Urban Road 1 (no markings) than for Urban Road 2 (markings) and slower speeds in the Night condition on Urban Road 1 (no markings) than for Urban Road 2 (markings).

Observed differences between the two rural road types were confirmed as statistically significant for both the dry and wet road conditions. Participants chose slower speeds for the dry condition on Rural Road 1 (no markings) than for Rural Road 2 (markings) and slower speeds in the wet condition on Rural Road 1 (no markings) than for Rural Road 2 (markings). Overall, these findings suggest that drivers are more sensitive to conditional changes on Urban Road 1 (no markings) compared to Urban Road 2 (markings) and Rural Road 1 (no markings) compared with Rural Road 2 (markings).

Are Speed Choices of All Drivers Dependent on Driving Conditions?

The mean speeds for each road type and condition were calculated for the two environments in order to determine whether fixed and variable road characteristics influence speed choice for Novice and Experienced Drivers. The speed choices are graphically represented in Figure 24:

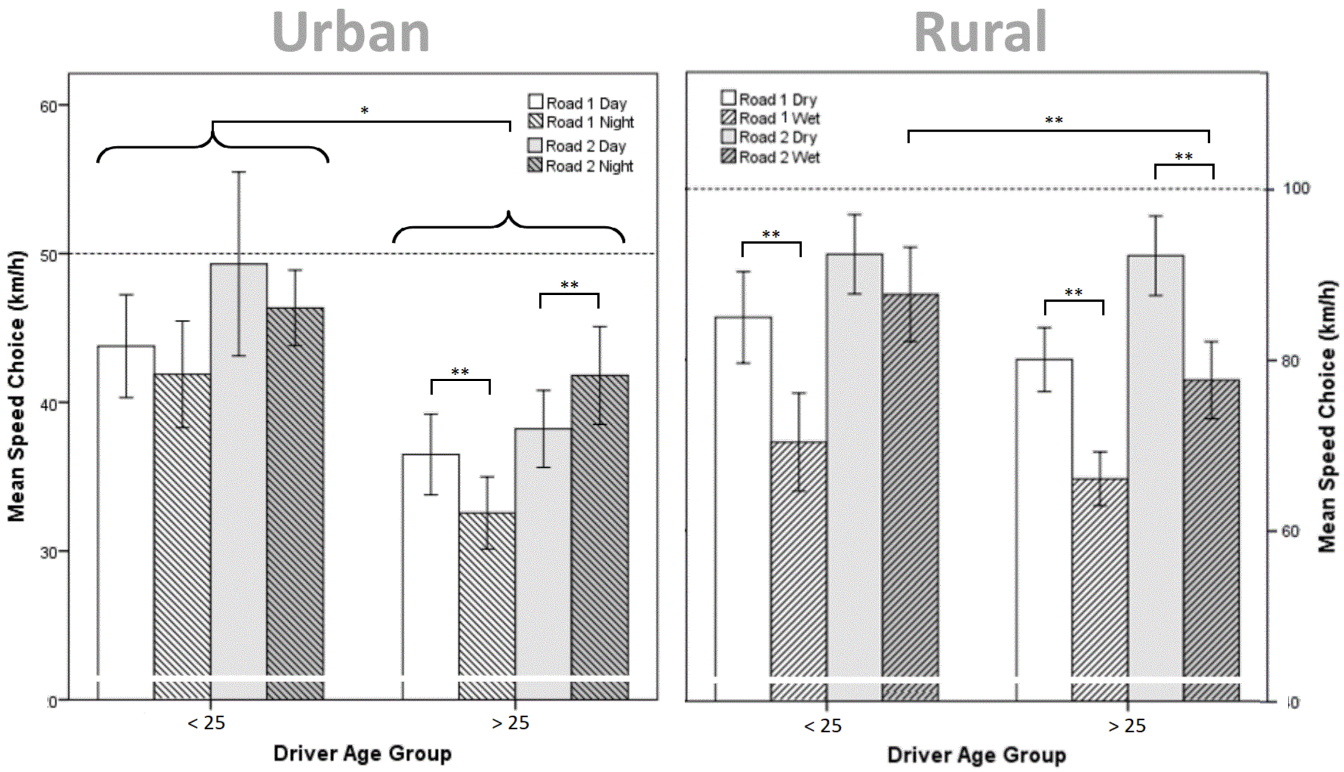

***Figure 24**:* The Speed Choices for Road Type and Condition for Urban (left) and Rural (right) Environments, by Driver Group. The horizontal dotted line indicates the road speed limit. Error bars represent 95% CI. Significance values are indicated, p< 0.05 *, and p< 0.01 ** (Braces show between-group differences). Road 1 indicates a without lane markings, and Road 2 indicates lane markings.

From inspection of the figure, there are significant differences between the two driver groups for the Urban Roads, with Experienced drivers selecting slower speeds under both Day and Night conditions for both road types. There does not appear to be any significant within-subject differences between Condition and Type for Novice drivers, though Experienced drivers appear to choose slower speeds on both Night roads compared with Day roads, and there appears to be a difference in speed choice for Road 1 and 2 during Night conditions.

For Rural road conditions and types, both driver groups select slower speeds on Road 1 for Wet conditions compared to Day conditions. This difference does not appear significant for Rural Road 2 (markings) for Novice drivers, though it appears significant for Experienced drivers between conditions. Both driver groups selected faster speeds on Rural Road 2 (markings) than Rural Road 1 (no markings) under both Conditions, and there appears to be a between-subject difference in the speed choices for the Wet condition on Rural Road 2 (markings).

Inferential testing using multiple mixed ANOVAs were performed to determine if speed choices significantly differed between Driver Groups in relation to different Road Types and Conditions.

A mixed, two-way 2 (Driver Group,) X 2 (Road Condition, repeated measures) X 2 (Type (Road 1 vs., Road 2), repeated measure) ANOVA was conducted, revealing a significant effect for Urban Road Condition Wilks $\Lambda= 0.553$, $F_{(1,40)}= 31.555$, $p< 0.01$, $\eta_p^2= 0.447$, but not for Urban Road Type, Wilks $\Lambda= 0.955$, $F_{(1,40)}= 1.855$, $p= 0.181$, $\eta_p^2= 0.060$. There was a significant interaction between Driver Group * Type * Condition, Wilks $\Lambda= 0.746$, $F_{(1,40)}= 13.249$, $p< 0.01$, $\eta_p^2= 0.118$. No other significant interactions were observed.

For Rural roads, a similar mixed, two-way 2 (Driver Group,) X 2 (Road Condition, repeated measures) X 2 (Type (Road 1 vs., Road 2), repeated measure) ANOVA was conducted, revealing a significant effect for Rural Road Condition Wilks $\Lambda= 0.295$, $F_{(1,40)}= 93.097$, $p< 0.01$, $\eta_p^2= 0.705$, and for Rural Road Type, Wilks $\Lambda= 0.171$, $F_{(1,40)}= 188.439$, $p< 0.01$, $\eta_p^2= 0.829$. However, there were no significant interactions observed.

Post-hoc analysis using a mixed, two-way 2 (Driver Group, <25 years vs ≥25 years) x 2 (Condition (Urban Day, Urban Night) ANOVA was conducted on speed choices for each road type. The ANOVA revealed that for speed choices on Urban Road 1 (no markings), there was a significant main effect for Driver Groups, $F_{(1,41)}$= 29.814, *p*< 0.01, η_p^2= 0.277, though no significant effect between Day and Night Conditions, $F_{(1,41)}$= 3.670, *p*=.59, η_p^2= 0277. The ANOVA revealed that for speed choices on Urban Road 2 (markings), there was a significant main effect for Driver Group, $F_{(1,41)}$= 15.852, p< 0.01, η_p^2= 0.169, and a significant effect between Day and Night condition, $F_{(1,41)}$= 027, p= 0.87, η_p^2= 0.027. However, no significant interaction was perceived between Condition and Driver Groups for Urban Road 1, $F_{(1,41)}$= .449, *p*= 0.50, η_p^2= 0.006., or for Urban Road 2 (markings), $F_{(1,41)}$= 2.783, p= 0.99, η_p^2= 0.034.

A similar post-hoc analysis was conducted for speed choices on Rural Road Types using a mixed, two-way 2 (Driver Group) x 2 (Condition(Rural Wet, Rural Dry) ANOVA. The ANOVA revealed that for speed choices on Rural Road 1 (no markings), there was a significant main effect for Driver Groups, $F_{(1,41)}$= 4.007, *p*< 0.05, η_p^2= 0.049, and a significant effect between Dry and Wet Conditions, $F_{(1,41)}$= 38.437, *p*< 0.01, η_p^2= 0.337. The ANOVA revealed that speed choices on Rural Road 2 (markings), there was a no significant main effect for Driver Group, $F_{(1,41)}$= 0.461, p= 0.49, η_p^2= 0.006, though there was a significant effect between Dry and Wet Condition, $F_{(1,41)}$= 31.190, p< 0.01, η_p^2= 0.286. No significant interaction was perceived between Driver Group and Condition for Rural Road 1, $F_{(1,41)}$= .019, *p*= 0.89, η_p^2= 0.019., or for Rural Road 2, $F_{(1,41)}$= 0.367, p= 0.54, η_p^2= 0.005.

Table 5:

Comparing Speed Choices for Driver Groups on Urban and Rural Road Types and Conditions

				Driver Group			
				Novice		***Experienced***	
	F-value	Sig	η_p^2	M	SE	M	SE
Urban Day 1	10.622	0.01**	0.214	43.7	1.66	32.5	1.15
Urban Day 2	11.415	0.01**	0.226	49.3	2.97	36.4	1.29
Urban Night 1	5.378	0.05*	0.121	41.8	1.72	41.81	1.56
Urban Night 2	18.886	0.01**	0.326	46.3	1.22	38.2	1.56
Rural Dry 1	0.415	0.52	0.01	84.9	2.58	80.0	1.78
Rural Dry 2	0.01	0.93	0.001	92.3	2.23	92.1	2.22
Rural Wet 1	2.212	0.14	0.052	70.3	2.76-	66.0	1.49
Rural Wet 2	6.751	0.05*	0.144	88.6	2.67	77.6	2.15

Significant values: * = p < 0.05, ** = p < 0.01

A one-way ANOVA was conducted to examine the individual road types for the urban road condition and found that novice drivers chose significantly faster speeds than experienced drivers on Urban Road 2 (markings) under both day and night driving conditions. Similarly, novice drivers chose significantly higher speeds than experienced drivers on Urban Road 2 (markings) during the day condition, and significantly faster for the night condition.

For Urban Road 1 (no markings), Experienced drivers selected significantly slower speeds in the Night condition compared to the Day condition. Unexpectedly, experienced drivers chose a significantly faster speed choice on Urban Road 2 (markings) with a speed choice of 41.8 km/h (SE= 1.56) during Night driving conditions than the slower speed choice of 38.2 km/h during Day Conditions (SE= 1.56).

In examining speed choice for the individual Rural road types, there was no significant effect on speed choice between driver age groups for Rural Road 1 in either Dry or Wet conditions. On Rural Road 1, Novice drivers' speed choice was significantly different in wet compared to in the Dry condition. Experienced drivers' speed choice was also significantly different in dry conditions compared to in wet conditions.

Within-subject contrasts found that in the absence of shoulders or road markings, both Driver groups showed a significant reduction in speed choice in the Wet condition compared to Dry condition for both Rural Road 1, $F_{(1,41)}= 68.60$, $p< 0.01$, $\eta_p^2= 0.774$, and for Rural Road 2, $F_{(1,41)}= 39.23$, $p< 0.01$, $\eta_p^2= 0.662$. Speed choice was significantly different between groups on Rural Road 2 where shoulder and road markings were present, $F_{(1,41)}= 41.37$, $p< 0.01$, $\eta_p^2= 0.697$. The experienced driver group selected a slower speed choice in the wet condition compared to the Dry condition. However, speed choice was not significantly ($p= 0.756$) different between the Wet compared to the Dry condition for Novice drivers.

Do Eye Movements differ between Driver Age Groups?

Eye movement data was analysed[10] at two different levels. The first level involved overall comparisons between the two Driver groups in relation to the number of fixations, fixation duration, spatial distribution of fixations, number and amplitude of saccades, number of blinks and pupil dilation. The second level involved a more nuanced approach, observing eye-movement comparisons between driver age groups for each road Environment, Type, and Condition. This approach will focus on fixations primarily and was intended to reveal any significant effects of variable visual cues, such as illumination and diminished visibility (weather), and the presence of other road users (vehicles and pedestrians), as well as the role of fixed road characteristics, such as visual cues related to the fixed infrastructure (e.g., markings and shoulders). The spatial distribution of fixations was examined to determine where drivers collect their visual information to make speed judgements.

Initial Examination of Eye-movement Data

The first stage of examining the eye-movement data was to determine if any participants or trials involved unusual patterns that would indicate miscalibration, distorted vision, or high drift levels. Six participants' data (3 Novice, 3 Experienced) were removed from the sample due to poor quality of eye-movement data due to incomplete data output from the eye-tracker or extreme drift or other distortion in the data. Post-Hoc drift correction[11] was performed for each trial across all participants, and fixation cleaning (SR Research Data Viewer) removed fixations shorter than 80ms.

Differences between Driver Age Groups

The number of fixations and fixation duration provided a good indication of how drivers process the visual scene and have been used extensively in driving research as primary measures of both visual-spatial attention as well as a proxy measure of

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[10] We used either the SR Research Data Viewer, or our own specially written code in MatLab or Excel – though statistical analysis was conducted in SPSS

[11] The countdown timer was present before the beginning of each trial and provided a good reference for the centre of the screen (visual field). This fixed reference point was used to adjust for slight vertical and horizontal drift.

cognitive load. The mean number and duration of fixations were calculated, and the differences between Driver Groups are shown in Figure 25:

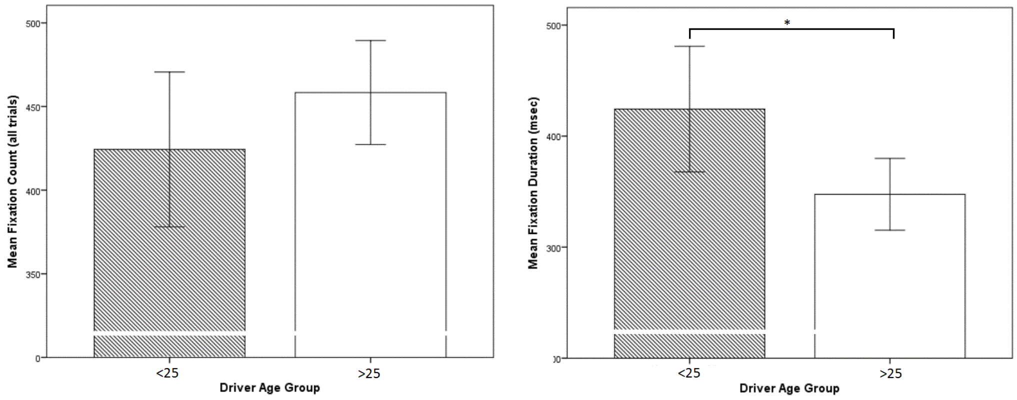

Figure 25*:* The Total Number of Fixations across all trials (left) and Fixation Duration (right), by Driver Group. The bars represent 95% CI Significance values are indicated, p< 0.05 *, and p< 0.01 **

Figure 25 clearly shows that the number of fixations per trial was slightly greater for Experienced drivers than novice drivers, though the difference does not appear to be significant. In relation to the average fixation duration per trial, the Novice drivers appeared to have a greater mean fixation duration than the Experienced drivers, who had much more rapid fixations.

A one-way ANOVA comparing the number of fixations across all trials between Novice and Experienced drivers revealed no statistically significant difference between groups, $F_{(1,38)}= 1.588$, $p= 0.217$, $\eta_p^2= 0.047$, with Novice drivers (N= 20) having an average of 424 fixations (SD= 93.02) and Experienced drivers (N= 19) an average of 458 fixations (SD= 62.53). However, a one-way ANOVA revealed that the duration of fixations was significantly different between Driver groups $F_{(1,38)}= 6.301$, $p < 0.05$, $\eta_p^2= 0.165$, with Novice driver group (M= 424.3msec, SD= 113.78) having longer fixation durations, compared to the Experienced drivers (M=347.5msec, SD= 64.97).

Saccades also provide useful information in relation to the distance between fixations, as the perceptual system uses saccades to direct the eye from one point of interest to another, which indicates search behaviour, with the number of saccades related to the general points of fixation and greater saccadic amplitude representing a greater distance between fixations within the visual field (Duchowsky, 2003; Velinchovsky, Rothert, Miniotas, Dornhofer, Joos, & Pannasch, 2003).

The Mean Number of Saccades and Saccadic Amplitude are shown in Figure 26:

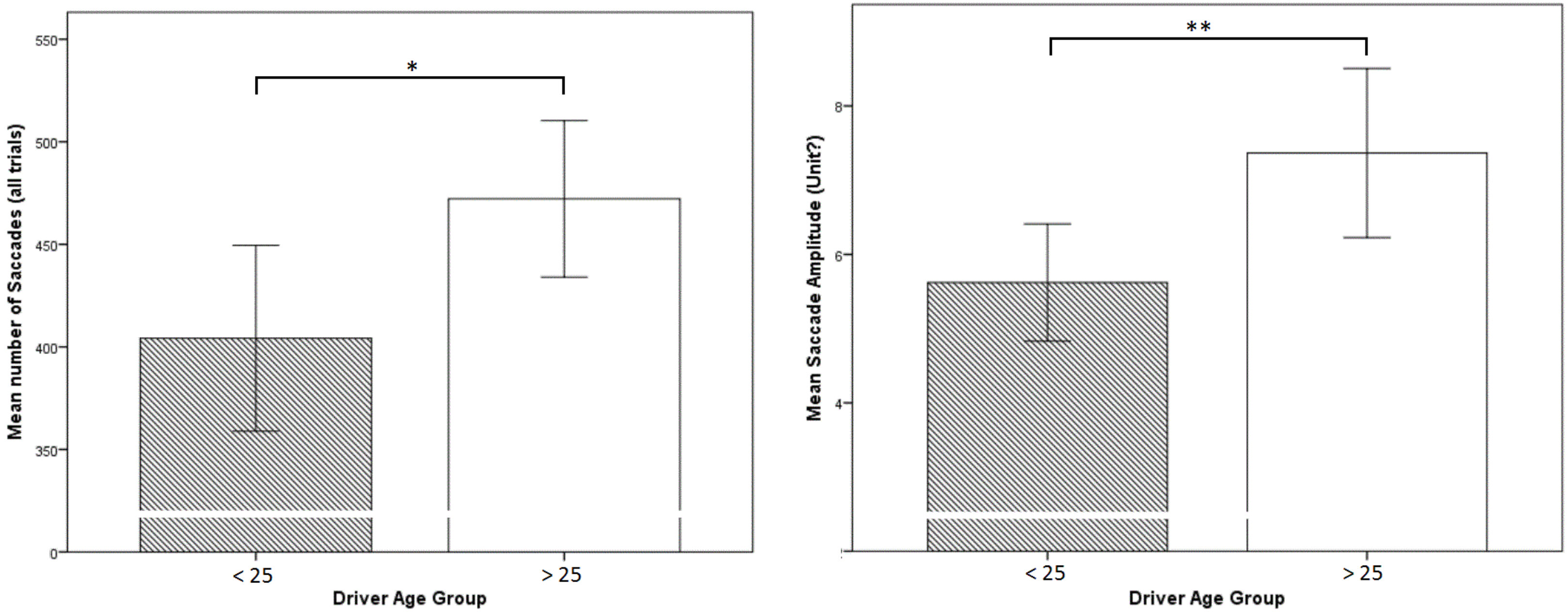

Figure 26: The Number (left) and Average Amplitude (right) of Saccades across all trials, by Driver Group. . Error bars represent 95% CI. Significance values are indicated, p< 0.05 *, and p< 0.01 **

As indicated in Figure 26, the Experienced driver group had a greater average number of saccades over all trials, as well as greater saccadic amplitude, indicating that the distance between fixations was overall larger than that of Novice drivers.

A one-way ANOVA comparing the number and amplitude of saccades between Driver Group indicated that the total number of saccades was significantly different, $F_{(1,38)}$= 5.707, $p< 0.05$, η_p^2= 0.151, with Novice drivers an average of 404 saccades (SD= 91.09), and Experienced drivers having an average of 472 saccadic eye movements (SD= 76.79). The amplitude of saccades was also significantly different between the Driver groups, $F_{(1,38)}$= 7.665, $p< 0.01$, η_p^2= 0.193, with the Novice drivers (M= 5.6° arc., SD= 2.29) having shorter saccades compared with the Experienced drivers (M= 7.3° arc. SD= 1.58).

Blinks and Pupil Dilation

As a measure of cognitive workload, blink rate and duration and pupil diameter were analysed between participant groups. A one-way ANOVA revealed that the number of blinks was not significant between Driver Group, $F_{(1,38)}$= 1.944, p= 0.17, η_p^2= 0.054 with the average blink number per trial being 25.8 (SD= 25.67). The mean blink duration, $F_{(1,38)}$= 0.597, p= 0.444, η_p^2= 0.017 was also found not to be significantly different between Driver groups (M= 76.6msec, SD= 48.21. Pupil dilation was also found not to be significant between Driver groups, $F_{(1,38)}$= 0.528, p= 0.444, η_p^2= 0.012, with a mean diameter measure of 692.5 µm (SD= 161.90).

Do Road Environment, Type, and Condition affect Drivers Eye movements?

The differences seen between Novice and Experienced drivers in fixation number and duration could be an initial indication that driver groups use alternative search strategies. Further analyses were conducted to examine how eye movements - in particular fixation behaviour - differ between Driver groups under various Road Conditions to understand better how drivers select ideal speeds.

Within and Between-Group Effects for Differing Road and Traffic Conditions

Considering that the duration of fixation, rather than the number of fixations, was significantly different between Driver groups in aggregate, two separate mixed ANOVA were conducted between driver groups to determine the effect of road type and condition on fixation duration. This analysis presents the results, with the number of fixations shown in Figure 27, and then fixations durations in Figure 28. The Figure illustrated that the only difference within Driver Groups for Urban road environments was that the duration of fixations was greater for the Novice driver group on Road 1 for Day and Night.

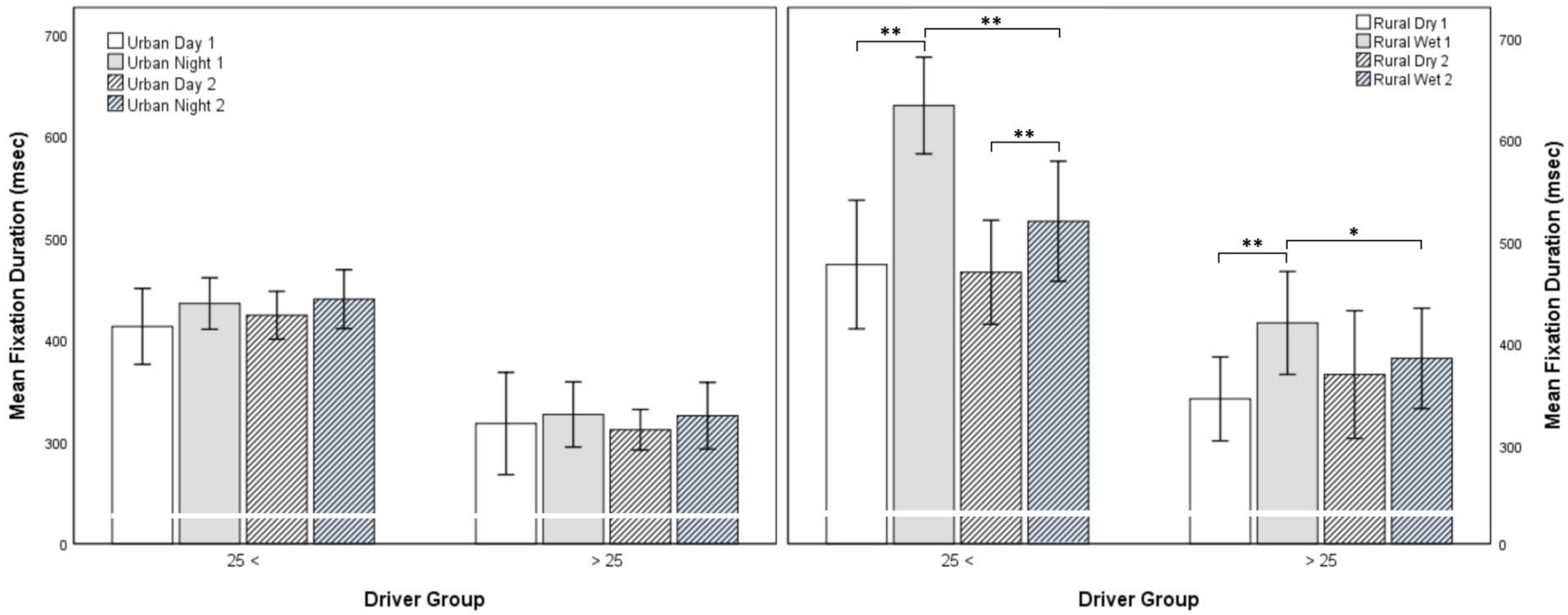

Figure 27: The Number of Fixations for each Road Environment, Type, and Condition, by Driver Group. Urban Environment for Day and Night Condition are shown (left), and Rural Dry and Night Condition (right). Error bars represent 95% CI. Significance values are indicated, p< 0.05 *, and p< 0.01 *

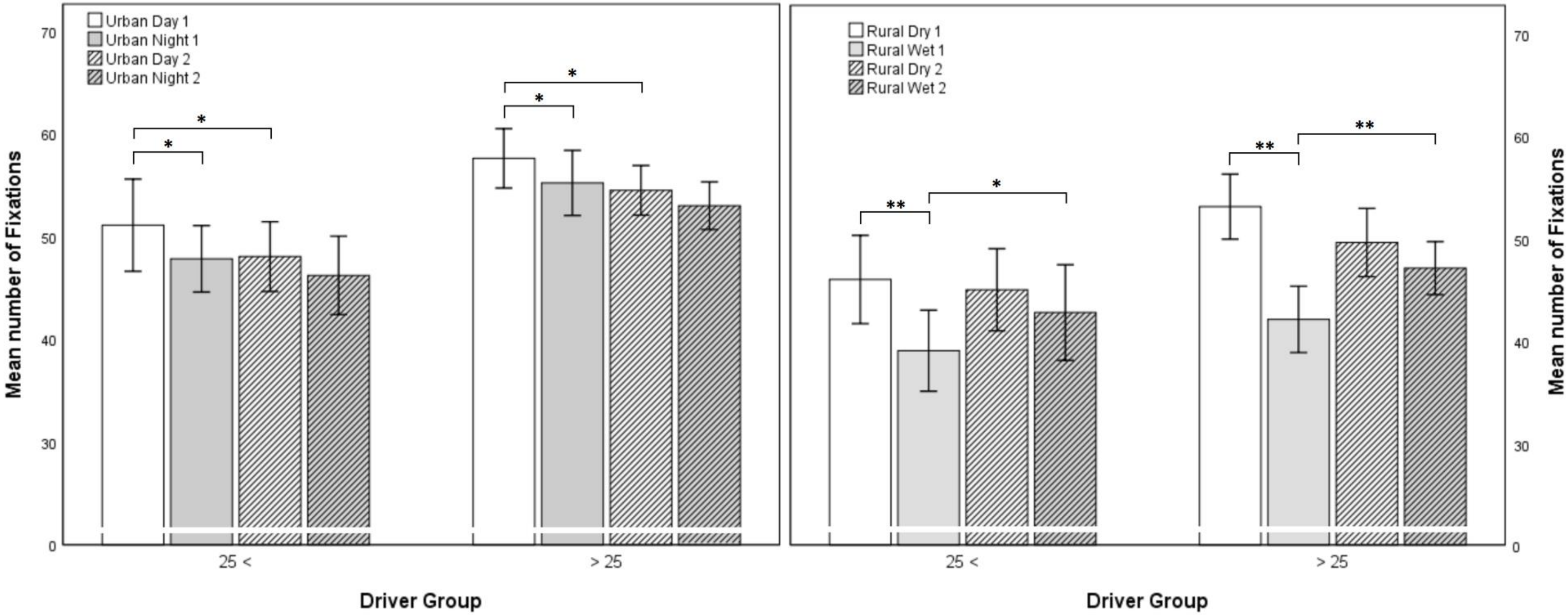

Figure 28: The Duration of Fixations for each Road Environment, Type, and Condition, by Driver Group. Urban Environment for Day and Night Condition are shown (left), and Rural Dry and Night Condition (right). Error bars represent 95% CI. Significance values are indicated, $p< 0.05$ *, and $p< 0.01$ *

Concerning the number of fixations displayed in Figure 27, there appears to be a significant difference between both driver groups for the Urban day scenario between both road type and condition, with drivers having a more significant number of fixations for Road 1 than Road 2, and interestingly, more fixations for day driving conditions than for night. A similar effect appears between drivers on Rural road, with greater fixations for Rural Road 1 compared with Road 2 under the Wet condition and a greater number of fixations for the Wet condition compared to the Dry on Rural Road 1. The number of fixations between conditions was also different for Novice drivers on Rural Road 2, which was not observed for the Experienced driver group. Experienced drivers had a greater number of fixations for all road conditions and types when compared to the Novice driver group.

Referring to Figure 28, the main difference observed was between Driver groups with more Experienced drivers having more rapid fixations than Novice drivers for all scenarios with a high degree of statistical significance. There appear to be significant within-subject differences on the Rural road environment for Wet and Dry conditions for Road 1. This difference indicated that both driver groups required significantly longer fixation durations for the Road 1 Wet condition than the Road 2 Wet condition. There also appears to be a difference for fixation durations between Novice drivers for Wet and Dry conditions on Rural Road 2, with Novice drivers using longer fixations for Wet driving. This effect is not observed for Experienced drivers.

For Rural roads, a similar mixed, two-way 2 (Driver Group,) X 2 (Road Condition, repeated measures) X 2(Road Type(Urban Day, Urban Night)) ANOVA revealed a significant between-subject effect for the number of fixations for Driver Group, Wilks $\Lambda = 0.231$, $F_{(2,38)} = 8.988$, $p < 0.01$, $\eta_p^2 = 0.321$, with a significant main effect for Driver group, $F_{(1,34)} = 37.32$, $p < 0.01$, $\eta_p^2 = 0.523$. There was also a significant main effect between Day and Night road conditions, $F_{(1,38)} = 4.616$, $p < 0.05$, $\eta_p^2 = 0.120$, though there was no significant main effect between the duration of fixations concerning Road Type, $F_{(1,38)} = 0.054$, $p = 0.81$, $\eta_p^2 = 0.056$. The analysis also revealed a significant difference in fixation durations between driver groups in Night conditions, Wilks $\Lambda = 0.231$, $F_{(1,38)} = 54.92$, $p < 0.01$, $\eta_p^2 = 0.769$, with Novice drivers having longer fixation durations for both roads compared to the Experienced driver group. No significant interaction between Driver Group and Urban Road condition ($p = 0.58$) or Type ($p = 0.51$) was perceived.

A similar analysis using repeated mixed two-way ANOVA revealed a significantly different fixation duration for both Rural Wet and Dry road conditions, Wilks Λ= 0.500, $F_{(1,38)}$=29.94, p< 0.01, η_p^2= 0.500. Concerning between-subject effects between Driver Groups, the examination of the table indicates that there is little difference in fixation duration between road types. However, there were significant differences between Driver Groups for all road conditions.

Planned contrasts from multiple one-way ANOVA are shown in Table 6:

Table 6:

Comparing the Mean Fixation Durations (post-hoc ANOVAs) between Novice and Experienced Drivers for each Road Condition

					Novice		***Experienced***	
Environment	Road	F-Value	Sig.	η_p^2	M	SE	M	SE
Urban Roads	UD 1	5.672	0.05*	0.159	413	17.6	318	23.8
	UD 2	63.151	0.01**	0.678	424	11.1	311	9.4
	UN1	21.829	0.01**	0.421	435	11.9	326	15.2
	UN 2	25.185	0.01**	0.456	440	13.7	325	15.5
Rural Roads	RD 1	15.110	0.01**	0.335	535	47.3	342	19.5
	RD 2	6.400	0.05*	0.176	502	25.3	366	29.7
	RW 1	40.830	0.01**	0.576	630	20.4	416	23.9
	RW 2	14.163	0.01**	0.321	554	35.3	381	23.3

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Table 6 shows that the mean fixation duration was significantly different for all conditions between Novice and Experienced Drivers. There appeared to be similar fixation durations within groups in Dry conditions, suggesting that the visual demands between road types were not significantly different. This was confirmed by a mixed 2(Condition) X 2(Road Type) ANOVA between Driver Groups, Wilks Λ= 0.986, $F_{(1,38)}$= 0.234, p= 0.631, η_p^2= 0.01. The fixation duration appeared to be different within-groups for the two road types under the Wet condition. Both groups had longer fixations for Rural Road 1 (no shoulder and markings).

Table 7:

Comparing the Mean Number of Fixations (post-hoc ANOVAs) between Novice and Experienced Drivers for each Road Condition

					Novice		***Experienced***	
Environment	Road	F-Value	Sig.	η_p^2	M	SE	M	SE
Urban Roads	UD 1	6.609	0.01**	0.163	51.1	2.12	57.6	1.37
	UD 2	10.649	0.01**	0.244	48.0	1.61	54.5	1.15
	UN1	11.835	0.01**	0.258	47.8	1.53	55.2	1.50
	UN 2	10.267	0.01**	0.232	46.2	1.81	53.0	1.10
Rural Roads	RD 1	5.991	0.05*	0.063	45.8	2.04	53.0	1.50
	RD 2	3.486	0.09	0.093	44.8	1.89	49.5	1.58
	RW 1	2.944	0.09	0.080	38.9	1.87	42.0	1.53
	RW 2	1.595	0.21	0.045	42.6	2.21	38.9	1.22

Significant values: * = p < 0.05, ** = p < 0.01

A mixed 2(Condition) X 2(Road Type) ANOVA revealed there was a significant difference between fixation duration on Wet Rural roads for Novice drivers $F_{(1,20)}$= 13.97, p< 0.01, η_p^2= 0.318. Fixation durations on being longer in duration on Rural Road 1 compared to Rural Road 2. A mixed 2(Condition) X 2(Road Type) ANOVA between Driver Groups revealed that there was no significant difference in fixation durations between Rural roads for Experienced drivers, $F_{(1,19)}$= 3.947, p= 0.056, η_p^2= 0.116. This may suggest that certain factors on Rural Road 1 require a longer fixation time to process under Wet conditions for Novice drivers.

The Novice driver group had a lower number of fixations on all rural road conditions compared to the Experienced driver group, who had a higher number of fixations, especially on roads that required vigilance. Inferential testing determined a significant difference between driver age groups on Rural Road 1 under the Dry condition, although no significant difference was found on Rural Road 2. Under the Wet condition, there was no significant difference between driver age groups for either Rural roads.

Referring to Table 7, planned contrasts using a two-way 2(Age Group) X 2(Condition) ANOVA confirmed this observation, with significant differences found in the number of fixations between Driver Groups for all Urban Road conditions. The analysis revealed that for both Urban Day and Night driving conditions, the number of fixations was significantly different between Driver Groups for both road types. The Novice driver group had fewer fixations than the Experienced driver group. A separate repeated measure ANOVA searched for any within-group effects in relation to the number of fixations, with no significant difference between Urban road types identified.

Within Group Effects between Road Types

Repeated mixed-measure ANOVA was conducted to explore within-group on the number of fixations for 2(Condition X 2(Road Type) between Driver Groups, Wilks Λ= 0.284, $F_{(1,33)}$= 19.552, $p< 0.01$, η_p^2= 0.716 revealing that Experienced drivers differ in their fixation count in Day condition $F_{(1,19)}$= 8.927, $p< 0.01$, η_p^2= 0.244, with a greater number of fixations for Urban Day 1 in comparison to Urban Day 2. However, there was no significant difference in the Night condition between Urban road types. For Novice drivers, there were no significant within-group effects for both Urban Day roads. Planned contrasts using a one-way ANOVA found a significant difference in the number of fixations between Wet roads $F_{(1,19)}$= 11.842, $p< 0.01$, η_p^2= 0.411, with Experienced drivers having significantly more fixations for Rural Road 1 compared to Rural Road 2. However, there was no difference observed for the Dry Rural condition. There were no significant with-subject differences in the number of fixations for Novice drivers found in any road condition. The only condition in which within-group effects were found to approach significance for Novice drivers were Wet Rural roads, where values approached but did not reach significance $F_{(1,20)}$= 3.979, p= 0.062, η_p^2= 0.190.

The Spatial Distribution of Fixations

Deviation from the central field was calculated for both vertical and horizontal meridians as a measure of spatial distribution (spread of fixations) and are represented as distribution plots to demonstrate the differences in the horizontal spread of fixations between driver age groups, notably in the peripheral region. The Experienced driver group fixating on a broader area over the horizontal axis compared with Novice drivers, where attention is focused directly ahead in the centre-field.

One way of numerically indicating the spread of search is to use the standard deviation of the fixation distribution. While the mean represents the average visually attended location, the standard deviation provides an indication of the shape of the distribution. There was no significant difference in the deviation from the mean between Driver Groups for the vertical axis $F_{(1,36)}= 0.378$, $p= 0.543$, $\eta_p^2= 0.013$. However, fixation distribution about the horizontal (x) meridian was found to be significantly different, $F_{(1,36)}= 5.460$, $p< 0.05$, $\eta_p^2= 0.158$, for the Experienced driver group, which had a larger average spread of horizontal fixations, indicated by the higher Standard Deviation (SD) of 333.6 pixels (*M*= 967 pixels), compared to the SD of 147.8 pixels for the Novice driver group (*M*= 1006 pixels).

The representation of the spatial location of search (fixations) across trials was calculated and plotted for both groups of drivers, and these can be seen for Novice (Figure 29) and Experienced (Figure 30) driver groups. The spatial distribution was plotted directly from raw fixation data, with horizontal and vertical axes, as well as density-plots were shown over a frame from the corresponding video trial. This provides a way of observing eye-movement data without smoothing out the small details that indicate particular ways drivers search the road[12]. As discussed by Holmqvist et al. (2011), we note that attention maps represent the spatial distribution of data, and caution should be taken when assuming that where participants look is not the same as why they look at that location. This being said, Holmqvist et al. (2011) suggest that attention maps are a versatile and useful method for showing visual behaviour.

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[12] This was necessary at this stage, as while all members of a group can be aggregated, and numbers such as the range and mean values for spread of search. However, when trying to represent where drivers devote visual attention, aggregation from a large sample tends to leave a large "blob" in the center of the road, due to the noise present in the fixation data (i.e. drivers all view some aspect of the environment, such as a tree, but this is unique for each driver, creating large amount of visual noise). To remove visual noise, distributions are generated for all participants, and then sorted into novice/experienced groups for each condition so that the researcher can inspect the general trends. This also allows for the identification of distorted or invalid data before analysis. Following inspection of overall trends, data representing the overall trend is aggregated which removes the noise. Although this requires some subjective judgement, it remains the best solution that represents the visual behaviour of the most participants faithfully. Later analysis can be performed, and all data will be made available.

Figure 29: Representative Spatial Distribution of Fixations for Novice Drivers. Blue circles represent the Location of Fixations, and their size represents their Relative Duration in msec. The distribution plots show the horizontal and vertical spread of the distribution. The unit measure in pixels.

Figure 30*:* The Representative Spatial Distribution of Fixations for Experienced Drivers. Blue circles represent the Location of Fixations, and their size represents their relative Duration in msec. The distribution plots show the horizontal and vertical spread of the distribution. The unit measure is in pixels.

From a comparative observation of Figure 29 and Figure 30, it can be clearly seen that Experienced and Novice drivers look at different locations on the roadway. A distinctive double-peak on the vertical axis indicated that the majority of drivers examined features in the distance ahead of the vehicle. Novice drivers seem to devote their attention to the centre of the marked carriageway and look quite close, almost directly ahead of the vehicle with short glances into the distance. Experienced drivers, by comparison, search both to the centre, left, and right-hand sides of the lane and dedicate a considerable amount of visual attention to scanning the road and traffic situation further ahead of the vehicle compared to Novice drivers. Furthermore, it appears as if drivers rely to some degree on the lane markings, especially novice drivers. When lane markings are absent or less apparent, visual search appears to be more broadly distributed.

The Distribution of Search over Differing Road Environments and Conditions

The distribution of search was calculated and then plotted for each participant in both Novice and Experienced driver groups for each of the different roads. In order to illustrate differences that might exist between driver groups across the different road situations, each distribution plot was examined in relation to the Driver Group, and representative plots were selected that best conveyed the overall behaviour of the group. These are represented below, in the order of Urban Road 1 (Figure 31) then Urban Road 2 (markings) (Figure 32). The distribution of fixations on Rural roads is shown for Rural Road 1 (Figure 33), followed by Rural Road 2 (Figure 34):

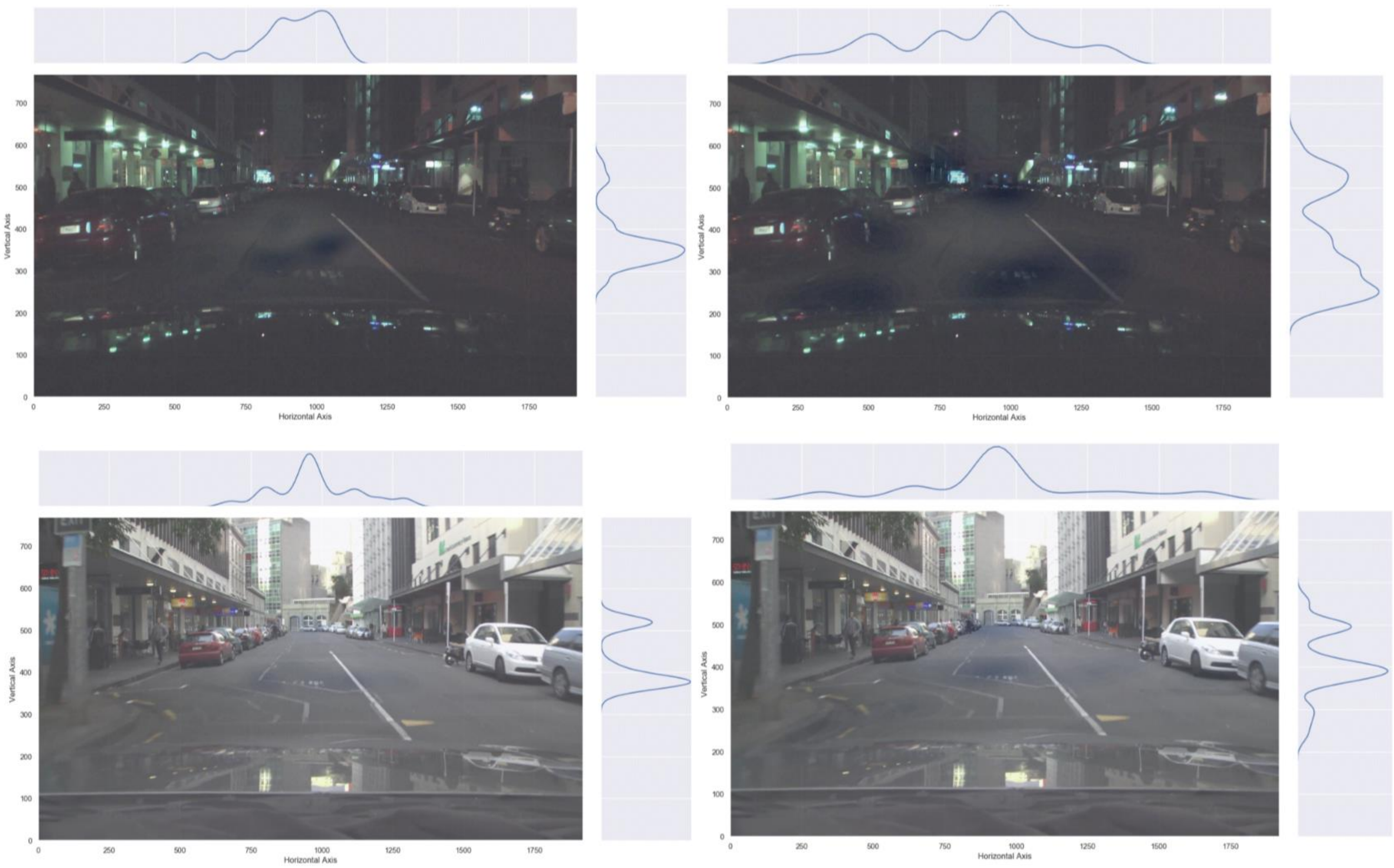

Figure 31: The Spatial Distribution of Fixations for Novice (left) and Experienced (right) Drivers for Urban Road 1 Environment and Road-Type for the Night (top) and Day (bottom) Conditions. The Distribution Plots show the Horizontal and Vertical Spread of The Distribution of Fixations.

Figure 32: The Spatial Distribution of Fixations for Novice (left) and Experienced (right) Drivers for Urban Road 2 (markings) Environment and Road Type for the Night (top) and Day (bottom) Conditions. The Distribution Plots show the Horizontal and Vertical Spread of The Distribution of Fixations.

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Table 8:

The Statistical Values for both Urban Road Types and Conditions for Novice (<25) and Experienced (≥25) drivers.

Environment	**Urban Roads (Horizontal Search)**							
Road Type	***Road 1 (no markings)***				***Road 2 (markings)***			
Condition	Day		Night		Day		Night	
Driver Group	<25	≥25	<25	≥25	<25	≥25	<25	≥25
Mean	979.4	964.8	920.7	848.2	1007.1	890.5	810.5	916.4
Standard Dev.	147.45	333.31	125.98	375.60	122.52	354.81	175.86	218.58
Min	661	278	580	226	812	234	338	399
Max	1296	1698	1113	1359	1229	1564	1489	1464
Kurtosis	-0.18	0.15	0.18	-1.33	-0.88	-0.63	1.07	1.52

Table 8 shows considerable differences between the breadth of visual search between Novice and Experienced Drivers. Experienced drivers generally have broader search areas and a flatter horizontal distribution of fixations. It is apparent that there is a difference between Day and Night, with the distribution of search increasing during Night driving. There are also differences between road types, suggesting that lane markings and road width may play some degree in influencing drivers search, especially Novice drivers, with the range of fixation values coinciding with the coordinates of the lane margins.

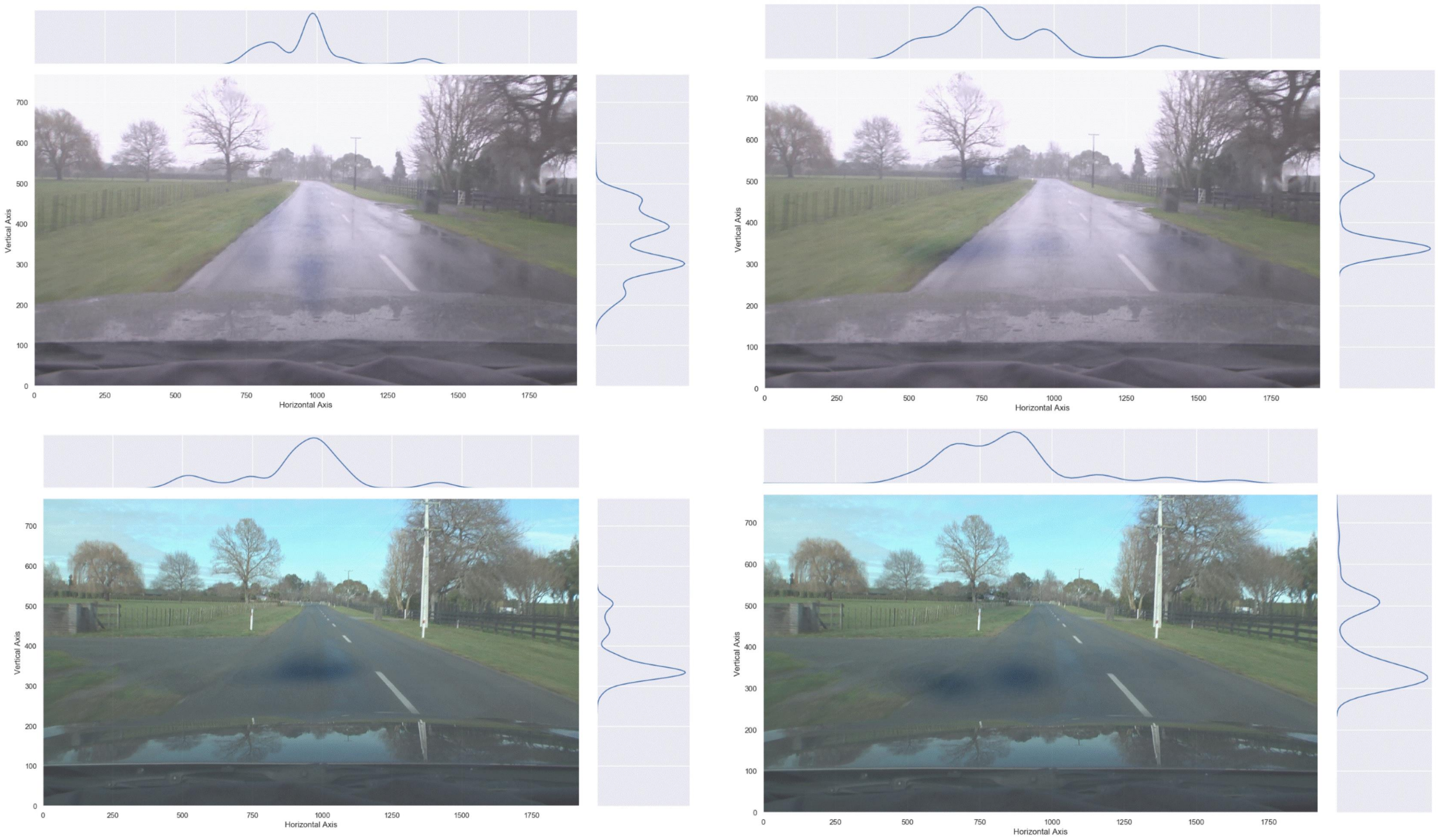

***Figure 33**:* The Spatial Distribution of Fixations for Novice (left) and Experienced (right) Drivers for Rural Road 1 Environment and Road-Type for the Wet (top) and Dry (bottom) Conditions. The Distribution Plots show the Horizontal and Vertical Spread of The Distribution of Fixations.

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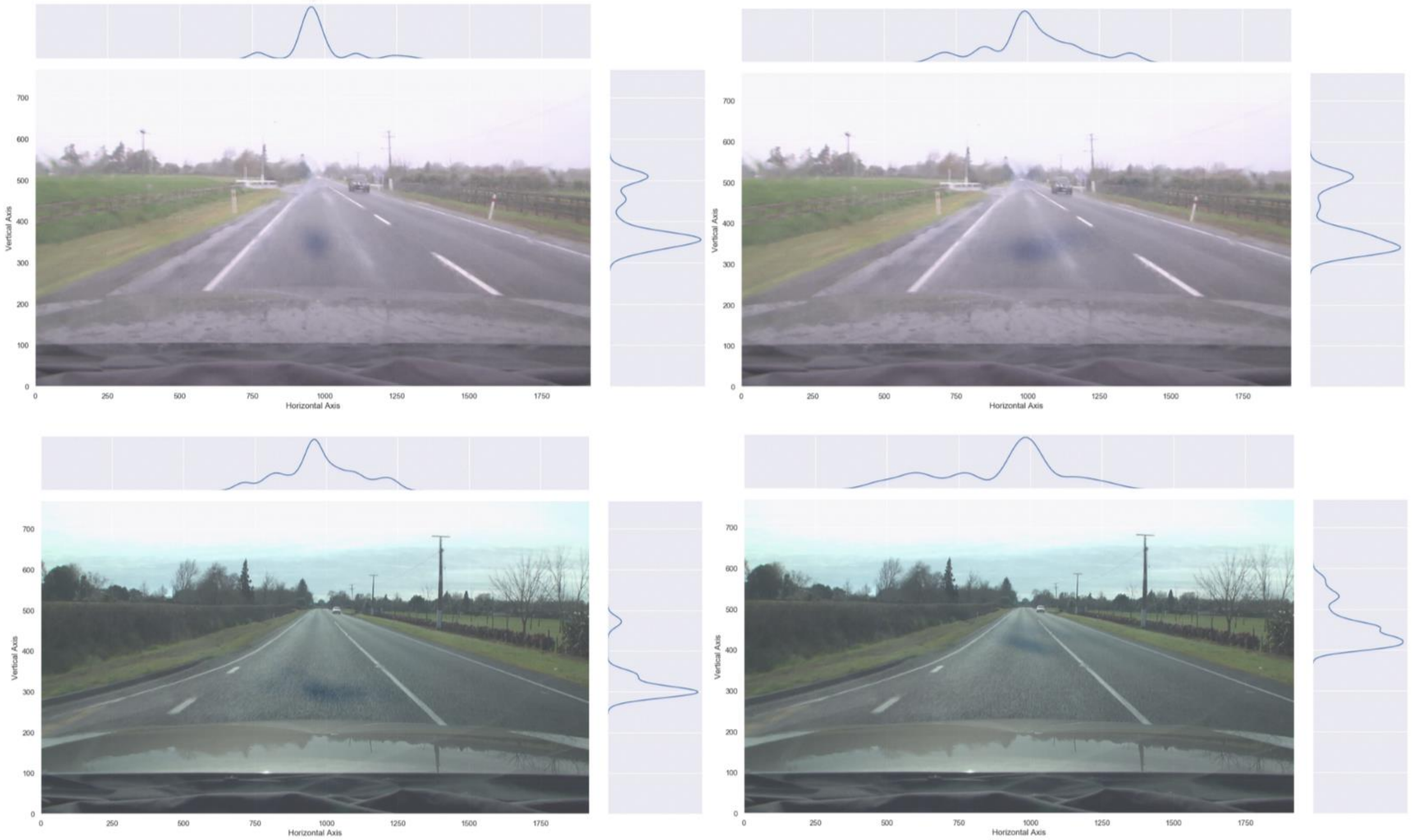

***Figure 34**:* The Spatial Distribution of Fixations for Novice (left) and Experienced (right) Drivers for Rural Road 2 Environment and Road-Type for the Wet (top) and Dry (bottom) Conditions. The Distribution Plots show the Horizontal and Vertical Spread of The Distribution of Fixations

Table 9:

The Statistical Values for both Rural Road Types and Conditions for Novice (<25) and Experienced (≥25) drivers.

Environment	**Rural Roads**							
Road Type	***Road 1 (no shoulder or markings)***				***Road 2 (shoulder and markings)***			
Condition	Dry		Wet		Dry		Wet	
Driver Group	<25	≥25	<25	≥25	<25	≥25	<25	≥25
Mean	977.5	896.2	969.4	1019.7	911.0	890.5	952.8	841.6
Standard Dev.	203.1	354.81	138.33	321.67	131.37	209.54	100.44	159.13
Min	478	234	741	476	695	439	750	681
Max	1447	1564	1386	1488	1246	1315	1314	1361
Kurtosis	0.82	-0.63	2.42	-0.78	-0.34	-0.61	2.90	0.07

Table 9 shows that drivers' distribution of search is also broader for Experienced drivers on Rural Roads. There is a notable difference in the distribution of visual search between road type, with Road 1 having a greater amount of visual examination. The breadth of visual search also appears to narrow when the road is Wet compared to Dry, which means drivers may be more vigilant to the road itself, and less to the surrounding roadside features. Similar to Urban roads, the fixation pattern indicates that lane markings and road width may influence drivers' visual search behaviour.

By observing the distribution of fixations, it is clear that there are significant differences between road environments, which appear to be consistent for both Driver Groups. On Rural Road 2, drivers from both groups do not scan the road as broadly as on the unmarked Rural Road 1 environment, where drivers generally have broader scanning, primarily devoted to the approaching bend as well as the edge of the road. During Night driving on both roads, drivers had a broader search compared to day driving. This effect seemed to be related strongly to markings, with drivers having a distinct change in visual behaviour on the more challenging Urban Road 1, where distributions were much more devoted to the sides of the road as to the centre. This effect was supported by the differences previously reported regarding fixation number and duration.

There is also a characteristic effect related to the lane markings, with drivers limiting the amount of visual scanning outside these corridors formed by the lane markings. A similar observation can be made about Urban road environments. There are significant differences in the search behaviour between Driver Groups and across conditions.

Another interesting observation is a characteristic vertical two-peak effect, which is slightly more pronounced for experienced drivers. This seems to indicate that Experienced drivers devote more attention to further down the road as opposed to Novice drivers – as while this twin-peak phenomenon occurs, the second peak is smaller, indicating less vertical allocation. The distribution of fixations is not smooth and forms a bimodal distribution on the vertical axis, indicating discrete moments of search further ahead of the vehicle.

Discussion

The first research question was to determine whether the video-based speed choice task had ecological validity. Determining ecological validity is essential, as participants' behaviour in laboratory settings, while often representative, does not necessarily correspond to real-life behaviours (i.e., Iverson, 2004). A review of the literature and previous research suggested that young novice drivers tended to drive faster than experienced drivers and were less capable of assessing risks while driving, which would presumably lead them to respond less appropriately to different road and traffic conditions (Delhomme, 2002).

This primary distinction between drivers formed the first aspect of this study, in determining whether the speed choice task was reliable in differentiating between drivers with more or less experience, in a way that reflected anticipated behaviour observed under real-world driving conditions – from which relative ecological validity can be inferred. In the current study, young novice drivers selected faster overall speeds than experienced drivers. Furthermore, novice drivers also tended to choose faster speeds than experienced drivers under differing road types and driving conditions. Overall, the speed selections were consistent with real-world observations (i.e., Ahie, 2012; Ministry of Transport, 2017, 2019). This observation provided reasonable evidence that the video speed task (VST) measure is ecologically reliable.

Additionally, it was found that drivers were sensitive to different road types, which exceeded our expectations, as drivers adjusted their speed selections to differing road types as well as conditions (i.e., when marking were present or absent on the rural roads). If drivers speed choices did not differ across different roads under similar conditions (e.g., Urban Road 1 Urban Road 2 during daytime), it would be difficult to know whether the drivers were genuinely responding to different situational cues. However, the differences observed between the driver groups on different road types and conditions indicate that drivers are both engaged with the task and respond to various aspects of the road, as they were to differing conditions. This finding provides additional support for both task sensitivity and further supports relative ecological validity. Additionally, the findings from this study align with previous findings from similar video-based laboratory studies, which have shown young novice drivers tend to select faster speeds than older, more experienced drivers (Horswill & McKenna, 1999; Cantwell, 2010).

In this experiment, novice drivers' choice of speed was faster on urban roads in both day and night driving conditions, which NZTA (2017) has identified as a high-risk environment for pedestrian and cyclist crashes. Additionally, novice drivers also chose faster speeds in the wet rural condition, which is a situation in which young drivers are over-represented in loss of control crashes (Accident Compensation Corporation & Land Transport Safety Authority, 2000). This finding suggests that novice drivers may be less competent in selecting speeds that are appropriate for the road conditions for these two common road types, and might be an essential area to target in future driver training and education.

In this experiment, the different road conditions influenced both Novice and Experienced drivers' speed choices. Both driver groups chose slower 'ideal' speeds in night conditions compared to day conditions. Bridger and King (2012) noted that there was an increased risk during night driving, potentially due to reduced visual clarity. Jackett and Frith (2012) also observed a reduction in drivers speed under night-time conditions, which may be due to drivers' becoming aware of increased risk and reducing speed to accommodate this change. While drivers were not requested to rate the risk on the road in this experiment, we can conceptualise drivers' choice of an appropriate subjective speed for each road as a proxy measure for risk. This approach is not unwarranted, as it has been used by other researchers, such as Horswill and McKenna (1999).

In this experiment, the experienced driver groups chose significantly slower speeds on the narrower urban road during night driving conditions. In contrast, the novice driver group did not significantly reduce their choice of speed on either urban roads during the night condition. What is unusual is that experienced drivers selected faster speeds on the wider-laned urban road during night driving conditions than during the daytime conditions. This finding was inconsistent with studies that predict speed reduction at night (Williams, 2003). However, this finding reflects those made by Renge (1998), who observed that drivers do not reduce speed selections under night conditions to the same extent as day conditions. Renge (1998) also found that drivers noticed fewer hazards during night driving, which could partially explain this finding. Given that the reviewed literature showed that both alternatives (of either a decrease or increase of chosen speed) under night driving conditions were possible, it may be that the effect is dependent on factors such as road markings and traffic conditions, rather than solely on the night condition and accompanying reduction in visibility.

Overall, speed choice did not differ between Urban Road 2 (markings) conditions, which may indicate that drivers perceived less risk between day and night on roads where there were clear markings for both the roadside margins and centre-line. There were notable differences observed in the visual search behaviour, illustrated by the fixation distributions between the two urban roads under night conditions. This finding suggested that under night driving conditions, the limitation of visibility is potentially more taxing on drivers' limited cognitive and perceptual resources. A similar number and duration of fixations were observed for both urban road types at night. There were significantly fewer fixations compared to the day condition.

Moreover, there was a clear pattern that suggests novice drivers constrained their search within the road markings, which has been observed in other studies where novice drivers attend to road markings in order to maintain lane position (Mourant & Rockwell, 1972). This limited search behaviour related to markings may be the result of under-developed situation awareness, which is overly dependent upon the median and lane markings to maintain lateral position. When there are fewer markings available for navigation and lane positioning, drivers may require a broader search for vital information related to vehicle position (Underwood, 2005). What is interesting in this experiment is that visual search was devoted to the aspects of the scene needed for lane positioning, which is usually a requirement for active driving, but less so when navigation is not an essential component of the task (Mackenzie & Harris, 2015).

It was found that the rural dry road condition was the only driving scenario in which there was no significant difference in speed choice between the driver age groups. Both groups selected a mean speed choice slightly below the speed limit, which suggested that the perception of risk in the traffic situation did not differ substantially between the two driver groups (Yao, Carsten, Hibberd, et al., 2019). Similar speeds were observed in a separate study that involved similar roads, with speed choices on Rural Dry Road 2 being similar to speeds[13] observed by Ahie (2012) using a radar speedometer and those discussed in New Zealand 2015 speed data (Ministry of Transport, 2015). Lewis-Evans (2012) also studied speed behaviour concerning risk and determined that subjective feeling of risk (and task difficulty) did not increase concurrently with speed until a threshold was met (i.e., Lewis-Evans (2012) estimates

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[13] Ahie (2012) observed real road speeds using a radar, and then asked drivers to provide their speed and risk rating for a range of roads. The road used in her experiment (Ruakura A & B) are remarkably similar in width, markings, shoulder width, visible horizon, and roadside furniture to the rural roads used in this experiment. Ahie's results confime the results published by the Ministry of Transport (2019).

~110km/h on an open/rural road), after which subjective feeling of risk would proportionately increase with speed.

Given the risk ratings from Ahie's (2012) study, the threshold of risk provided by participants in that study seemed to be higher than actual measured speeds. These findings were remarkably similar to the ideal speed choices selected by participants in this experiment, which provided some additional ecological validity to the video speed task. Furthermore, the findings of this experiment were consistent with the mean recorded speed for both open road (96km/h), and urban road (47km/h) speeds reported by the Ministry of Transport (2019) Ministry of Transport (2017).

The effect of shoulders and markings appeared to influence the driving behaviour of both groups of drivers, and it is a well-documented phenomenon that road markings do influence drivers speed choices (Charlton et al., 2018; Elliott et al., 2003; Eriksen & Yeh, 1985; Godley et al., 2004). This effect was highly consistent with the characteristics that Weller et al. (2008) found, with drivers perceiving roads without shoulder or markings as more demanding. This is illustrated by the marked reduction of speed by both driver groups in the rain condition on the rural road where shoulders and clear lane markings were absent. Both driver groups chose similar speeds on the rural road with shoulders and lane markings in the day condition. However, experienced drivers slowed significantly more than novice drivers in the wet condition. This finding shows that experienced drivers were sensitive to the increased risk of driving in wet conditions on roads that potentially had the appearance of greater safety due to the presence of width and lane markings (Davidse et al., 2004). Lewis-Evans (2012) mentions that perception of risk and task demand are related, suggesting, "… a feeling of risk provides continuous feedback to drivers allowing them to maintain the difficulty of driving within preferred levels". (p. 61)

Novice drivers selected significantly faster speeds than experienced drivers on both urban roads in day conditions, despite there being considerable differences in lane width and the presence or absence of roadside furniture (i.e., parked cars). During the day driving condition, experienced drivers selected slower speeds than novice drivers on both urban road types, but more so on the narrower urban road. This indicated higher sensitivity to risk factors affecting the speed choices of Experienced drivers and suggested that novice drivers were less sensitive to environmental cues when making speed judgements (Horswill & McKenna, 2004; Parmet et al., 2015).

Does eye movement behaviour differ between the two driver groups?

Based on a review of the eye-movement data, it appeared that pedestrians and vehicles on the left-hand side seemed to be substantial potential risk factors. These were given more significant consideration by experienced drivers, whose visual search strategies were largely unaffected by driving conditions. Konstantopoulos et al. (2010) found that simulated night driving conditions resulted in increased processing time and reduced visual sampling for both novice and experienced drivers, with a decrease in the number of fixations, and a corresponding increase in fixation durations. However, the spatial distribution of visual search was unaffected. Similarly, in this experiment, while the number and duration of fixations were affected to a lesser degree, spatial search strategies remained consistent in day and night driving conditions.

Godley et al. (2004) noted that one hypothetical explanation for slower speeds on narrow roads is the heightened perception of risk, although steering workload also contributes to reduced speeds. The speed selection of experienced drivers seems to be better explained by perceived risk, with night conditions being the most substantial contributor to slower speed choices, while similar speeds were observed between the two urban roads during day conditions despite the difference in lane width. This is not to say that (fixed) infrastructure does not play a role in speed choices, as overall speed choice was slower on the narrower urban road (Day Road 1). This suggested that fixed road features are just one of the factors associated with the perception of risk, in which variable factors were found to be the strongest predictor of speed choice (Edquist et al., 2011; Wilmot & Khanal, 1999).

Providing further support of the relative sensitivity of the task, driving in the night condition appeared to place a slightly higher demand on novice drivers’ visual search, as evident in their reduced number of fixations and longer fixation durations. However, this was not significantly different from the visual behaviour of novice drivers in the day condition. Konstantopoulos et al. (2010) also found that drivers typically had more fixations during day driving than during night driving. In addition, this experiment found that the duration of fixations was slightly elevated at night, but did not reach statistically significant values for either novice or experienced drivers.

There were notable effects in drivers' visual behaviour on the rural roads both in response to type and condition. In dry conditions, neither driver group had significant within-group effects in relation to the number or duration of fixations. There were significant within-group effects in wet conditions, with both groups demonstrating significantly increased visual processing load, potentially indicating a greater amount of perceived danger (Chapman & Underwood, 1998). Novice drivers required greater processing time and reduced visual sampling rate when shoulders and markings were absent compared to the road where both were visible. They also showed a similar pattern in the number of fixations, though this was non-significant. Experienced drivers showed a more significant number of fixations in wet conditions for both rural roads, with the greater visual load on the road without shoulders or clear marking, though the fixation durations were unaffected. This supports the idea that roads with markings and shoulders are perceived as less risky and require less visual attention (Charlton & Starkey, 2016).

As discussed previously, fixed environmental factors, such as width, curvature, and length of roadway ahead, are not the only factors relevant to speed choice. Variable factors, such as weather and illumination, and the presence of other road users whose behaviour needs to be anticipated carefully, are also considerations drivers make when choosing an appropriate speed (Parmet et al., 2015). When driving, the majority of visual information is neglected (Desimone & Duncan, 1995), though if some feature is perceived as more relevant to the driving task and to increase risk, a driver who is quicker and more accurate in perception is more likely to be able to respond in a way which prevents a potential incident (Vlakveld, 2011).

Visual search has been well studied as driver behaviour and is very closely associated with hazard perception, which has been identified as the greatest skill gap that divides experienced from novice drivers (Horswill & McKenna, 2004; McKenna et al., 2006). For hazard perception to be ‘efficient’, information needs to be rapidly extracted from the driving context and then evaluated. This demands an enormous processing load from a vast array of neuro-cognitive systems.

Research by Mourant and Rockwell (1972) was supported by the findings of this experiment, which indicated that Novice drivers are more likely to have a narrow spatial distribution of fixations. In contrast, older drivers tended to have a wider horizontal spatial distribution of fixations. This effect has been consistently replicated in contemporary research (for example, Konstantopoulos (2009)). Greater spatial distribution of fixations suggests that older drivers are looking more broadly across the environment and potentially scouring it for implicit and explicit cues concerning appropriate speed given the perceived risk. This pattern of broad scanning of the road environment is a behaviour critical for safe driving (Underwood & Crundall, 2002). It is worth noting that both groups of drivers allocate the majority of their attention to the centre of the roadway, likely to avoid potential collisions with other vehicles and that the direction of steering is related to the drivers' gaze (Land & Lee, 1994). This explained why devotion to peripheral search often involves rapid fixations rather than prolonged gaze (Mourant & Rockwell, 1972).

In this experiment, a greater number of short fixations were observed among the experienced driver group than fewer long fixations in the novice driver group. This confirms results in previous research, which suggested experience leads to a general improvement in visual scene processing when driving (Underwood, 2007; Geoffrey Underwood et al., 2002; G. Underwood et al., 2002; Vlakveld, 2011). This capacity to extract meaningful information quickly from a visual scene demonstrates mental procedures that have become more finely tuned with experience, enabling a driver to determine what information is relevant for the driving task and enhancing the ability to ignore irrelevant information (Desimone & Duncan, 1995; Lappi, 2014; Lemonnier et al., 2015; Salvucci & Gray, 2004).

The practical application of the effect of road markings is highly significant, as road markings, while being beneficial in identifying the drivers' side of the road and related margins, may also have the potential to adversely affect the range of drivers’ visual search, especially for inexperienced drivers (Mourant & Rockwell, 1972). Future research into the role of road markings for particular areas, especially shared spaces or locations where multiple road users intersect (e.g., where cyclists, pedestrians, and cars are all present) could have a significant effect on reducing the accident rate, especially for vulnerable road users such as pedestrians.

Limitations

One of the main limitations of this experiment, common to the study of young novice drivers, is that the role of experience is a confounding variable. McDonald (2004) has noted that it is often difficult to disentangle the role of experience from age, as the two tend to be highly related, with few drivers older than 25 years with a learner or restricted licences available to participate in research. In instances where older novice drivers have been participants, a similar risk of crash involvement existed in the first 6-months after receiving their licence (Mayhew, Simpson, & Pak, 2003). However, the role that age has on older novice drivers' visual search behaviour is virtually unknown. The risk-taking behaviour that accompanies adolescence may likely be absent in this study cohort. In this respect, it would be helpful to better understand how different degrees of driving experience interact with age in seeking to determine speed choice behaviour.

Following on from this point, in this experiment, limited information related to participants' psychological makeup was collected, as this was not of primary interest beyond the collection of basic demographic data and driver history. However, previous research has linked psychometric measures to a propensity to speed or engage in risk-taking. Employing a diverse range of psychometric measures related to personality, risk-taking, and attitudes toward driving behaviours could help paint a clearer picture of those drivers likely to choose faster speeds. This may be useful in determining whether self-perceived skill differs significantly between driver groups, which could point towards 'poor calibration' and the willingness to accept greater risk when driving. It was noted that Novice drivers had a significantly higher self-rated level of driving skill than Experienced drivers, though this was just above the rating of 'similar to the average driver'.

Reasonable caution is always warranted when relying on visual information to support research findings when using video-based simulations compared to real-world behaviour. Naturally, there will be differences between the engagement of participants between the real-world and laboratory setting (Mackenzie & Harris, 2015; Steinman, 2003), especially as noted by Horswill and McKenna (1999) the absence of risk. Martens and Fox (2007) suggested that the resolution of video-based tasks may restrict participants' ability to detect certain aspects contrasted with real-world driving.

Driving in naturalistic settings is more dynamic, and hence there is a greater need for the driver to focus on multiple visual elements reducing fixation duration while increasing distribution and count. With these considerations in mind, we noted that repeated exposure to the same roads did not result in variation in fixation duration, unlike Martens and Fox's (2007) study. Furthermore, fixation behaviour differed between Novice and Experienced drivers as anticipated, as well as there being a variation in fixations between road type and condition (Konstantopoulos et al., 2010). We, therefore, conclude that any video-based influence on visual search, while a noted constraint of laboratory tasks, was an ecologically valid representation of real-world behaviour with good physical correspondence (Blaauw, 1982), even though there may be small variations between the laboratory task and real-world driving (Santos et al., 2005).

Another critical issue that was potentially present in this experiment, which cannot be ruled out, was whether there was a sampling bias in the way different video scenarios were selected, which could potentially favour experienced drivers over novice drivers. Selection of the clips was conducted partially based on the situation present, as scenarios needed to be consistent across speeds and contain sufficient detail to elicit a response from the participants. Driving speeds were often impractical or unsafe for filming the scenarios, so clips could be somewhat contrived in that the researchers were unwilling to subject pedestrians and other road-users to unsafe risks during filming, especially at greater speeds. This could introduce a bias with an unknown effect, as has been observed with other film-based tasks involving hazard-type situations, which influenced the validity of the task (regarding task validity, refer to Horswill and McKenna, 2004).

One of the most important considerations was the difference between risk-perception and hazard perception. There was a strong theme of risk appraisal and perception being related to speed choice in the literature review. However, it has been observed in several studies that there is no such corresponding relationship between perceived risk and hazard perception (Farrand & McKenna, 2001; Watts & Quimby, 1979). Using speed as a proxy measure for risk-acceptance, such as by Horswill and McKenna (1999), while reasonable when paired with additional measures, is not in itself the same as saying that speed is synonymous with risk-taking or acceptance. While there were observed differences between roads in this experiment which could be considered more or less risky than their rural or urban counterparts, using this as a means of justifying the differences in speed as evidence of the presence or absence of actual risk, or the perceived risk of participants, needs to be considered with due caution.

Additional Critique and Alternative for Analysis

One area of this experiment that was not examined in detail were the differences in visual behaviour over the three filmed vehicle speeds for each road environment. Preliminary analysis revealed that there was no substantial difference between drivers' speed choices on the three different vehicle speeds for both Urban and Rural Roads. Interestingly, there was also no significant difference between eye-movement behaviour on these different roads despite the slower vehicle speed providing presumably more opportunity to examine the roadsides. It is a well-known phenomenon that drivers narrow their visual search when the vehicle speed is greater (Bartmann et al., 1991). However, this was not observed in this study, and there are several potential reasons for this lack of narrowed search. As this task did not occupy a large amount of the peripheral visual field, drivers were not required to move their gaze far from the central field when inspecting the roadside. Experienced drivers selected different speeds that seemed to correspond to roads with higher risk while not substantially altering their search behaviour. This rapid speed selection may be due to experienced drivers 'thin-slicing' the visual scene. In the process of thin-slicing, drivers can rapidly collect information related exclusively to the most relevant aspects of the road and use this to make their judgements.

On the other hand, novice drivers could merely be disregarding certain features despite the opportunity to observe them due to a lack of experience on what to focus on when selecting appropriate speeds. This, however, remains purely speculative. While this question could be presented as a limitation in the realism of the experimental method, it could also be revealing something important about drivers' visual search when selecting appropriate speeds, even when the vehicle speed is different. A more comprehensive analysis focusing on specific visual cues could potentially provide greater insight into drivers' behaviour under different vehicle speeds.

Hazard perception was a reasonable explanation for the observed differences between drivers' visual search and was assumed to be as much. Although this interpretation is warranted, this task did not involve the specific perception of hazards. Post-hoc coding and assessment of hazards is still an available option for determining the differences in visual search between novice and experienced drivers. This could be accomplished by inviting expert drivers such as Police Drivers with advanced training, or Driving Instructors to participate, then perform a post-hoc coding of all hazards that these expert drivers identified. Additionally, it may be possible to identify hazards based on the superimposed eye movements over the hazard clips. The characteristic features of the road environment that were the focus of participants' visual attention could be coded similar to the consensus-based approach to hazard perception used by Renge (1998) in their first study. Following the coding of hazards, a cluster-analysis could be conducted to determine the sets of visual features which differentiated novice from experienced drivers. In a sense, this assessment was informally performed in a subjective evaluation by this researcher in viewing the available footage. However, a more scientific approach using post-hoc coding could yield more information about the role of specific road features and traffic conditions that could influence drivers speed choice. This could be a valuable addition to this experiment and confirm that hazard perception plays a role in speed choices, as speculated from observation of visual behaviour.

While the estimates of speed choice were not reported in this experiment, the preliminary analysis indicated both groups of drivers over-estimated the vehicle speed. Novice drivers selected speeds that were closer to that of the actual vehicle speed when compared to Experienced drivers. However, this should not be considered a measure of accuracy given the range of unaccounted factors that could influence drivers perception of speed. The estimates of vehicle speed did not seem to relate to drivers' speed choices. However, as drivers were asked to estimate the speed, this could mean that they were more reliant on a search of the roadside in making this judgment. While drivers who were told the vehicle speed did not substantially differ in their speed choices or visual behaviour to those drivers who were asked to estimate the speed, there could still be an effect simply by asking for an estimate, even when provided with the actual speed.

An additional aspect to this experiment is the time that was taken for drivers to make their speed choice decision and the number of times that the participant adjusted the needle before clicking "Okay" and moving to the subsequent trial. It was thought that experienced drivers would be more homogenous in the time and number of decisions in selecting speed. In contrast, novice drivers would display a greater amount of variability as they are likely to be less confident in both estimating speeds and judging what is appropriate for the road and traffic condition. This aspect of the experiment has not been examined in the present study.

The Rationale for Experiment 2

1. Increasing the number of participants and including a broader participant sample would provide the opportunity to examine the relationship between speed choice, age, and experience. There is value in investigating the division between drivers with different licence types, which could provide a means of determining the role of experience separate from the potential age-related developmental factors which accompany adolescence.

2. An important next step is to investigate the role of hazard perception on speed choice. As noted in this study, drivers' speed behaviour differed based on the environmental variables (e.g., presence of pedestrians, absence or presence of lane markings and shoulders). Considering that eye-tracking data confirmed more experienced drivers viewed the road differently than novice drivers, this indicates that the awareness of hazards might play a significant role in determining drivers speed choice.

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Experiment 2

Introduction

In the previous experiment, there was a significant relationship between the road environment and the different speed choices made by drivers. Overall, 'Novice' drivers, on average, chose faster speeds than 'Experienced' drivers aged 25 years and older. This was an anticipated finding, with previous research showing similar patterns of young drivers choosing faster speeds than drivers aged 25 years and older (Accident Compensation Corporation & Land Transport Safety Authority, 2000). Furthermore, the previous experiment indicated that there was relative ecological validity for the video speed task, which indicated that this would be an appropriate task for further examination of drivers speed choice behaviour under differing conditions.

One of the limitations noted in Experiment 1 was that 'Novice' drivers were treated as a homogenous group in relation to their driving behaviour. This was particularly relevant to their selection of speeds, which was taken as a primary indicator of attitude toward accepting speed related risk when driving. However, it is known that not all Novice drivers choose faster speeds than more experienced drivers. While it remains a broad generalization that young drivers tend to choose faster speeds due to lack of skill and a more risky driving style (McKnight & McKnight, 2000), it is incorrect to assume that all young drivers behave in the same way or have similar levels of competence or driving experience. For example, Day et al. (2018) found that young drivers self-perceived driving safety and sense of security improved over three months, though they note that necessary driving skills are not fully automatized at the age young drivers acquired a full licence, likely due to a lack of training. While it is well known that age is a predictor of crash likelihood before the age of 25 years, the amount of quality driving experience also plays a role in how drivers make appropriate speed choices.

Examining the role of experience as a separate variable alongside age is an essential step in furthering our understanding of how motivational and performance-related factors influence a driver's speed choice behaviour (Mayhew et al., 2003). Although age-related factors are somewhat fixed, driving experience can be enhanced (e.g., with increased quality of driving instruction) through the development of essential driving skills. Drivers with a higher degree of experience tend to have a higher ability to perceive hazards and hence may choose slower, more appropriate speeds for the traffic conditions (A. R. Quimby & G. R. Watts, 1981). While drivers' age and experience are often highly entangled, with novice drivers typically being young, there is still value in examining increasing experience on drivers' speed choice and hazard perception ability, despite age being a factor that cannot entirely be discounted.

In Experiment 1, the finding that specific road characteristics, such as the presence of road-side furniture, pedestrians, and lane markings, as well as weather and lighting conditions, have an essential influence on drivers speed choice behaviour was consistent with other research findings (Elliott et al., 2003; Goldenbeld & van Schagen, 2007). What was noteworthy was that drivers, overall, irrespective of age group, chose slower speeds on roads which may have been potentially perceived as more challenging to negotiate safely; however, experienced drivers seemed to be generally more responsive. Novice drivers did not appear to differ in their choice of speed under day or night conditions between the two distinct urban road types (i.e., roads with and without clear markings and differences in lane width). Novice drivers generally selected faster speeds than experienced drivers on urban and rural roads when there was a greater potential risk (i.e., night driving or when the road surface was wet). While novice drivers did select slower speeds during the wet than the dry conditions on rural roads with no markings, showing they responded to some potential risk factors. However, their behaviour on roads with markings showed no difference in speed choices between dry and wet conditions. This may indicate that novice drivers are less responsive to risk factors or may evaluate these cues differently from more experienced drivers, influencing their choice of speed.

Additionally, it was found that visual search behaviour differed significantly between novice and experienced drivers; this appeared to be influenced by road and traffic situation and weather and lighting conditions. This was a significant finding and indicated that visual search behaviour could play an essential role in determining drivers speed choices. These observed differences in visual behaviour could indicate that experienced drivers were searching for specific features to make speed judgements. This observation could be an indication that experienced drivers were searching for hazards, as the pattern of visual search behaviour was similar to that observed by Crundall and Underwood (1998), G. Underwood et al. (2002) and Konstantopoulos et al. (2010).

In this thesis, we have speculated a connection between hazard perception and driver's choice of speed, and there is clear evidence to support this. Hazard perception could play a critical role in drivers' capability to make appropriate speed choices for the traffic and road conditions. The inability to perceive hazards may be related to drivers' perception of whether road speed limits are credible, how drivers form habitual speed behaviour, and the inclination to drive at speeds that are not suited to the conditions.

As previously discussed, hazard perception refers to the skill of 'reading the road' (McKenna et al., 2006; Mills et al., 1998) and the ability to recognize and anticipate dangerous traffic situations (Horswill et al., 2004). Despite numerous studies which identified a relationship between poor hazard perception and increased crash likelihood (Boufous et al., 2011; M. S. Horswill et al., 2013), relatively few studies have explicitly focused on the relationship between speed choice and hazard perception. Speed choice is recognized as one of the most critical factors related to crash likelihood and severity, and there is some evidence that a relationship with hazard perception exists (Edquist et al., 2011; McKenna et al., 2006; Renge, 1998). Furthermore, experiments in a naturalistic setting have demonstrated that slower driving speeds are frequently associated with higher hazard perception ability (Grayson et al., 2003).

In summary, the available literature indicates that selecting appropriate speeds reflects both risk perception and the capacity for a driver to 'read the road'. This "reading of the road" was demonstrated in the previous experiment by examining drivers visual search behaviour, which seems highly indicative of hazard perception. However, the relationship between these variables is poorly understood.

McKenna et al. (2006) and Horswill and McKenna (1999) hypothesized that better hazard perception skills would be associated with more appropriate speed choices. The validated speed choice task from the previous experiment was paired with a separate, validated video-based hazard perception task to determine if this hypothesis was correct. The use of an additional hazard perception task may reveal whether drivers speed choices were related to their ability to perceive immediate hazards. Experiment 2, therefore, examines the influence of age and driving experience on hazard perception and speed choice using the speed choice task used in Experiment 1, with the inclusion of a validated Hazard Perception task (Isler et al., 2009; Williamson, 2008).

Research Questions

1. Do drivers' hazard perception skills and speed choices improve with age and experience?

As hypothesised from the reviewed literature, we anticipate that hazard perception skills will improve incrementally with age and accrued experience (Crick & McKenna, 1991; Crundall, 2016; Farrand & McKenna, 2001; Horswill & McKenna, 2004). Concerning speed choice, the central hypothesis is that experienced drivers will demonstrate more advanced hazard perception skills and choose more appropriate speeds than younger, less experienced drivers.

This hypothesis is composed of two complementary ideas. Firstly, (a) drivers will make more appropriate speed choices[14] as they increase in age and experience. Secondly, (b) drivers with more experience will naturally possess a higher level of driving competence, which ought to manifest as more appropriate speed choices, especially in road and traffic situations lower in perceived risk (e.g., dry rural roads).

However, drivers may feel comfortable selecting speeds proportionate to the amount of perceived risk. As argued previously, hazards are a significant factor in determining how risky the road is perceived. Therefore, we would expect drivers to adjust their speed choices concerning the perceived risk, though less so on roads where drivers are more competent in handling a range of different conditions. Overall, we expect the speed choices to be consistent with those observed in Experiment 1.

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[14] Using an approach related to Fullers' model (2005), we can consider defining 'appropriate' speed choices as drivers adjusting their speed choice for varied road types and conditions in a way that minimises subjective-risk and maximises drivers perceived control and comfort. Generally speaking, this means that as the road conditions become more risky (e.g., low-visability or wet surface conditions), drivers would select slower speeds if they are 'calibrated'. This definition of appropriate speed was used by Fuller et al., (2007) as the maintainance of an "adequate margin between task demand and their capability" (p. 9). One consideration is that exceeding the speed limit, while illegal, may not be necessarily innappropriate, and as Fuller et al., (2007), determine innappropriate speed requires evaluation of specific accceptable speed margins of the particular traffic and road situation (p. 26).

2. *Do more advanced hazard perception skills correspond to more appropriate speed choices?*

Based on the finding of visual search behaviour indicative of hazard perception in the previous Experiment 1, as hazard perception improves with age and experience, it is anticipated that more experienced drivers will select slower speeds, which are appropriate for the road and traffic situation. The reviewed literature supports this hypothesis. This increased awareness of risk should correspond to speed choices appropriate for the road type and conditions. For instance, drivers with more advanced hazard perception skills will show higher compensation in speed choices between wet and dry road conditions or between roads with different lane width and markings. A relationship between speed choice and hazard perception is expected to present as a correlation, where slower speed choices will correlate with more advanced hazard perception.

Method

Participants

A total of 138 drivers (68 males and 70 females) were recruited to participate in this experiment. Participants ranged from 15 to 73 years of age, with a mean overall age of 29.7 years (SE= 1.37, SD= 15.94). The majority of participants identified as New Zealand European (N= 94) or of Maori descent (N= 15). The remaining 29 participants identified as Asian or Pacifica, so the sample was considered representative of the general New Zealand population.

Eligibility requirements were that participants held a current New Zealand learner, restricted or full drivers' license, and had normal or corrected to normal vision. Participants were assigned to one of five driver groups based on their self-reported license type and age, with each group being gender-balanced. This research was conducted in accordance with the University of Waikato Ethical Guidelines concerning human testing (the University of Waikato Handbook on Ethical Conduct in Research, 2001).

A between subjects and mixed measures design was used in this research to examine speed choices and attitudes between five driver groups (between subjects), hazard perception ability and speed choices across different traffic environments and road conditions (repeated measures).

Five driver groups were used in this experiment. The 'Learner' group contained drivers' aged 15-18 years old drivers with learner license, and the 'Restricted' group comprised drivers aged 15-21 years with a restricted license. Drivers were recruited using several strategies. 'Learner' and 'Restricted' drivers were primarily recruited from several local secondary (high-schools) schools in the Hamilton East area near the University campus. The 'Full (<25)' group contained drivers' aged 18-24 years old drivers with a full license and were recruited from the Waikato University student body through poster boards and in-class advertisements. The majority of drivers in the 'Full 25<50' group were recruited from University noticeboards and had a full license, and aged between 25 and 50 years of age. The drivers in the 'Full (>50)' group were required to be aged over 50 years old (with a cut-off at 70 years old) and hold a full license and were recruited through advertisements placed both about the University campus and through notices placed at community centres.

Table 10 presents, for each driver group, the (mean) age, driving experience, and distance travelled in the average week, as well as traffic histories for each group. Standard deviations are shown in the brackets. Table 11 shows the normality tests for each of the driver groups.

Research Design

Similar to the previous Experiment 1 video-speed task, this experiment was designed as a within and between-subject study with multiple repeated measures. The independent variables being examined are the road environment (urban or rural), road type (i.e., with or without shoulders/markings), and condition (i.e., day or night, dry or wet). The dependent variable was the driver's choice of speed for each clip, measured in km/h. This design allows for comparison between driver age groups for different road environments (rural and urban), conditions (dry or wet, day or night), and different road types (e.g., presence of shoulders; width and visual distance). Additionally, this task is paired with a Hazard Perception Dual Task, which measures drivers hazard perception skills over eight trials. The dependant variables are the number of hazards, the time to detect hazards, the number of clicks on non-hazards, the number of tracking errors, and the total tracking error duration[15] for the secondary task. These measures will be introduced in the Apparatus section of this experiment.

In this experiment, the validity of the Hazard Perception Dual-task will be confirmed based on the ability to differentiate between Novice and Experienced drivers (Wetton et al., 2011). The results of the Video Speed Task are thought to replicate what was observed overall, as well as between drivers in relation to speed choices for each road type and condition.

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[15] These tracking error measures from the Hazard Perception Task will be discussed in greater detail throughout the method section.

In order to explore the role of experience alongside age, drivers were grouped according to the driver licence that they held and the convention of Novice and Experienced based on separating participants according to their age, using a cut-off of 25 years old. The following Table 10 shows the demographic information of these five Driver Groups:

Table 10:

The Means and Standard Deviation (Brackets) of Self-Reported Driver History Demographics for the Five Groups

Driver Group	**n**	**Age (yrs)**	**Driving Experience (yrs)**	**Distance per Week (Km)**	**Crashes / Near-miss (NM)**	**Mean NMs**	**Mean Crashes**
Learner	28	16.5 (2.09)	0.5 (1.32)	56.1 (81.48)	1 / 11	0.7 (0.34)	0.06 (0.063)
Restricted	29	18.8 (2.10)	2.7 (1.71)	93.0 (98.95)	9 / 44	1.8 (0.43)	0.36 (0.140)
Full (25<)	30	23.2 (2.37)	6.5 (2.19)	112.3 (123.00)	4 / 38	1.7 (0.57)	0.18 (0.084)
Full (25<50)	24	34.9 (7.14)	18.4 (6.98)	190.4 (153.30)	4 / 96	4.0 (1.77)	0.17 (0.098)
Full (>50)	25	57.5 (8.58)	38.2 (8.91)	222.3 (210.40)	1 / 25	1.8 (0.94)	0.08 (0.077)

The demographic information related to near-misses was excluded, as the self-reported rate varied by such a substantial degree. This indicated that the measure was open to interpretation by participants. Crashes provided a more concrete meaning, and while this meant the variable was a more useful self-report measure, the rates were low. Restricted drivers reported the highest number of crashes, with the lowest number being Novice drivers.

Table 11:

Kolmogorov-Smirnov Values Test for the Normality of the Five Driver Groups

Driver Group	***df***	**Urban Speed Choice**	**Rural Speed Choice**	**No. of Hazards Perceived**	**Hazard Perception Time**
Learner	28	.136	.223	.202	.129
Restricted	29	.134	.179	.153	.110
Full (25<)	30	.127	.109	.203*	.157*
Full (25<50)	24	.140	.127	.166	.088
Full (>50)	25	.187	.163	.181	.199

Apparatus

The validated Video Speed Task (VST) used in Experiment 1 to measure drivers speed choice was used in this experiment. The task was identical in all respects to the previous task; however, all participants were required to estimate the vehicle speed before choosing their ideal speed for each condition in the present video task.

The hazard perception dual-task involved showing video clips of various urban traffic situations to participants, in which they needed to click when they perceived a hazard while also moving the mouse to ensure a small circle remained within the confines of a rectangle superimposed on the screen. Participants were required to click and briefly mention the hazard they had seen whilst moving the dot with the mouse. Before the task commenced, participants were given the opportunity to practice the task. Once a level of 80% hazard perception competence was reached and participants were happy to advance, then eight separate video scenarios were shown. Once the experiment was complete, the program ended.

The Hazard Perception Dual-Task (HPDT)

In order to study the potential role of hazard perception in speed choice, the validated hazard perception task developed by Isler, Starkey, and Williamson (2009) was used in this experiment. In this task, participants were required to search for immediate hazards while also performing a secondary tracking task. An immediate hazard was defined as a hazard that could potentially get into the driver's way so that an evasive driving action would be required, such as braking or steering away. Examples included cars braking, pedestrians, road workers, and cyclists crossing the road. The secondary task involved the participant tracking a randomly moving dot with a small square that was controlled directly by the mouse, overlaid in the centre of the screen. If participants allowed the moving dot to leave the confines of the square, a tracking error occurred, accompanied by a buzzing sound and a change from blue to purple of the top and bottom areas of the screen. The still image taken from the task is shown in Figure 35:

Figure 35*:* Screenshot showing one of the video clips used in the Hazard Perception Dual Task. A simulated vehicle interior and mirrors can be seen, with the secondary dual-task (white rectangle and moving dot) overlaid.

The Hazard Perception Dual-task was designed to give a realistic impression of a driver's perspective travelling along a section of road where hazards could manifest. It included a digital 'fully functioning' dashboard including a moving steering wheel, a 'functional' speedometer, and wing and rear-view mirrors. The video scenarios were created using urban roads and ranged in duration from 8 to 75 seconds in length. There were eight video scenarios, with a total of 40 immediate hazards identified beforehand by driving instructors. The videos used in the experiment were created using footage of New Zealand roads, encompassing various urban and suburban situations (e.g., school crossings, multiple lane roads), displayed from a drivers' perspective, including synchronised mirrors and dashboard (see Figure 3). The videos were compressed to 1080p resolution and presented without audio.

Each video contained five immediate hazards for participants to identify. Initially, the participant was presented with a blank screen. A mouse click on the button in the centre labelled "Click here to Start Video" began the three-second countdown before displaying each clip. Initially, participants were able to practise the primary and secondary tasks before progressing to the experiment in a training loop. Once participants had correctly identified all four hazards in the training loop and were competent with both the tracking task and verbal identification of hazards, the experimenter allowed the testing to begin. The instructions given to the participants were:

> Your task will be to detect immediate hazards by clicking on them with the mouse as soon as you detect them and then by verbally pointing them out. Immediate hazards are hazards such as braking cars, pedestrians walking over the road, cyclists, road workers etc., which potentially could get into your way so that a driving action would be required. (e.g., braking, steering away etc.,). You also need to track a randomly moving dot within a large rectangle with the mouse and make sure that you keep the dot always covered with a small rectangle.

While watching each video, the participant was required to click the mouse as soon as they perceived a hazard as well as verbally identify what each hazard involved (e.g., "pedestrian to my left"). Audio recordings of the verbally identified hazards were made for each participant and matched with mouse clicks to determine the number of correctly identified hazards for each clip, as well as the time to detect the hazard from the moment it first appeared.

Each click was associated with a beeping sound and was recorded by the computer along with a time-stamp in milliseconds from the start of each trial so that the time from the appearance of each hazard could be calculated (*hazard perception time*) along with the number of hazards perceived. Each hazard had previously been allocated a time window in which they occurred to calculate participants' reaction times for each hazard perceived. In order not to skew the data in favour of more experienced drivers, only the reaction times for hazards perceived were analysed, with group means used for missed hazards, keeping with the original task developed by Isler et al. (2009).

At the same time, the participant was required to perform a secondary tracking task. This secondary task involved participants ensuring a randomly moving dot (moving 10 mm/s) was contained within a small square (30 x 30 mm), the position of the box controlled by using the mouse. Both the moving dot and the controlled box were contained within a larger stationary rectangle (130 x 80 mm), which was superimposed over the centre of the traffic scene within the confines of the front window. The dot 'bounced off the edges of this larger rectangle. If the moving dot went outside the square, a buzzing was heard in conjunction with the screen background turning purple for 500ms. The computer recorded the time and occurrence of the tracking error.

Once participants had completed a trial, the original blank screen appeared, and participants could click to start the next video trial in the sequence. Each participant performed the traffic simulation trials in the same order, and after each clip had been displayed, the experiment concluded.

Procedure

Participants were initially briefed concerning the experimental procedure. After consenting to take part in the research, participants were seated on a reclining chair with the monitor directly in front at a 1-meter distance. They were provided with a mouse and mouse-pad which they could move to their preferred hand. Depending on the assigned order group (odd and even-numbered), participants either began with the hazard perception task or ended with the video speed choice task – or vice versa. The video-speed choice task was similar to the previously validated task; however, eye movements were not recorded in this experiment. Participants were instructed to watch each video clip. Afterwards, adjust the position of the needle using the mouse to select the speed they thought was most appropriate for themselves as the driver.

Participants were asked to complete the hazard perception dual-task, which has been described above. They were instructed to click the left mouse button when they perceived an immediate hazard and asked to identify the hazard they had perceived briefly verbally. Participants were also required to move the mouse to position a square box over a moving dot, which simulated the typical cognitive demands when driving. They were provided several practice trials to become familiar with the task. Once they were comfortable and perceived above 80% of hazards on the practice clip, they were invited to begin the experiment. Once the final clip had been displayed, the task ended with a blank screen.

Irrespective of the task order, all participants completed the online Questionnaire measures after the laboratory-based tasks. Once the laboratory-based experiment was completed, participants completed the questionnaire measured by computer using the Qualtrics™ online survey software. Once participants had completed the questionnaires, the answers were stored online along with the participants' unique identification number. Participants were thanked for their involvement in the research and able to ask questions related to the research. Participants were either provided a $10 MTA/Warehouse voucher for their involvement or 2% research participation course credit for first-year students.

Results

An initial analysis of the speed choices for all participants was conducted, performed in a manner identical to the analysis in Experiment 1, to determine if the high level of ecological validity of the choices was reproduced in this experiment. Appendix 3 (p. 335) shows this analysis, and very briefly, the results indicated that speed choices were remarkably similar to those in Experiment 1 for speeds across road types and conditions. This provided greater assurance that the speed choices in the laboratory had considerable ecological validity.

The analysis also involved comparing the speed choices of 'Novice' and 'Experienced' drivers, identical to the approach used in Experiment 1. Both groups selected slower speeds for the night and wet driving conditions. However, a notable between-subject effect was that experienced drivers selected faster speeds than novice drivers for both night and dry conditions. This difference is examined in the context of the five driver groups used in this experiment.

Examining the Role of Age and Experience on Speed Choice

In order to examine the role of experience more thoroughly, a large cohort was recruited, covering a range of age and experience levels. Results from the Speed Choice task were organised into five groups: ranging from 'novice' drivers aged under 25 with 'Learner', 'Restricted', and 'Full' driver's license, and drivers aged between 25 and 50 years as 'Full (25<50)', and then an older driver group 'Full (<50)' with a Full licence for drivers aged over 50 years of age. The demographic information can be seen in the method section of this experiment (p. 142). The speed choices on both Urban and Rural roads under different conditions is displayed in Figure 36, arranged by Driver Group:

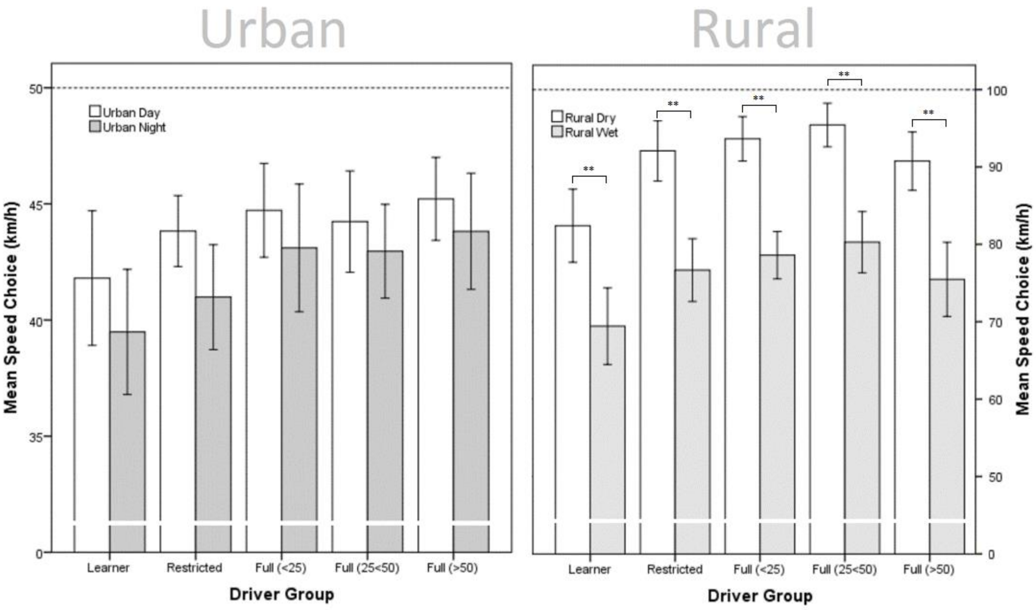

***Figure 36**: The Mean Speed Choice for both Urban and Rural Road Conditions by Driver Group. Speed Limit indicated by the horizontal dotted line. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, p< 0.05 *, and p< 0.01 ***

Visual inspection of Figure 36 indicated that the Learner group selected slower speeds under all road conditions compared with the other driver groups. Similar speeds were observed for each condition and road environment for each of the other driver groups, with a small increase of speed with age and similar confidence intervals. There was a slight decline in speed choice for the Full (>50) driver group. Drivers were observed to prefer slower speeds under Night (Urban) and Wet (Rural) conditions, which was consistent with the findings from Experiment 1 (see Appendix 3, p. 335).

The speed choices for the five driver groups are shown in Table 12, presented according to road condition in Figure 36:

Table 12:

The Mean Speed Choices (brackets represent the Standard Deviations) for each of the Driver Groups

Environment	**Condition**	***Learner***	***Restricted***	***Full (<25)***	***Full (25<50)***	***Full (>50)***
Urban Roads	Day	41.8 (7.47)	43.8 (4.01)	43.3 (7.38)	44.2 (5.16)	45.2 (4.32)
	Night	39.5 (6.95)	40.9 (5.93)	41.9 (8.16)	42.9 (4.78)	43.8 (6.06)
Rural Roads	Dry	82.4 (12.17)	92.1 (10.25)	92.9 (7.67)	95.4 (6.66)	90.7 (9.13)
	Wet	69.4 (12.77)	76.7 (10.64)	77.7 (8.39)	80.3 (9.36)	75.5 (11.61)

A one-way ANOVA was performed to compare the total of speed choices across the Driver Groups, with a significant difference being revealed, $F_{(4,135)} = 4.965$, $p < 0.01$, $\eta_p^2 = 0.132$. Subsequently, individual road Environment, Type and Condition were analysed to determine the differences between Driver Groups.

The results of the analysis between driver groups for both Urban and Rural roads are shown in Table 13:

Table 13:

The Main Effects for the Speed Choices for each Road Environment, Type, and Condition for the five Driver Groups

Environment	**Type**	**Condition**	**F-Value**	**Sig.**	η_p^2
Urban Roads	1 (Narrow)	Day	1.789	0.14	0.054
	-	Night	2.481	0.05*	0.073
	2 (Wide Margins)	Day	1.229	0.30	0.038
	-	Night	1.114	0.35	0.034
Rural Roads	1 (Markings)	Dry	7.584	0.01**	0.194
	-	Wet	3.880	0.05*	0.110
	2 (No Markings)	Dry	4.733	0.01**	0.131
	-	Wet	3.242	0.05*	0.093

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Post-hoc analysis of speed choices between driver groups revealed a significant difference in speed choice between Learner (M= 35.4km/h, SD= 7.37) and Full (>50) (M= 41.4km/h, SD= 7.63) drivers for Urban Road 1 (no markings) for the Night condition ($p< 0.01$), and between Learner drivers and all other groups ($p< 0.01$) for all Rural Road scenarios. None of the other groups showed pairwise differences. All drivers selected significantly slower speeds under the Rural Wet condition. There were no significant differences between Day and Night conditions for any driver group, though all drivers selected slower speeds under the Night condition.

Across driver groups, the overall finding from this was that Learner drivers selected slower speeds. In comparison, the other driver groups chose faster speeds similar to each other (not significantly different). This distinguished the Learner driver group as unique regarding speed choice, being the only group that was significantly different in relation to speed choice.

In order to examine the overall speed choices of driver groups across all road Environments, Types, and Conditions, speed choices were normalised, and then a total sum of z-scores was calculated to represent the differences in speed choice despite the differences in speed limit and environment[16]. This composite sum of z-scores was graphed by driver group, and is shown in Figure 37:

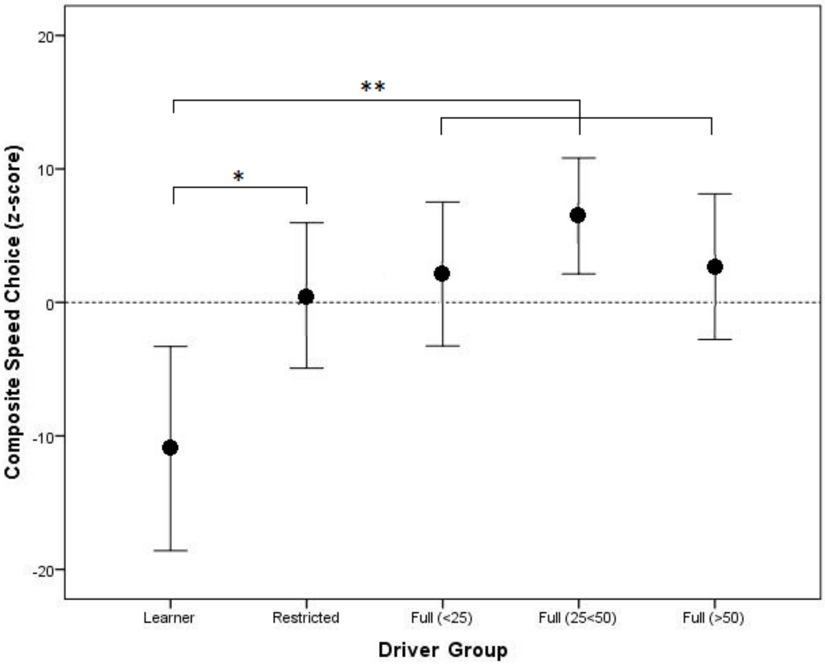

***Figure 37**:* Mean Composite Speed Choice z-scores, by Driver Group. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p < 0.05$ *, and $p < 0.01$ **

Visual inspection of Figure 37 clearly shows that the pattern of normalised speed choices follows a half-crescent shaped pattern in relation to each driver group's increasing age and experience, with 'Learner' drivers showing the slowest speeds and the other driver groups not differing by a substantial degree. A one-way ANOVA was performed to examine the differences in overall normalised speed choice between driver groups, indicating a significant main effect $F_{(4,135)} = 4.870$, $p < 0.01$, $\eta_p^2 = 0.134$. Post-hoc analysis using a Bonferroni corrected Tukey's HSD (Table 14) revealed that the Learner novice group chose significantly slower speeds than all the other driver groups, with a significance of $p < 0.05$ for the Restricted driver group and a significance of $p < 0.01$ for the remaining groups. There were no other significant pairwise interactions. This confirms the previous observation that Learner drivers select considerably slower speeds than their more experienced or older counterparts.

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[16] Because road enviornments had substantially different speed limits, as well as different conditions and type, normalizing the speed choices for each road condition and type, then calculating a total overall score, would provide a means for comparing the overall behaviour of each driver group.

Table 14:

Post-hoc Pairwise comparisons in Normalized Composite Speed (z-score) between Driver Groups

Group	***n***	**Mean**	***SD***	***Learner***	***Restricted***	***Full (<25)***	***Full (25<50)***	***Full (>50)***
Learner	28	-0.745	1.2318	-				
Restricted	29	0.018	0.8810	0.05*	-			
Full (<25)	30	0.106	0.9706	0.01**	0.73	-		
Full (25<50)	24	0.367	0.7868	0.01**	0.19	0.36	-	
Full (>50)	25	0.082	0.9393	0.05*	0.81	0.93	0.38	-

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Within-subject differences for Road Types and Conditions

The differences between drivers' chosen speeds were examined for both Urban and Rural road types and conditions. Speed choices for each driver group are shown in Figure 38 as the difference between the road types (e.g., with or without clear marking and shoulders) for both Day and the Night condition:

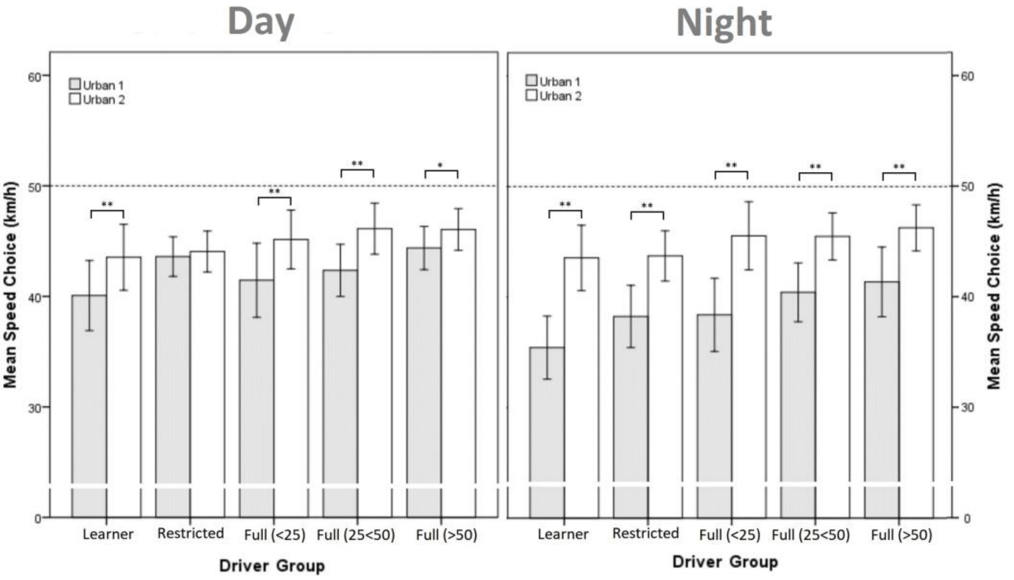

***Figure 38**: The mean Speed Choice for both Urban road types showing the difference between Day (left) and Night (right) conditions, by Driver Group. Speed Limit is indicated by the horizontal dotted line. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p < 0.05$ *, and $p < 0.01$ **

On visual inspection of the figure, it is noted that speed choice seems to differ between the day and night condition on Urban Road 1 (narrow), whilst on Urban Road 2 (wide, clear markings), there is little difference between speed choices between Day and Night condition. Furthermore, the speed choice on Road 2 is consistently faster than the speed choices on Road 1.

The difference between conditions for each road type can be seen in Figure 39:

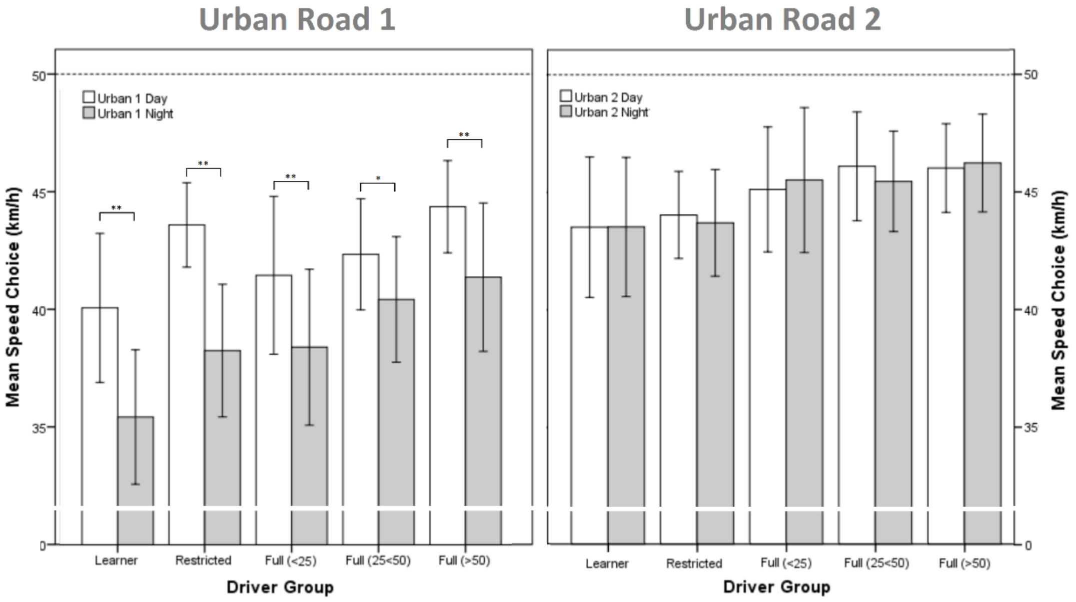

Figure 39: Mean Speed Choices for Day and Night Urban Road Conditions Without (left) and With Markings and Shoulders (right), by Driver Group. Speed Limit is indicated by the horizontal dotted line. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p< 0.05$ *, and $p< 0.01$ **

Inspection of Figure 39 indicated that there was a significant difference between Day and Night conditions on Urban Road 1 (no markings) for all Driver Groups, though there was no significant difference in speed choices for Urban Road 2 (markings). This was consistent with the findings of Experiment 1. All driver groups selected significantly slower speeds for the Night condition on Urban Road 1 (no markings) compared to Urban Road 2 (markings). All driver groups speed choices were slower for Urban Road 1 (no markings) in the Day condition compared with Urban Road 2, apart from the novice Restricted-licence group who made similar speed choices for both day-time roads.

A mixed, two-way 5 (Driver Group) x 2 (Road Condition (Urban Night vs Urban Day) x 2(Road Type, repeated measure) ANOVA revealed a significant main effect between the speed choices made between Road Conditions and Type, Wilks $\Lambda= 0.696$, $F_{(1, 135)}= 57.230$, $p< 0.01$, $\eta_p^2= 0.304$, confirming that speed choices were faster on Urban Road 2 (markings) than Urban Road 1 (no markings) for both Day and Night Conditions. However, there was no significant interaction between Driver Groups for either Road Type, Wilks $\Lambda= 0.973$, $F_{(4, 131)}= 0.895$, $p= 0.469$, $\eta_p^2= 0.027$, or for Condition, Wilks $\Lambda= 0.942$, $F_{(4, 131)}= 2.005$, $p= 0.098$, $\eta_p^2= 0.058$. and no significant interaction between Driver Group, Road Type, and Condition, Wilks $\Lambda= 0.945$, $F_{(4, 131)}= 1.902$, $p= 0.114$, $\eta_p^2= 0.055$.

The mixed ANOVA revealed a significant within-subject effect in speed choices between Day and Night Conditions, $F_{(1,135)}$= 117.803, p< 0.01, η_p^2= 0.473, in which drivers chose slower speeds during the Night condition (M= 38.6km/h, SD= 7.77) compared with the Day condition (M= 42.3km/h, SD= 6.86). There was also a significant within-subject effect for Road Type, $F_{(1,135)}$= 29.102, p< 0.01, η_p^2= 0.182 which confirmed the observation that drivers chose a slower overall speed for Urban Road 2 (M= 38.6km/h, SD= 7.77) compared to Urban Road 1 (M= 44.9km/h, SD= 6.61). There was no significant difference between conditions for Urban Road 2 perceived. Post-hoc tests revealed that there were no significant differences between driver groups.

Rural roads were graphed similarly to Urban roads, firstly by comparing Road Type (e.g., with and without shoulders and markings) and then comparing road condition (e.g., Dry or Wet). These are represented in Figure 40 (Road Type) and Figure 41 (Condition), respectively:

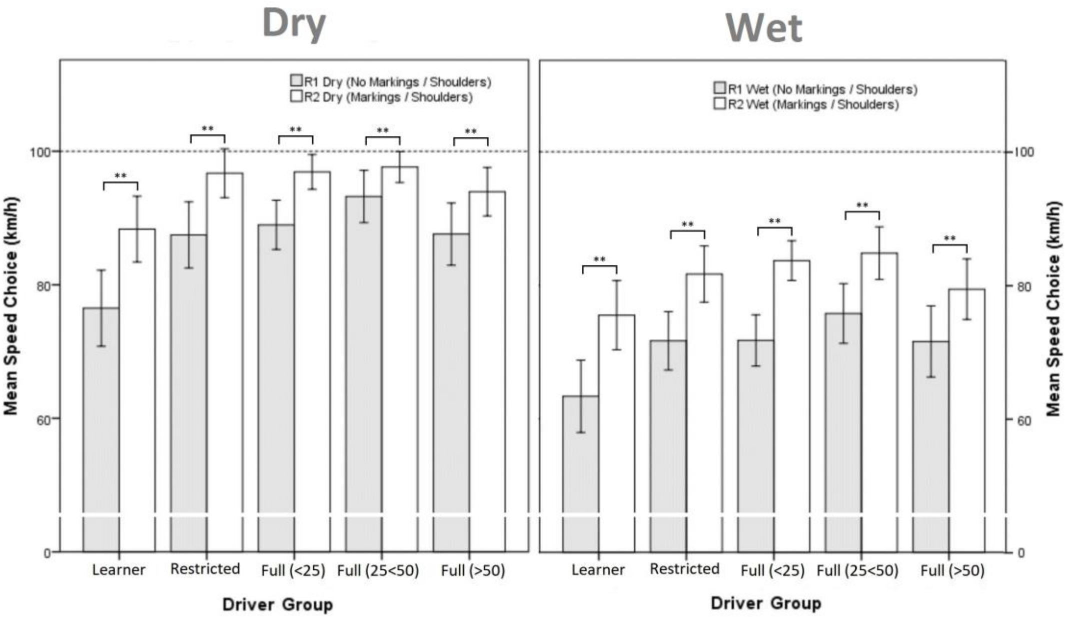

Figure 40: The mean Speed Choice for both Rural road Types showing the difference between Dry (left) and Wet (right) Conditions, by Driver Group. Speed Limit is indicated by the horizontal dotted line. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, p< 0.05 *, and p< 0.01 **

Visual inspection of Figure 40 shows that there are differences between both road condition and type, with learner drivers selecting the slower speed and then the other driver groups selecting faster albeit relatively consistent speeds. There also are apparent within-subject effects with drivers choosing faster speeds for both Dry and Wet conditions on the roads with clear markings and shoulders (Road 1) when compared with the roads without clear markings and shoulders (Road 2). The difference between drivers' speed choices for Rural Road condition is shown in Figure 41:

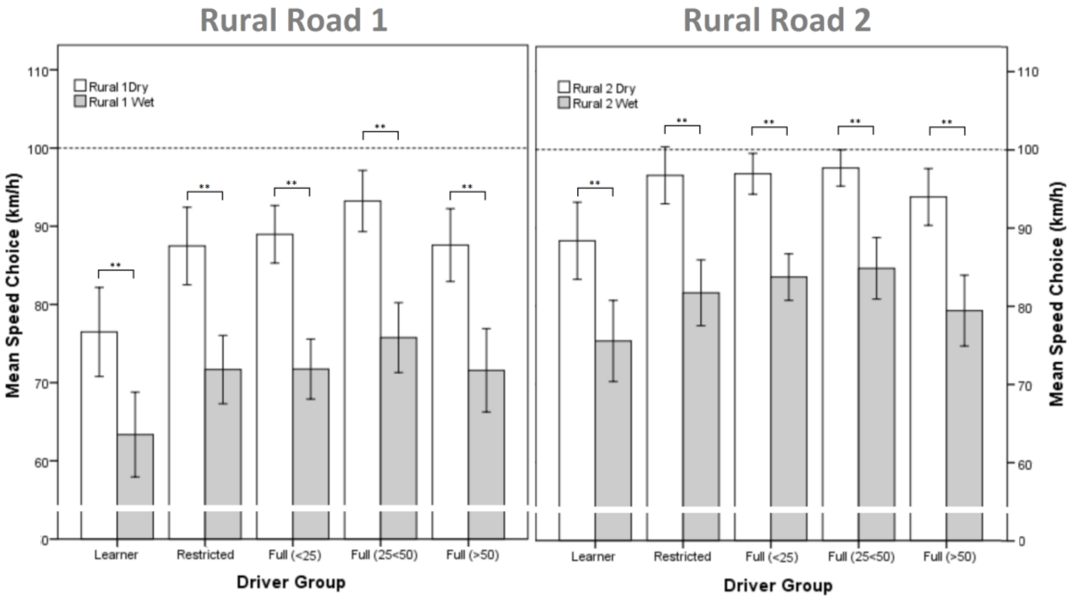

Figure 41: The mean Speed Choice for both Rural Dry and Wet Conditions on road types without (left) and with markings and shoulders (right), by Driver Group. Speed Limit is indicated by the horizontal dotted line. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p< 0.05$ *, and $p< 0.01$ **

Visual inspection of Figure 41 showed that there was a significant difference between speed choices on Wet and Dry Road conditions for all drivers, irrespective of road type. Drivers chose significantly faster speeds on Dry roads than wet roads, and speed choices were faster for roads with markings (Road 2) than roads without markings (Road 1).

A similar mixed ANOVA investigating Drivers speed choices between Condition and Road Type was conducted for Rural Roads, revealing a weak significant interaction between drivers speed choices for different conditions and road types, Wilks $\Lambda= 0.946$, $F_{(1, 135)}= 7.463$, $p< 0.01$, $\eta_p^2= 0.054$, however, there was no significant interaction between Driver Groups for either Road Type, Wilks $\Lambda= 0.982$, $F_{(4, 131)}= 0.586$, $p= 0.673$, $\eta_p^2= 0.018$, or for Condition, Wilks $\Lambda= 0.933$, $F_{(4, 131)}= 2.365$, $p= 0.056$, $\eta_p^2= 0.067$. and no significant overall interaction between Driver Group, Road Type, and Condition, Wilks $\Lambda= 0.966$, $F_{(4, 131)}= 1.136$, $p= 0.343$, $\eta_p^2= 0.034$.

Several significant within-subject effects were found for drivers speed choices on Rural roads under both Dry and Wet conditions, $F_{(1, 135)}= 7.463$, $p< 0.01$, $\eta_p^2= 0.054$. The main effect for Dry roads was $F_{(1,135)}= 93.074$, $p< 0.01$, $\eta_p^2= 0.415$, with drivers selecting slower overall mean speeds on Rural Road 1 (M= 86.6km/h, SD= 12.92) compared to Rural Road 2 (M= 94.7km/h, SD= 9.63).

For Wet Rural roads, the significant main effects was $F_{(1,135)}= 236.828$, $p< 0.01$, $\eta_p^2= 0.664$, with drivers selecting slower overall mean speeds on Rural Road 1 (M= 70.7km/h, SD= 12.41) compared to Rural Road 2 (M= 80.9km/h, SD= 11.05). A significant between-subjects effect was observed for Driver Group, $F_{(4,131)}= 6.139$, $p< 0.01$, $\eta_p^2= 0.158$. Post-hoc tests indicated that Novice learner drivers selected significantly slower speeds than all other groups on Dry ($p< 0.01$), and Wet roads ($p< 0.05$). No other between-subject effects were observed.

All Driver Groups selected significantly slower speeds for the Wet condition than the Dry condition for both Rural Road 1 and 2. All groups favouring significantly slower speeds on Rural Road 1 compared with Rural Road 2 for both weather conditions. Appendix 3 includes a table of the differences between road type and condition for both Urban and Rural Roads.

Overall, this finding is consistent with previous research findings that all driver groups select slower speeds on the narrow Urban road during the Night and the Rural road where shoulders and clear markings are absent. Novice learner drivers selected significantly slower speeds on both Rural roads, which is apparent when comparing different road conditions.

Hazard Perception and Driver Groups

Hazard perception measures are primarily the number of hazards perceived and the time taken to perceive each hazard. Other measures, such as tracking errors and the number of clicks on non-hazards[17] were calculated, but principally these results will be in relation to hazards perception measures. The number of hazards and hazard perception times are shown in Figure 42:

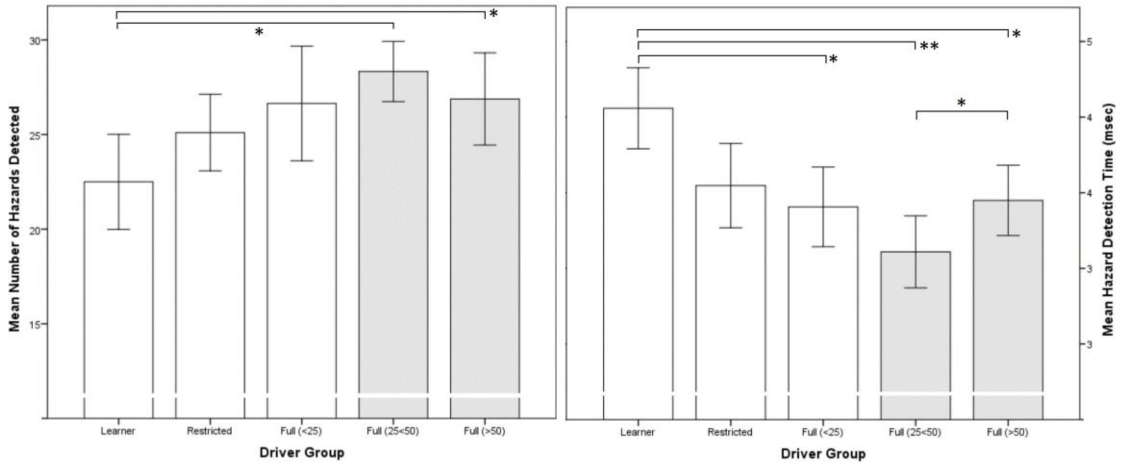

***Figure 42**: The Mean Number of Hazards Perceived (left) and Hazard Perception Times (right), by Driver Group. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, p< 0.05 *, and p< 0.01 ***

Visual inspection of Figure 42 indicates that the number of hazards increases linearly with age and experience (Driver Groups), declining slightly in the experienced (>50) age group. In a similar, albeit inverted pattern, it can be seen that the time taken to perceive hazards steadily declines in a staggered linear fashion with increased age and experience (across groups), with a slight increase in response latency for the experienced (>50) group.

A one-way ANOVA was conducted to examine the differences observed in the number of hazards perceived and hazard perception times between Driver Groups. Significant main effects were observed between Driver Groups for the number of hazards perceived $F_{(4,131)} = 3.546$, $p < 0.01$, $\eta_p^2 = 0.098$.

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[17] The number of clicks on non-hazards could be an indication of drivers perceiving covert hazards, so will be investigated briefly. Without eye-tracking, it is difficult to know whether these are related to actual covert hazards.

Post-hoc pairwise differences between Driver Groups were calculated with a Bonferroni corrected Tukey's HSD test and are presented in Table 15:

Table 15:

Post-hoc Pairwise comparisons in Number of Hazards Perceived between Driver Groups

				Tukey's HSD Comparisons				
Group	***n***	**Mean**	***SD***	***Learner***	***Restricted***	***Full (<25)***	***Full (25<50)***	***Full (>50)***
Learner	28	22.50	6.478	-				
Restricted	29	25.10	5.321	0.48	-			
Full (<25)	30	26.46	7.592	0.01**	0.90	-		
Full (25<50)	24	28.33	3.773	0.01**	0.30	0.79	-	
Full (>50)	25	26.88	5.897	0.05*	0.81	0.99	0.91	-

Significant values: * = p < 0.05, ** = p < 0.01

There were also significant main effects found between Driver Groups in relation to hazard perception times $F_{(4,131)} = 7.332$, $p < 0.01$, $\eta^2 = 0.183$. The Bonferroni corrected post-hoc pairwise differences between groups are presented in Table 16:

Table 16:

Post-hoc Pairwise comparisons in the Hazard Perception Time between Driver Groups

				Tukey's HSD Comparisons				
Group	***n***	**Mean**	***SD***	***Learner***	***Restricted***	***Full (<25)***	***Full (25<50)***	***Full (>50)***
Learner	28	4.057	0.6901	-				
Restricted	29	3.547	0.7325	0.05*	-			
Full (<25)	30	3.437	0.6668	0.01**	0.96	-		
Full (25<50)	24	3.109	0.5638	0.01**	0.11	0.35	-	
Full (>50)	25	3.449	0.5632	0.05*	0.98	1.00	0.36	-

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Tracking Errors between Driver Groups

One potential issue that needs to be addressed is in relation to the effect of the secondary task on the driver's performance. It could be suggested that differences in task performance are the product of the amount of attention devoted to either the primary or secondary task. For instance, if a driver devotes significant attention to the secondary tracking task, they may not have the cognitive resources or perceptual ability to perceive hazards in the primary task, which they would otherwise observe without the distraction. Distraction has been identified as a significant issue in drivers psychology (Klauer et al., 2006). Driver distraction plays a role in the common 'look but failed to see" accident accounting for a number of preventable crashes, due to the lack of detailed processing, or the sufficient presence of distractors that interfere with visual representations of the road environment (Werneke & Vollrath, 2012; Wickens, 2005).

In this experiment, participants were required to track a moving dot with the mouse whilst simultaneously clicking when identifying hazards. The tracking task intended to 'simulate' the natural demands placed on a driver present in the driving task itself, separate from the role of other related processes such as searching for hazards. The number and duration of tracking errors were recorded and are shown in Figure 43 and Figure 44, respectively:

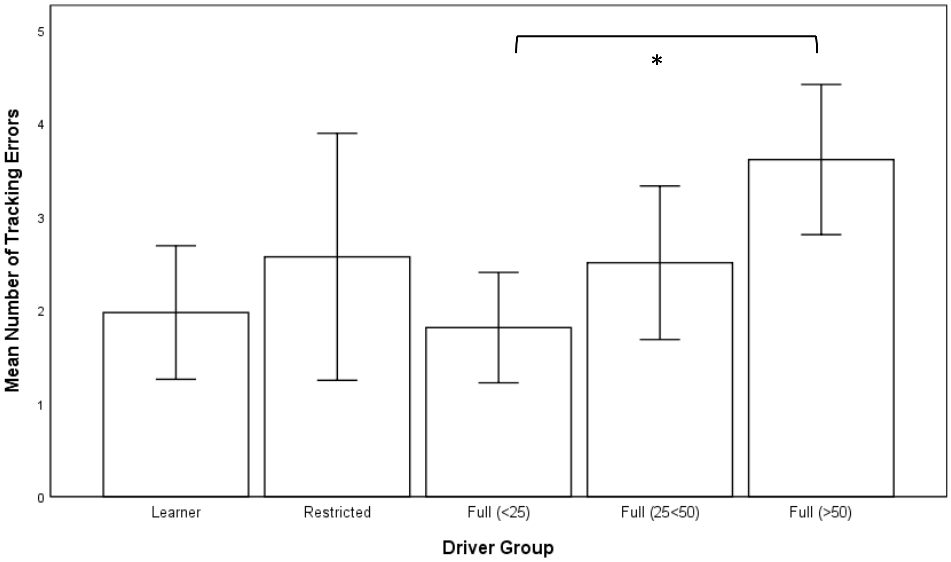

Figure 43: The Number of Tracking Errors, by Driver Group. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p < 0.05$ *, and $p < 0.01$ **

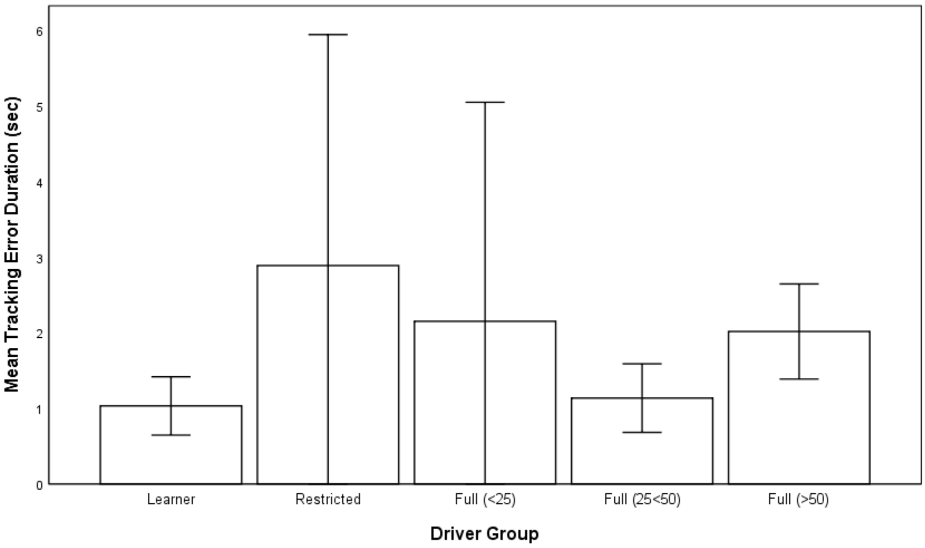

Figure 44: The Mean Duration of Tracking Errors, by Driver Group. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, p< 0.05 *, and p< 0.01 **

Visual inspection of Figure 43 showed that the number of tracking errors seemed to be roughly the same for all Driver Groups. However 'Full (>50)' appears to have a significantly greater number of tracking errors compared to the other Driver Groups. A one-way (5 Driver Groups) ANOVA was conducted to determine differences in the number and duration of tracking errors for each Driver Group. The ANOVA revealed a significant main effect between Driver Groups for the number of tracking errors, $F_{(4,131)}= 2.537$, $p< 0.05$, $\eta_p^2= 0.072$, though the effect was not statistically significant with the mean duration or each tracking error, $F_{(4,131)}= 0.587$, $p= 0.67$, $\eta_p^2= 0.018$. Post-hoc analysis using Tukey HSD showed that there was a significant mean difference ($M_D= 1.79$, $SE= 0.65$) in the number of tracking errors between Full (<25) drivers and Full (>50) drivers, with Full (>50) drivers having the greater number of tracking errors ($p< 0.05$). There were no other between-subject effects that reached statistical significance.

The number of clicks on Hazards and on Non-hazards was calculated. For discussion, we can consider that Clicks on Hazards refer to coded immediate hazards, whereas clicks on Non-Hazards could be considered either uncoded hazards or mistaken clicks. The number of clicks is shown in Figure 45:

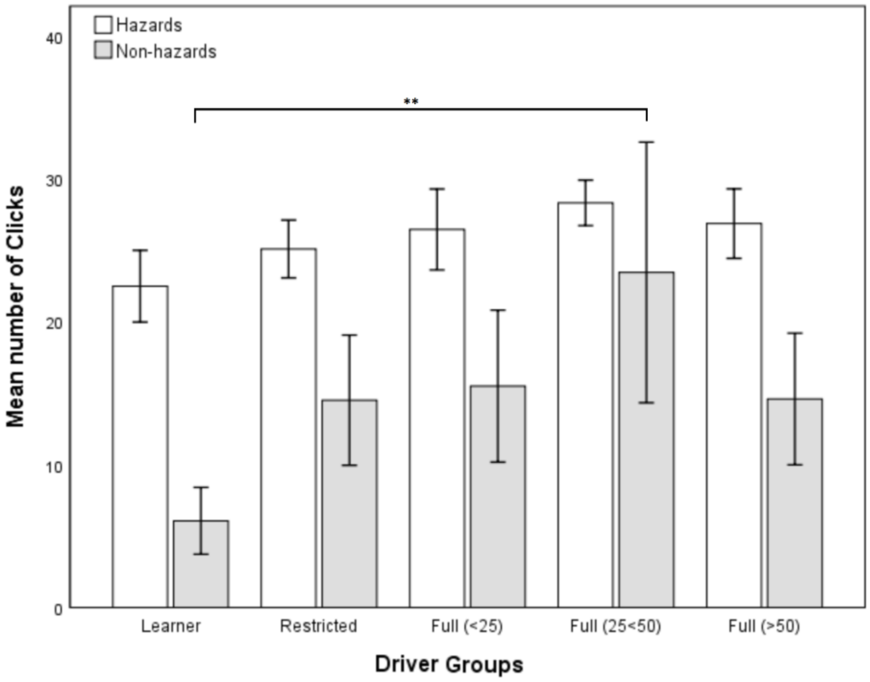

Figure 45: The Mean Number of Clicks on Non-Hazards in the Hazard Perception Dual Task, by Driver Group. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p < 0.05$ *, and $p < 0.01$ **

In Figure 45, there appeared to be a difference between Driver Groups in relation to the number of clicks on non-hazards, with learner novice drivers having the fewest and Full (25<50) drivers having the greatest number of clicks. A one-way ANOVA revealed a significant main effect observed between Driver Groups for the number of clicks on non-hazards, $F_{(4,131)}= 5.247$, $p< 0.01$, $\eta_p^2= 0.138$. The number of clicks on non-hazards does appear to roughly mirror the number of clicks on immediate hazards, which was confirmed through a repeated-measure ANOVA, with a significant main effect, Wilks $\Lambda= 0.930$ $F_{(4,131)}= 2.460$, $p< 0.015$, $\eta_p^2= 0.070$. There was a significant between-subject effect for the number of clicks on hazards and non-hazards, $F_{(4,131)}= 6.848$, $p< 0.01$, $\eta_p^2= 0.169$, with post-hoc Tukey's HSD comparisons revealing that the only significant difference between driver groups was between Learner and 'Full (<25<50)' drivers ($p< 0.01$). The normalised number of clicks for both Hazards and Non-hazards is shown in Figure 46:

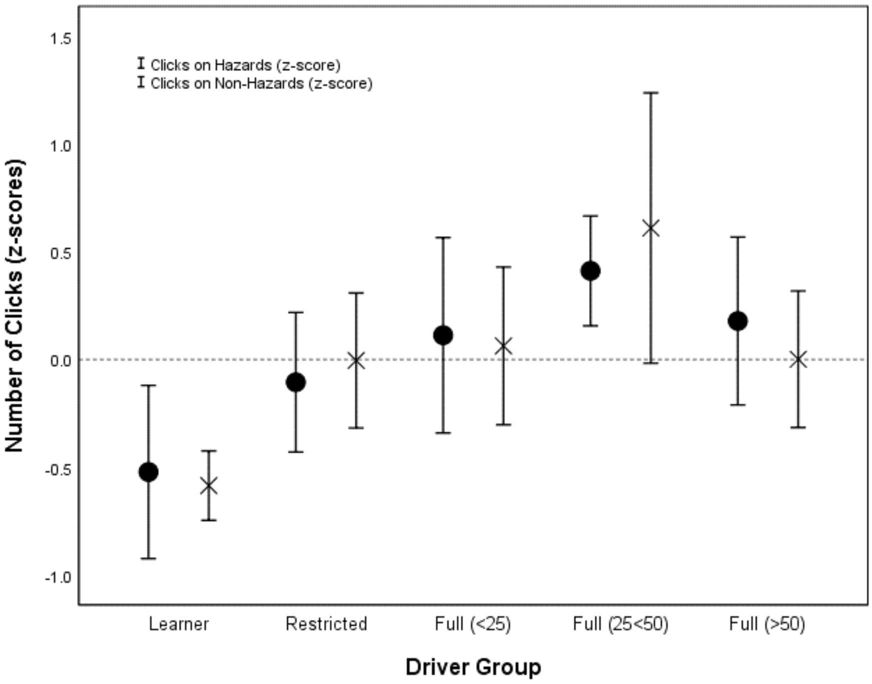

Figure 46: The Normalized number of Clicks on both (coded) Hazards, and Non-hazards, by Driver Group. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, p< 0.05 *, and p< 0.01 **

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The normalised number of clicks shown in Figure 46 reveals a similar pattern of clicks on Hazards to Non-hazards. This finding is significant, as it could be criticised that the reason that the more experienced drivers excelled at the task was that they were merely clicking in response to almost everything. However, the methodology of the task ensured that only those coded immediate hazards that met predefined criteria were accepted, which have been described in the method section and listed in Appendix 11. After analysing the recordings, many of the clicks on non-hazards could be considered potential or covert hazards that either did not present or had not yet materialised into immediate overt hazards. An eye-tracker would have been valuable in examining this identification of potential or covert hazards.

The Relationship between Hazard Perception and Speed Choice

Leading out of Experiment 1, with the difference in eye-movement behaviour, one of the main questions was whether there would be a significant relationship between speed choice and the hazard perception measures. Similar to the correlation-based approach employed by Renge (1998), Pearson's correlations between normalized composite speed choice, normalized number of hazards perceived, and normalized hazard perception times was conducted. A significant positive correlation was found between normalized speed choice and the number of hazards (r= 0.259, p< 0.01).

To visually represent the relationship between the two hazard perception measures and speed choice, normalised values were calculated and then plotted together. The left side represented normalized speed choice across Driver Groups, and the right-hand side representing one of the normalised hazard perception measures. Figure 47 shows the relationship between normalised speed choice and the normalised number of hazards perceived:

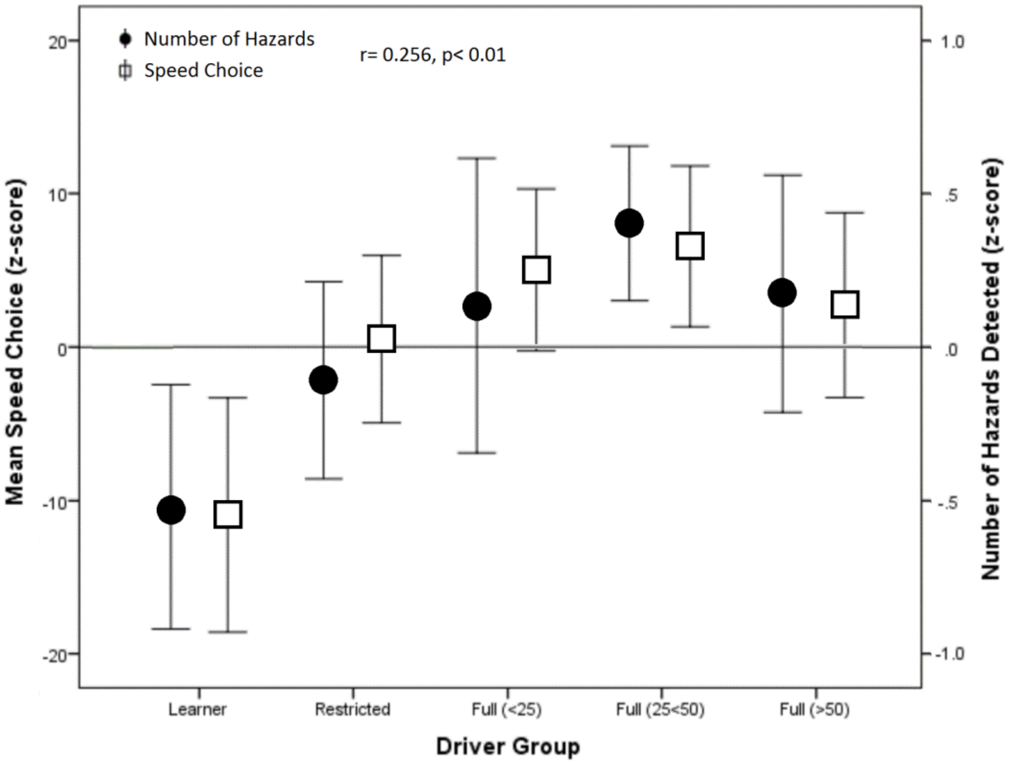

***Figure 47**: The Relationship Between Normalized Speed Choice (left-axis) and the Normalized Number of Hazards Perceived (right-axis), by Driver Group. Error bars represent 95% CI.*

From the positive correlation and visual inspection of Figure 47, it can be clearly seen that as the number of hazards perceived increases across Driver Groups, normalised speed choice follows a very similar trend. The relationship between speed choice and hazard perception suggests that as the number of hazards perceived increases, so too does the speed drivers choose. Learner drivers have the lowest speed choice and also perceived the least number of hazards. Restricted drivers were also found to be low in the number of hazards perceived, yet selected speeds that are more in line with those made by the more experienced Full (<25) and Full (>50) drivers.

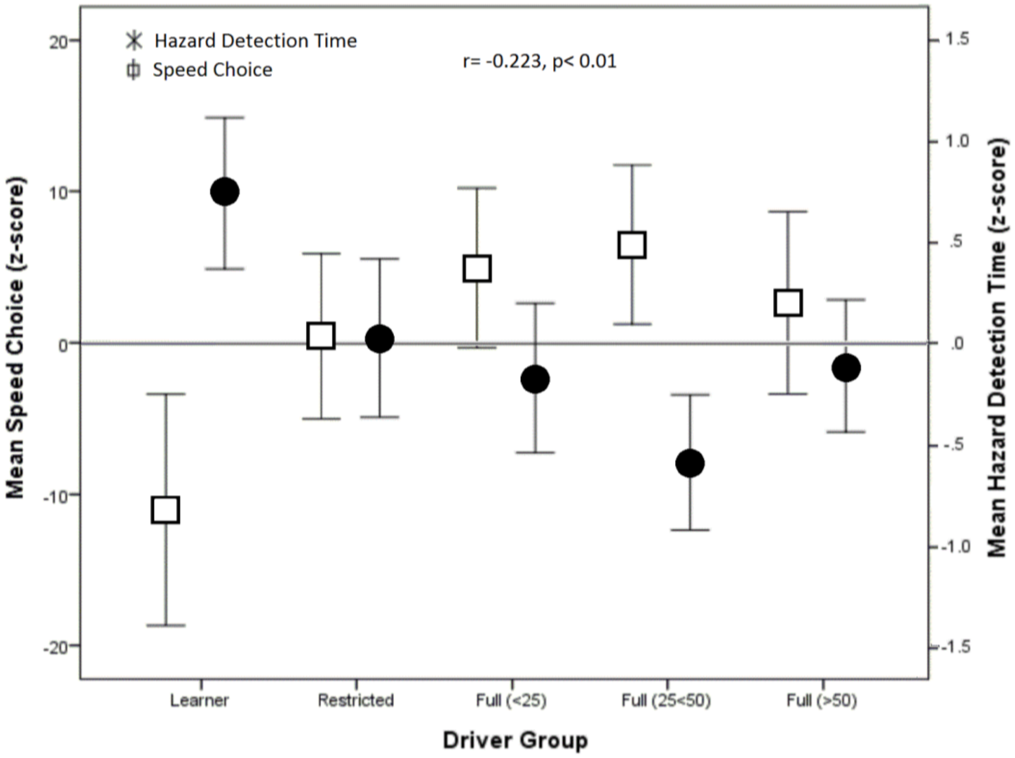

***Figure 48**: The Relationship between Normalized Speed Choice (left-axis) and the Normalized Hazard Perception Time (right-axis), by Driver Group. Error bars represent 95% CI.*

Figure 48 shows that speed choice follows an inverted U-shaped curve, while the time taken to perceive hazards follows a more quasi-linear trend down. A low value for hazard perception time means that participants perceived hazards in a small amount of time from when the first appearance. A negative relationship was found in relation to normalized speed choice and hazard perception time (r= -0.228, p< 0.01). This suggests that the relationship between speed choice and hazard perception is such that drivers chose faster speeds with quicker hazard perception times.

Given that learner drivers were significantly different from the other driver groups in both their hazard perception performance and speed choices, it was considered that learner drivers could strongly influence the correlation. Learner drivers were unique in that their typical driving context involved supervision, and their hazard perception was generally poor. When the learner driver group was removed from the analysis, the correlation between speed choice and the number of hazards perceived remained significant (r=0.212, p= 0.05). However, the correlation with hazard perception time was found to be non-significant (r= -0.203, p= 0.057).

Discussion

This experiment set out to examine the relationship between drivers' speed choice and hazard perception ability, using the video-based speed choice task validated in Experiment 1 accompanied by a separate, validated Hazard Perception dual-task developed by Isler, Starkey, and Williamson (2009). One of the significant findings was the positive relationship between the number of hazards perceived and speed choices. As we hypothesised based on the available literature, this finding was unexpected as drivers with more advanced hazard perception ability chose slower speeds. For instance, Renge (1998) found that slower speed choices were correlated to a higher number of identified hazards and greater recognition of situational risks. Additionally, McKenna et al. (2006) noted that drivers selected slower speeds in the presence of hazards following anticipation training (McKenna et al., 2006). It was noted that when learner drivers were excluded from the analysis, the correlation between speed choice and hazard perception time ceased to remain significant.

Another unexpected finding was that older, more experienced drivers chose significantly faster speeds than Learner-licence drivers, irrespective of the road environment, type, or condition. These findings were contrary to the speed choice behaviour of 'experienced' drivers observed in Experiment 1, which had employed the same task. While overall, speed choices under different road type and condition were highly consistent with the findings from Experiment 1, this was the case only when drivers' age or experience were not considered.

While the anticipated relationship between hazard perception and speed choice was not identified, there may still be potential for such a relationship. As the speed choices made by most drivers could be considered modest and potentially did not exceed the threshold where there is a significant change in the amount of risk that drivers experience (Lewis-Evans, 2006). Considering that many experienced drivers would be familiar with driving at their chosen speeds on similar roads as presented in the speed choice task, they are likely to have developed speed habits for these commonly encountered conditions. This seems reasonable given that the strength of the correlation was influenced by the slower speed choices of learner drivers. Learners are likely unfamiliar with many road situations, and driving outside of their everyday context may mean they choose slower speeds. Lewis-Evans (2012) noted that ratings task difficulty and feeling of risk do not linearly increase with faster speeds, but rather perceived risk starts relatively low and plateaus, and then increased only once a certain ‘threshold’ speed has been reached (Lewis-Evans, 2012; Lewis-Evans et al., 2011).

In this experiment, a noteworthy finding was that there were no significant differences in speed choice between the restricted drivers (novices) and experienced driver groups. This lack of difference suggests that restricted drivers (with 2.5 years of driving experience) may be overconfident in their abilities, which the literature defines as being ‘poorly calibrated’ (Kuiken & Twisk, 2001). Considering that restricted novice drivers were found to have significantly weaker hazard perception ability compared with experienced drivers, this may explain the discrepancy between their actual driving competency (hazard perception) and their perceived ability as demonstrated in their choice of faster speeds. When the role of experience (as indicated by age and license) was considered, one aspect consistent with the literature was that the learner novice drivers selected significantly slower speeds than the other driver groups.

Learner drivers legally require another driver to supervise their driving, and statistically, this is the safest driving period when complying with the conditions attached to the license (Mayhew, Simpson & Pak, 2003). Day et al. (2018) performed a longitudinal study of novice drivers self-reported driving behaviour throughout three months. They found that novice drivers had poor situation awareness after gaining a learner licence. Initially, these drivers were under-confident initially and less inclined to drive at speed. However, with experience gained over three months, there was a corresponding increase in confidence, with some participants reporting increased aggression or thrill-seeking (Day et al., 2018). The dramatic increase in crash involvement observed in the statistics occurs at the point where a driver transitions to a restricted license, where they can drive ‘solo’ without an instructor to aid in managing potential risks (Lewis-Evans, 2010; Mayhew et al., 2003).

Given the direction of the correlation, it was thought that the role of experience might play an essential role in the relationship between speed choice and hazard perception. Faster speeds were related to a more significant number of hazards identified. However, the relationship is likely more nuanced, as speed choices for novice restricted-license drivers were similar to those selected by experienced drivers, despite the substantial difference in driving experience (which may indicate that novice drivers were overconfident, displaying poor calibration). One of the best explanations for the observed positive relationship was that younger drivers might have been overconfident in their ability and chose faster speeds despite having relatively poor hazard perception. In contrast, experienced drivers were more competent where their perceived ability aligns well with their actual ability, with speed choices falling within an acceptable range (e.g., calibration). As both drivers selected speeds under the speed limit, these selections could be considered appropriate for the conditions (Fuller et al., 2007). Experienced drivers might also have a more developed ability to drive faster while maintaining greater comfort levels in the chosen road environments. This contrasts with the younger learner-licence drivers who are still developing in their speed selection behaviour and may experience greater feelings of risk and task demands at higher speeds (i.e., referring to Kuiken and Twisk, 2001). This could explain the finding that novice learner drivers chose the slowest speeds of all driver groups, while novice restricted and full-license drivers chose similar speeds, despite being separated by a large difference in the amount of driving experience.

What was consistent with Experiment 1 was that as road conditions changed, drivers speed choice changed consequently. All driver groups selected slower speeds for each night condition compared to daytime conditions, which may potentially indicate that drivers perceived the night driving to be marginally riskier. However, the effect was only significantly different for young learner drivers. Furthermore, the reduction in speed between day and night conditions was more pronounced for Urban Road 1 than Urban Road 2, reinforcing that speed choice for night driving depends very much on the road characteristics (e.g., lines, medians). All driver groups chose significantly slower speeds in wet driving than dry driving conditions for the rural roads. In both instances, speed choice was under the legal road speed limit.

In parallel with the previous experiment, there was a significant difference between drivers when the road conditions were perceived as potentially more demanding, illustrating increased task demand (Fuller, 2005). Drivers seem to reduce their speeds when the road conditions became more demanding (e.g., narrow roads, lack of clear markings, night, or wet road conditions), consistent with the task capability interface model (Fuller, 2005). According to this model, drivers adjust their behaviour to maintain a stable workload as task demands increase. This is demonstrated in this experiment, with drivers choosing slower speeds on roads that are more challenging.

Hazard perception ability was found to increase with age and experience as expected, with learner novice drivers perceiving the fewest hazards and having longer hazard perception times. There was a substantial improvement between learner and restricted driving. However, both the learner and restricted novice drivers' groups perceived a smaller number of hazards. They had significantly longer hazard perception times than their fully licensed peers (novice full), or the experienced group. This finding is consistent with much of the reviewed literature (McKenna, Horswill & Alexander, 1999), suggesting that hazard perception ability improves along with experience.

The tracking error number and durations suggested that the Older Experienced (>50) driver group had a higher number of tracking errors. In contrast, the learner novice drivers made the fewest tracking errors, which could indicate that novice drivers devoted more attention to the secondary task and deprioritised the main hazard perception task. While there is a possibility that this was the case, the pattern of tracking error durations and number was inconsistent with the number of hazards correctly identified or the time taken to detect hazards overall. For instance, learner, restricted, full and full (25<50) drivers had similar error number and time. Yet, there was a significant linear increase in the number of hazards perceived accompanying age and experience.

Additionally, there was a significant degree of variability within each of the driver groups as indicated by the large confidence intervals, suggesting that drivers ability to perform the tracking task varied substantially. In contrast, the confidence intervals on hazard perception times and the number of hazards perceived were comparatively small, suggesting that the primary task of detecting hazards was not interfered substantially by secondary task performance. The secondary tracking task could have been influential over primary task performance for the most experienced/aged driver group, and this was anticipated to some degree. However, their performance on the hazard perception task was only mildly lower than the other experienced driver (25<50 years old) group, suggesting significant secondary task interference, which points to even more advanced hazard perception in the older driver group.

A review of the literature related to measuring hazard perception has shown that not all hazard perception tasks differentiate between the ability of novice and experienced drivers. One of the leading criticisms of hazard perception tasks is that they may be biased in favour of experienced drivers due to using actors to stage hazardous scenarios and selection criteria that demonstrate significant differences between experience groups (Horswill & McKenna, 2004). In this task, the video scenarios, while having been shown previously to differentiate between experience groups, were not pre-selected with this criteria. The footage was taken from natural real-world traffic situations that are likely to minimize the influence of bias due to contrivance or preselection. The linear improvement of hazard perception ability across increments of both age and experience in this experiment suggests that the hazard perception task is sensitive to differences in driver experience.

Previous research has observed that changes in visual search behaviour often accompany advanced hazard perception. This is worth investigating in greater detail in future experiments, as visual perception plays a critical role in hazard perception ability and may play a role in drivers speed choices. Novice drivers typically have a narrower horizontal range of search for hazards than experienced drivers, and they tend to fixate longer on hazards (Crundall & Underwood, 1998; Mayhew & Simpson, 1995; Underwood, 2007).

As drivers' age exceeded 50 years, there was a slight decline in hazard perception time and the number of hazards perceived, with a corresponding reduction in speed choice. Quimby and Watts (1981) found that hazard perception times improved (e.g., became quicker) with age until the mid-50s and then began to worsen. This could be the consequence of degraded visual acuity and extended reaction times. While this is unlikely to be the cause of speed choices in this task, it could be that changes in speed choice could be the outworking of experienced drivers being aware of their limitations and adjusting their speed choices accordingly. What is interesting is that further research by Quimby et al. (1999) found that laboratory measures of speed choice and hazard perception were not correlated. They found that speed was not associated with any of the laboratory measures of visual performance or hazard perception, while age was correlated with measures of hazard perception. Visual acuity was found to decline with age as anticipated, while hazard perception times increased along with age, accompanied by a reduction in the number of observed hazardous manoeuvres. While older drivers determined more risky driving situations, this was not correlated with speed or hazard perception (Quimby et al., 1999).

While the findings of this experiment do not necessarily discredit the concept of a relationship between more advanced hazard perception and more appropriate speed choices, the direction of the correlation seems to run counter to what was anticipated from Renge (1998) and McKenna, Horswill, and Alexander (2006). However, it is possible that drivers with more advanced hazard perception also possess a more cautious approach to driving, despite choosing faster speeds than learner drivers. Greater caution for these drivers may manifest with speeds within their range of comfort and ability to manage, given their more developed skills. Slower speed choices may relate to poor hazard perception by coincidence due to learner drivers becoming prone to feeling unsafe on unfamiliar road and traffic situations while also possessing poor hazard perception. Regardless, the relationship between speed choice and the number of hazards perceived remained positive even when novice drivers were excluded from the analysis. An eye-tracker could help resolve these questions by demonstrating the factors drivers examine in making speed judgements (refer to Experiment 1). Additionally, a combined task that measures hazard perception and speed choice under the same conditions is more appropriate than measuring driver behaviour using two separate instruments. This will be the focus of the next experiment.

Limitations

One of the challenges in this experiment was clearly linking hazard perception and speed choice in a meaningful way. The two tasks provided anticipated improvements in hazard perception and speed choice measures with age, which were sensitive to different road conditions. However, it remained impossible to determine whether the more complex or demanding roads required more developed hazard perception skills in making an appropriate speed choice. This was due to the tasks being separate, measuring speed choice using one measure, and hazard perception ability on another. A combined task would overcome this limitation, allowing for speed choice and hazard perception to be measured under the same road conditions.

Another explanation for the unanticipated relationship between hazard perception and speed choice may be due to the criteria used for the video task. Based on criteria established by Horswill and McKenna (1999) and replicated by Cantwell (2010), video footage was selected to ensure flexibility to change speeds, which meant that there were few immediate hazards ahead of the vehicle. McKenna et al. (2006) suggested that individuals trained in hazard perception only reduced their approach speed more than untrained individuals only when a hazard was present. When hazards were absent, speed behaviour did not differ between trained and untrained participants.

Without observing where the driver focused their attention, it was not possible to determine whether speed choices were influenced by the presence of hazards over mere chance or other factors – the effect of ambient visual search without a specific focus on hazards. This issue presented with Experiment 1, in that the hazards were not operationally coded. Instead, the assumption was that search to the side of the road was the key indicator of the possible search for hazards in making speed judgements. For example, suppose a driver failed to focus on a potential hazard although selecting a slower speed. In that case, the slowing may not be associated with the potential hazard but may be the mere chance of other non-specific effects, such as the appearance of the road. While this may technically be the perception of 'hazards' (i.e., the road and traffic environment features that increase the perceived risk), this may be different from immediate traffic hazards. This effect has been observed by Muttart (2013), where experienced drivers reduced speed on approach to intersections even when they were not explicitly glancing at other vehicles or road users. In contrast, novice drivers did not reduce speed unless they observed potentially risky traffic scenarios.

Another issue was that the secondary task involved a dot that moved randomly so that the direction may differ between participants despite the starting point being the same. The unpredictable movement of the secondary-task dot introduced the problem that the dot may draw some participants visual attention closer to the location of hazards for some participants than for others. Given the random movement and sample size, it was unlikely that this would have a powerful biasing effect across an entire group of participants, though it is still worth considering. The secondary task may also create differences between novice and experienced drivers. Novice drivers are likely to have faster reaction times and higher computer 'literacy' than older drivers. While this may provide novice drivers with some advantage, it further shows the degree to which experienced drivers are more adept at detecting hazards. Additionally, it has been observed by Hills et al. (2018) that 'carry-over' eye movements have a more detrimental effect on novice drivers' scanning behaviour than experienced drivers, which may bias the primary hazard perception task in favour of experienced drivers. While secondary task performance was not significantly different between driver groups, it is unknown to what extent the additional task demand influences drivers.

The Rationale for Experiment 3

Initially, a new experimental task will need to be developed and tested, which measures both hazard perception and speed choice reliably. The task could employ aspects of both tasks used in this experiment, merging them so that drivers hazard perception is measured in a similar way to the Hazard Perception dual-task, and then presenting the speedometer from the speed choice task after the video clip concludes.

Additionally, the use of an eye-tracker would resolve the question raised concerning speed and more demanding scenarios, emphasising how different drivers search for hazards and how this influences their speed choice. The key research question concerns the relation between speed choice and the perception of specific hazards. In this experiment, it was not possible to compare speed choices under particular situations to specific hazards. This issue can be addressed through eye-tracking and a singular instrument measuring both variables.

Experiment 3

Introduction

In the previous experiment, an unanticipated positive relationship between hazard perception and speed choice was identified. In reviewing the available literature, there was little information to explain why speed choice would increase with more advanced hazard perception; instead, it was thought that there would be a corresponding reduction in speed choice. For instance, Renge (1998) found a negative correlation between speed choices and the number of hazards perceived. While there were several plausible explanations as to why more advanced hazard perception skills might correspond to the faster choice of speed, the questions related to this relationship could not be sufficiently resolved in Experiment 2 using two separate tasks. Hence, there is a need for further examination using a different experimental approach using a single task.

Nevertheless, the finding of a positive relationship between hazard perception and speed choice led to the conclusion that the use of two separate instruments – one to measure speed and the other to measure hazard perception - was not ideal, as each task measured drivers' behaviour on different roads with differences in traffic conditions, hazards, and levels of potential risk. It might be that drivers only reduce speeds when they become aware of immediate hazards, as McKenna, Horswill, and Alexander (2006) indicated. This conclusion led to a change in the experimental approach, with the development of a combined task that merged the hazard perception and speed choice tasks into one task. This new combined task was complemented by using an eye-tracker to measure participants' visual behaviour.

In Experiment 1 the different speed choices of novice and experienced drivers with concurrent differences in eye-movement behaviour suggested that more experienced drivers may have a more developed underlying process for selecting speeds, which is informed by visual factors related to hazard perception. Horswill and McKenna (2004) described hazard perception as the capacity to anticipate potentially dangerous risk factors by 'reading the road' – and this appears to be an accurate metaphor, as novice drivers were observed to have a limited range of visual search behaviour compared with experienced drivers in Experiment 1, which was consistent with other reviewed research (Konstantopoulos et al., 2010; Underwood, 2007; Geoffrey Underwood et al., 2002).

To use Horswill and McKenna's (2004) words and expand upon their metaphor, it may be the case that drivers *read the road in the language of hazards*. In this new combined task, the use of eye-tracking and measures of both driver's hazard perception ability and speed choice behaviour can test the truth to this analogy by providing evidence that drivers use their perception of hazards when making speed-related judgements.

Underwood, Crundall, and Chapman (2011) argued that driving-related measures derived from the simulator, such as speed and braking, provide a behavioural signature that indicates whether drivers have spotted the hazard and what behaviour they have chosen to avoid it (i.e., hazard mitigation). Such behavioural signatures distinguish between experienced and novice drivers and between groups of learner drivers (e.g., Crundall, Andrews, van Loon, & Chapman, 2010). Hence, examining the behavioural signature of drivers may reveal information related to their responsiveness to hazards.

Speed management encompasses drivers' ability to choose an appropriate driving speed, considering traffic safety as the primary goal while compensating for prevalent conditions, such as other road users, access to the road (i.e., intersections), and volume of traffic (Global Road Safety Partnership, 2008). Suppose young novice drivers show inferior strategies in speed management, especially where potentially hazardous situations are involved. In that case, an argument can be made that poor hazard anticipation skills are at the root, or a determinant, of poor speed management. Since, together, inappropriate speed choices and poor hazard perception constitute the major causes of crashes among novice drivers (McKnight & McKnight, 2003), it is of considerable practical and scientific significance if one could trace failures in speed management skills to under-developed hazard perception skills.

Evidence suggests that awareness (or lack of awareness) of hidden or obscured hazards may affect drivers' speed choices (Borowsky et al., 2012; Parmet et al., 2015). For example, as part of a study designed to examine the behaviour of calibrated and uncalibrated drivers, De Craen, Twisk, Hagenzieker, Elffers, and Brookhuis (2008) presented randomly ordered pictures and asked participants to report their preferred speed for each picture. The pictures were non-sequentially presented pairs of nearly identical traffic scenes, with one picture in each pair modified to include an additional object that made the scene more complex. Participants were able to inspect each picture once throughout the experiment. De Craen et al., (2008) found that young novice drivers were generally poorly calibrated (i.e., less able to assess their driving skill correctly) and chose higher speeds for the more complex scenes than the speed choices of older experienced drivers.

The dependency of speed management on drivers hazard awareness skills have also been demonstrated in simulator-based studies (Fisher et al., 2002), reporting differences between novice and experienced drivers for several specific traffic scenarios. In one such scenario, which presents a curved road immediately followed by a stop sign, the novices braked much later and harder just before the stop, suggesting that they did not anticipate the stop sign, in contrast with the gradual reduction of speed by more experienced drivers. In another road scenario, in which participants drove straight through a two-lane signalised intersection while there was a truck in the left-turn lane, experienced drivers applied their brakes more often than the novices, suggesting that experienced drivers were aware of cars that might pull out into their driving path from behind the truck. A similar finding was made by Muttart (2013), showing that experienced drivers reduce approach speed to intersections irrespective of the extent of visual surveillance. Novice drivers are more likely to maintain speed unless accurately identifying and focusing visual attention on risky traffic scenarios (Muttart, 2013).

These specific cases provide evidence that there may be dependencies between speed management and hazard anticipation but do not provide a complete understanding of when and where these dependencies occur. If a relationship between hazard anticipation and speed management can be confirmed, we would hypothesise that experienced drivers, as a group, would pay attention to the same elements of the road and the road environment at any given moment in a given scenario. The result would be selecting similar speeds that are more likely to be appropriate to the momentary road and traffic conditions.

These drivers, as a group, would, therefore, demonstrate more homogenous speed choices than young novice drivers. On the other hand, young novice drivers, as a group whose members pay attention to a variety of elements in the environment at any given moment (sometimes these elements are attended to arbitrarily). This will result in more random and individual-based behaviour resulting in greater variability in speed choices. Each driver in this group will choose a different speed depending on the elements that he or she perceives at a given moment. This conjecture was explored briefly in Experiment 2. However, to examine this hypothesis, the use of a more sophisticated speed-related task is required, where drivers' attention to hazards can be measured simultaneously. The current study is designed to understand better how novice and experienced drivers behave under various traffic situations.

The cumulative case so far is that there were differences in the speed choices made by novice and experienced drivers in Experiment 1. There was a correlation between hazard perception and speed choice in Experiment 2. Hence, it was decided that a single task that bought together both speed choice and hazard perception measures provide a more reliable indication of the relationship between the two measures. Observations about speed, hazard perception, and eye-movement behaviour could all be made to a single road situation. A combined measures task was developed, which united the two tasks using the same hazard task video clips used in the previous experiment for consistency.

Research Questions

1. Do drivers choose slower speeds when aware of concurrently occurring hazards?

As anticipated from the reviewed literature, as hazard perception improves, drivers become orientated towards safer driving generally, accompanied by slower and more appropriate speed choices in particular (e.g., Renge, 1998). However, the findings of the previous experiment suggested that drivers with more advanced hazard perception chose faster speeds than those with less developed hazard perception skills. It might be the case that a) these faster speeds did not correspond to an appreciable increase in the amount of perceived risk, and hence, ought to be considered appropriate to the conditions. Alternatively, b) as we measured speed choice and hazard perception under different road and traffic conditions, it is not methodologically sound to compare hazard perception performance in one setting to speed choice decisions occurring in another setting. This second explanation seemed reasonable, and hence this experiment further examines the relationship between SC and HP using a single combined task. The original hypothesis based upon the work of Renge (1998) and McKenna et al., (2006) remains standing.

2. Do eye movements mediate hazard perception ability?

The reviewed literature would indicate that accompanied improved hazard perception would be a broader and strategic visual search behaviour (e.g., G. Underwood et al. (2002). This will involve a broader horizontal search pattern, a higher number of short fixations, and lower fixation duration on perceived hazards, as well as a more top-down knowledge-driven approach to perceiving hazards (evidenced by fixations on higher priority hazards: e.g., Konstantopoulos (2009); Vlakveld (2011).

Method

The findings presented in this Experiment were collected over six months between 2016 and 2017, comprising three distinct data collection periods throughout which the experimental technique remained consistent. An initial pilot study was conducted to validate the new combined Hazard Perception - Speed Choice task and ensured that the eye-tracker and related equipment were performing accurately. A small sample study followed this. Based on the findings of this initial study, a much larger participant sample was recruited to investigate the effects observed.

Participants

This research was conducted in line with the University of Waikato Ethical Guidelines concerning human testing (the University of Waikato Handbook on Ethical Conduct in Research, 2001). Application for human testing was submitted to the University Ethics Committee in 2014 with an amendment in 2015.

Eligibility requirements were that participants held a current New Zealand learner, restricted or full drivers' license, and had normal or corrected to normal vision.

Participants were recruited using convenience sampling by placing advertisements throughout the Faculty of Arts and Social Sciences and through word of mouth from participants who had taken part already. Additionally, a broad and representative sample of New Zealand drivers was preferable in understanding the general public drivers' behaviour. Consequently, advertisements were placed on community notice boards in the suburb surrounding the Hamilton campus and in the School of Psychology and School of Engineering and placed on Social Media and community bulletin boards. Eligible first-year psychology students received course credit for participation. Demographic questions were focused on driving experience, and so no information regarding citizenship or ethnicity was collected.

Participants contacted the researcher, and a time was arranged for them to take part in this experiment. In total, 89 drivers (39 male, 50 female) participated in this experiment. In relation to driver license, 16 participants held a Learner license

(Novice= 15, Experienced= 2), 26 held a Restricted license (Novice= 23, Experienced= 3), and 47 held a Full license (Novice= 15, Experienced= 32)[18].

Demographic Information on Participants

Demographic information was collected from participants, including driver history. The demographic information for each of the driver groups is shown in Table 17 below. The number of near-misses was determined to be an unreliable measure of driver history, though crashes and fines were discrete events, and so they are used to represent the average rate of the number of incidents per person in each group in the final column (avg. Incidence).

What is important to note from Table 17 in comparison to the previous experiment is that the Novice Learners are more similar to the Restricted Novice drivers rather than the Learner Novice from Experiment 2. This is likely due to convenience sampling for this experiment, which relied heavily on participation from University undergraduate students as opposed to High School Students, as has been used in Experiment 2 for the novice ‘Learner’ group. Because of the similarity between the different learner, restricted, and full-licence novice groups in relation to age, we decided to collapse the experience/age groups into two ‘novice’ and ‘experienced’ groups according to driver age.

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[18] As novice and experienced drivers held multiple license types, the distinction between experienced and inexperienced becomes a categorical issue. An experience group was created which did not consider the age of the participant, but rather their license status and number of kilometers travelled.

Information regarding distance driven and traffic incidents are reported in Table 17.

Table 17:

The Demographic information for the Driver Groups

Driver Group	**n**	**Age (Y)**	**Driving Experience (Y)**	**Med. Distance per Week (Km)**	**Crashes**	**Fines**	**Near Misses**	**Ave. Incidents**
Learner	16	18.7 (0.67)	1.7 (0.95)	1 – 30	0	0	24	0
Restricted	20	19.5 (2.14)	2.3 (1.66)	31 – 60	6	4	46	0.5
Full (<25)	14	20.1 (2.20)	3.9 (1.57)	31 - 60	2	3	30	0.35
Full (≥25)	38	33.8 (11.12)	15.8 (12.18)	61 - 120	10	4	68	0.36

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Apparatus

The two instruments employed in previous experiments have been the Hazard Perception dual-task, and the Video Speed Choice task. Both these laboratory methods have demonstrated good ecological validity and clearly differentiated between drivers with differing levels of' driving experience. As discussed in the previous experiment, the natural evolution of these tasks from their separate use was developing a singular combined task that incorporated aspects of both tasks. Despite the two tasks measuring different aspects of driving behaviour, due to this standard video-based method, they may be effectively combined to explore a relationship between hazard perception and speed choice.

This combined Hazard Perception and Speed Choice task utilised the video clips used in Experiment 2 (refer to p. 146), combined with the digital speedometer from the Video Speed task used in Experiment 1 (refer to p. 77). The videos used from the previous hazard perception task were used as they had clearly defined immediate hazards. The sequence for each trial in the task is displayed in Figure 49:

What do you think would be the ideal speed for this road condition?

NOTE: Drag the needle to the value you wish

Click to Start Video

Eye-tracking Calibration

Hazard Perception Dual-task

Speed Choice

What do you think would be the ideal speed

for this road condition?

Figure 49: The sequence for each trial of the combined task Hazard Perception & Speed Choice task.

As shown in Figure 49, participants clicked on a button to initiate each of the eight trials. The trial began with the presentation crosshair in which drivers were instructed to focus their eyes. This was done to calibrate the eye-tracker drift before each trial. Following a three-second countdown, a single video clip from the hazard perception dual-task began. Participants could identify immediate hazards through a mouse click along with a verbal indication of each hazard. The task involved the secondary tracking task in a manner identical to the task used in Experiment 2. Following the completion of each hazard perception video clip, a digital speedometer appeared, asking participants to indicate what speed they perceived to be ideal for the road condition they had just viewed. During the task, participants' eye movements were measured, which allowed for comparison in eye-tracking and hazard perception performance. This process was repeated for each of the eight hazard perception clips.

The measures used in this experiment are the number of hazards perceived, hazard perception time, and mean speed choices selected, both overall and according to each clip. Additionally, the eye-tracker provides measures of the number and duration of fixations, the number and amplitude of saccades, the number of blinks, and pupil dilation.

Eye movements related to the Secondary-task

As there was a secondary task that added additional visual focus within the centre of the road, the eye-tracking data was processed before analysis to control for the influence of eye movements of drivers attending to the secondary task. Including eye movements associated with the secondary task could influence the overall examination of fixation number and duration, particularly the distribution of visual search by drawing the majority of fixations into the centre field. Preliminary analysis of the fixation data without removing the secondary-task fixations was found to not significantly distort or misrepresent the fixation number and durations between driver groups. Removal of the secondary task fixations was primarily performed in order to examine the distribution of visual search.

The removal of tracking task fixations was performed frame-by-frame, with Area of Interest (AOI) assisting the process in isolating fixations within the confines of the secondary task rectangle. As fixations related to the tracking task were rapid dwell on the dot's position, these were easily identified. Gaze devoted to the mouse position was also an indication of secondary task focus, and these were also identified as tracking task fixations.

Regarding performance on the secondary task, preliminary analysis revealed no significant differences between the driver group(s) concerning the number or duration of tracking errors.

Procedure

Participants were instructed as to what would be involved in the experiment, and the eye-tracker was demonstrated to participants. Following consent, participants were then asked to be seated comfortably in front of the display (in a fixed location). The head-mounted eye-tracker was attached and made as comfortable as possible. The positions of the cameras were adjusted, and lenses focused as required for each participant.

***Figure 50**:* A participant demonstrating the use of the Head-mounted Eye-tracker while engaging in the Hazard Perception Task.

Participants were then run through a practice run of the hazard perception task to familiarise themselves with the task and be able to adjust their posture to comfortably sit in the chair facing the monitor and were instructed to move as little as possible during testing. The eye-tracker was calibrated and validated for each participant prior to the hazard perception task commencing, then practice trials were conducted.

The Hazard Perception Task practice trials involved two video scenarios. Participants identified hazards and clicked the mouse button, verbally stating the identified hazard and maintaining the mouse cursor's location over the moving-dot secondary task.

Once participants identified approximately 80% of the hazards in these scenarios and were comfortable with the secondary task, the experiment commenced. The combined task involved eight video-based trials. Once the trials had completed, the experiment ended, and participants were thanked for their time and provided a debrief. Eligible students received course credit.

Results

The results in this experiment will be reported with the initial examination into any potential relationship between speed choice and the hazard perception measures. Analysis of between-group differences will be examined to determine if there are measures that differentiate between novice and experienced drivers. This will be followed by an analysis of between-group differences for hazard perception and speed choice. Analysis of the eye-tracking measures will then be presented regarding hazard perception ability between novice and experienced drivers.

The Relationship between Hazard Perception and Speed Choice

The primary focus of this experiment was to examine further the relationship observed in Experiment 2 through the use of a combined task explicitly designed for this experiment. A correlation-based analysis was conducted between drivers hazard perception skills and speed choices, and this relationship is visually represented in Figure 51:

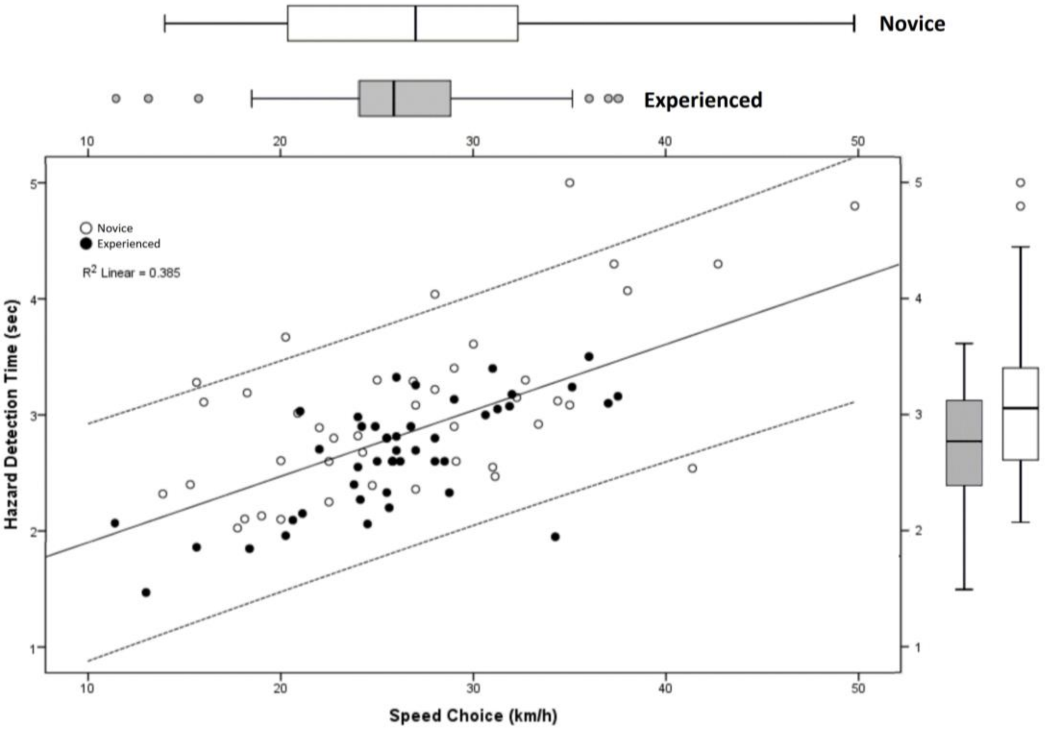

Figure 51: The relationship between Hazard Perception Time and Mean Speed Choice, by Driver Group. The hollow circle represents the Novice driver group, and the solid circle (grey in box plot) represents the Experienced driver group. The continuous line represents the linear regression line, and the dotted line represents 95% CI. Box-plots are also included to show the distribution of Hazard perception time (vertical axis) and Speed Choice (horizontal axis).

Mean speed choice and measures of hazard perception skill (e.g., mean number of hazards perceived, mean time to perceive hazard), were correlated using bivariate Pearson product-moment to see if there were significant relationships. The single most striking observation to emerge from the analysis was a significant strong positive correlation between speed choice and hazard perception time, with a coefficient of $r= 0.609$, $p< 0.01$. This correlation suggested that as hazard perception response times increase, so too do speed choices (i.e., the longer it takes to perceive a hazard, the faster speed choices).

Interestingly, the correlation in the combined task goes in a different direction to that found in Experiment 2, which had suggested faster speeds were related to quicker hazard perception times. The opposite result was found in this combined task. What can be observed in the above scatterplot (Figure 51) is that novice drivers have relatively large variability in both speed choice and hazard perception times. By contrast, experienced drivers display less variability and are more tightly clustered together towards slower speeds and quicker hazard perception times. This may indicate that novice drivers have a much more varied degree of capability contrasted with experienced drivers.

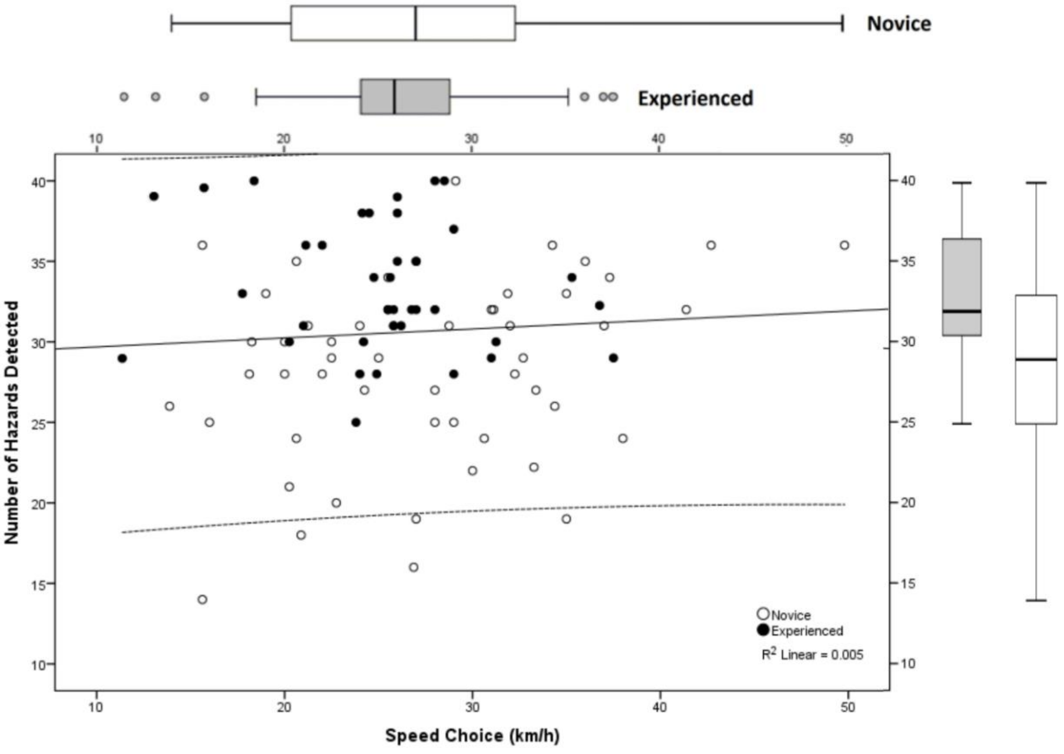

Figure 52: The relationship between Speed Choice and Number of Hazards Perceived by Driver Group. The continuous line represents the linear regression line, and the dotted line represents 95% CI. Box-plots are also included to show the distribution of Number of Hazards Perceived (vertical axis) and Speed Choice (horizontal axis).

The number of Hazards perceived was correlated with Speed Choice, and this is represented in Figure 52. Visual inspection of the scatter plot indicates that there does not appear to be a relationship between the two variables, with the regression line being almost horizontal. A Pearson product-moment correlation between speed and the number of hazards perceived confirmed the absence of a relationship, r=0.039, *p*= 0.78, which was unexpected. It was anticipated that both measures (e.g., number of hazards and perception times) of hazard perception would be related to speed choice behaviour. What is worth noting from visual inspection of the figure is, like Experienced drivers hazard perception times, the number of hazards perceived shows a minor degree of variability when compared to Novice drivers, who show a much more considerable amount of variation.

Hazard Perception between Novice and Experienced Driver Groups

The number of hazards perceived, as well as the hazard perception times, were calculated for Novice and Experienced driver groups and are displayed in Figure 53:

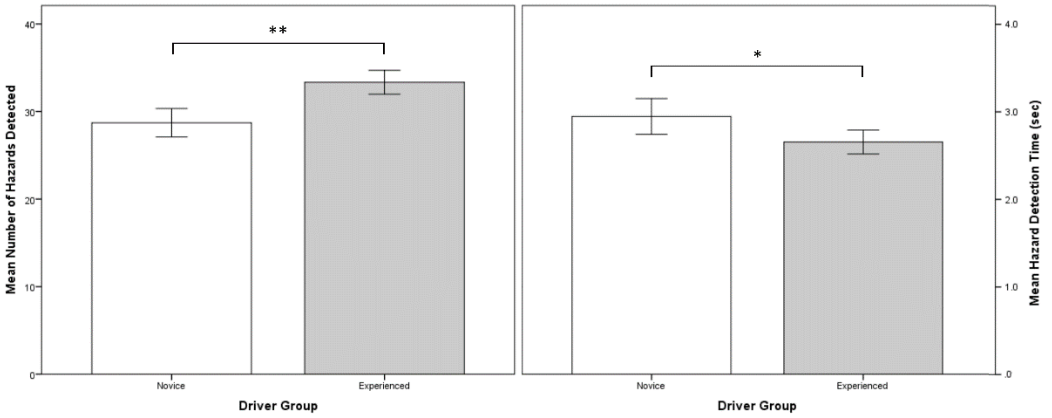

Figure 53: The Number of Hazard Perceived (left) and the Mean Hazard Perception Time (right), by Driver Group. Error bars represent 95% Confidence Intervals (CI).

Visual inspection of Figure 53 shows that the Experienced driver group had more advanced hazard perception skills than Novice drivers, as demonstrated by the greater number of perceived hazards and shorter hazard perception times.

A one-way ANOVA was conducted to determine significant differences between the mean hazard perception times of the two driver groups. A significant main effect between driver groups was identified for the mean hazard perception time, $F_{(1,88)}$=

5.685, $p < 0.05$, $\eta_p^2 = 0.062$, with perception times for Experienced Drivers (M= 2.6 sec, SD=0.39) being significantly quicker than Novice drivers mean of 2.9 sec (SD= 0.74).

A one-way ANOVA also revealed that Experienced drivers perceived significantly more hazards, $F_{(1,88)} = 14.996$, $p < 0.01$, $\eta_p^2 = 0.148$, perceiving an average of 33 hazards (SD= 4.2), compared with Novice drivers who averaged 28.8 correctly identified hazards (SD= 5.85). There were no significant gender effects identified. These results agree with those of Experiment 2, with Novice drivers perceiving fewer hazards than more Experienced drivers.

Speed Selection and Hazard Perception for Individual Roads

The second part of the analysis focused on the speed choice and hazard perception scores for each of the eight road scenarios. Figure 54 shows the overall speed choice for each of the eight road conditions with the mean hazard perception time for each road superimposed. Visual inspection of the figure indicates that there is overall significant speed variation between task trials, with speed choice selections well below the speed limit. The most surprising aspect to the trend in the hazard perception times for each road is how similar that trend is to the speed choices selected

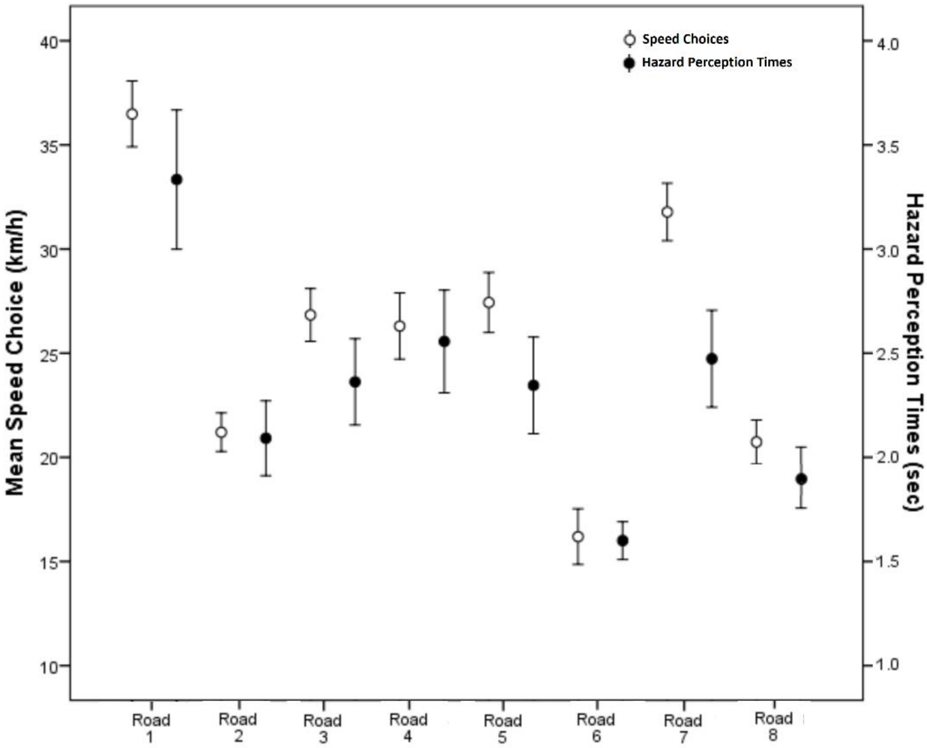

***Figure 54**:* The relationship between Overall Mean Speed Choice (Left Axis) and Hazard Perception Times (Right Axis) for the Eight Road Scenarios used in the combined task. Error bars represent 95% CI

Visual inspection of Figure 54 indicated that there might be a relationship between the speeds that participants chose for each road, and the hazard perception times for those roads. Despite the appearance of a relationship between speed and hazard perception times at the level of individual roads, a mixed ANOVA showed no significant interaction between Road and Hazard Perception times $F_{(1,88)}= 1.022$, $p= 0.486$, $\eta_p^2= 0.664$.

Considering this, a multiple linear regression was performed to determine whether hazard perception number, time, and road type predicted speed choices. Summary of the multiple linear regression analyses predicting speed choices using the number of hazards, hazard perception time, and the Road number. The results are shown in Table 18:

Table 18: *The results of the step-wise regression, with hazard perception time, Road 1, 4, and 7 predicting speed choice.*

Step	**r^2**	**r^2_{change}**	**Variable**	**Standardized β**	**Sig.**
1	.121	.015	Number of Hazards	0.1213	0.16
2	.306	.094	Hazard Perception Time	0.2811	0.01**
3	.545	.297	Road 1	0.4919	0.01**
			Road 2	0.0269	0.82
			Road 3	0.1902	0.10
			Road 4	0.2533	0.04*
			Road 5	0.1957	0.09
			Road 7	0.4042	0.01**
			Road 8	0.0388	0.71

Significant values: * = $p < 0.05$, ** = $p < 0.01$

The analysis revealed the Hazard Perception time was a significant predictor of speed choices, along with roads 1, 4, and 7. There was no moderating relationship between hazard perception time and road, showing that the trend observed in Figure 54 was not significant.

Table 19:

Mean Speed Choice for each Road for Novice (n=42) and Experienced (n= 37) Drivers

			Novice		***Experienced***	
Road Scenario	M Overall	SE	M	SD	M	SD
Road 1 Commercial (L)	33.7	0.91	33.6	9.17	33.9	7.10
Road 2 Construction	22.1	0.78	22.6	7.49	21.6	6.70
Road 3 Busy	27.5	0.97	28.1	9.37	26.9	8.33
Road 4 School Zone 1	27.3	0.96	28.3	9.06	26.1	8.54
Road 5 School Zone 2	26.6	0.90	27.7	9.02	25.3	7.08
Road 6 Shared Space	20.0	1.09	21.6	11.44	18.1	7.43
Road 7 Central road	27.9	0.97	27.9	9.28	27.9	8.56
Road 8 Commercial (B)	22.2	0.93	22.2	9.29	22.1	7.51

Inferential analysis revealed no between-group differences in speed choices across road scenarios (Table 19).

Eye-movement Behaviour

Fixation and Saccade differences between driver groups:

Table 20 shows the differences between eye-movement behaviour for novice and experienced drivers. One-way ANOVA revealed that the average number of fixations was found to be significantly different between Driver Groups, $F_{(1,88)}= 4.929$, $p< 0.05$, $\eta_p^2= 0.011$, as was average fixation duration, $F_{(1,88)}= 30.362$, $p< 0.01$, $\eta_p^2= 0.064$. The average number of fixations was 118 (SD = 72.4) for Novice drivers, and 135 (SD = 80.05) for Experienced drivers). The average fixation duration was 316.43msec (SD = 83.38) for Novice drivers and 274.96msec (SD = 42.69) for Experienced drivers.

Table 20:

The measures of Eye-movement Behaviour for Novice (n=42) and Experienced (n=37) Drivers per clip

				Novice		***Experienced***	
	F	p	η_p^2	M	SD	M	SD
Fixation Number	4.928	0.05*	0.011	117.9	72.43	135.0	80.05
Fixation Duration	30.66	0.01**	0.064	316.4	83.38	274.9	42.69
Saccade Number	4.928	0.05*	0.010	117.2	72.39	134.2	80.05
Saccadic Amp.	0.378	0.53	0.110	6.79	1.778	6.68	1.690
Number of Blinks	1.005	0.31	0.020	4.6	7.39	5.3	6.89
Pupil Diameter	42.51	0.01**	0.087	878.5	304.59	690.8	217.72

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Data from Table 20 shows that the average number and duration of fixations were significantly different between driver groups. Experienced drivers, on average, had a greater number of short fixations than the Novice driver group. Given that there was a significant difference between driver groups in relation to the number and duration of fixations[19], the further analysis focused on the potential relationship with hazard perception measures, which were also different between Driver Groups. The primary

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[19] The findings of this experiment are consistent with the results in Experiment 1, with novice drivers having fewer fixations of longer duration compared with Experienced drivers.

reason to focus on these factors was that differences in the number, duration, and distribution of fixations was the key difference between driver groups in relation to visual measures. Furthermore, hazard perception measures also clearly differentiated Novice and Experienced driver groups.

A scatter diagram (Figure 55) and Pearson's product-moment correlation was used to determine the relationship between the number of fixations and hazards perceived ($r= 0.294$, $p< 0.05$). The correlation suggests that as the number of fixations increases, so too does the number of hazards perceived. What is interesting is that despite the majority of participants having a total fixation count (*M*= 960, *SD*= 151.5) between 750 and 1250, the Experienced drivers show less variability in the number of hazards perceived, clustering about 35 hazards perceived when compared to Novice drivers (see Figure 55).

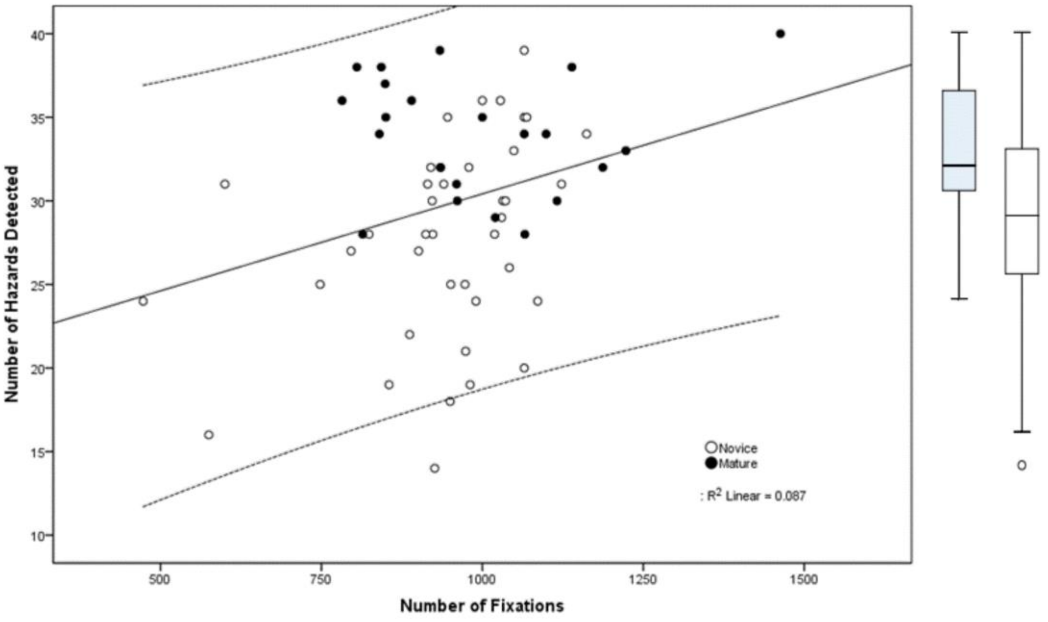

Figure 55*:* The Positive relationship between the Number of Fixations and the Number of Hazards Perceived. Markers are used to identify the different Driver groups. The solid line represents the linear regression line, and dashed lines represent 95% CI

The observed 'clustering[20]' between Driver Groups was examined by comparing the number of fixations per perceived hazard. A one-way ANOVA revealed that there were significant differences between Driver Groups, $F_{(1,88)}= 7.166$, $p< 0.01$, $\eta_p^2= 0.107$, with Experienced drivers requiring fewer fixations ($M= 29$, $SD= 5.6$) per hazard perceived compared with Novice drivers ($M= 35$, $SD= 9.2$). This suggested that Experienced drivers used their fixations more effectively to detect hazards[21].

A similar examination was conducted to determine the relationship between hazard perception time and the number of fixations, shown in Figure 56. A significant negative correlation was identified ($r= -0.285$, $p< 0.01$), suggesting that as the number of fixations increases, the hazard perception time decreases.

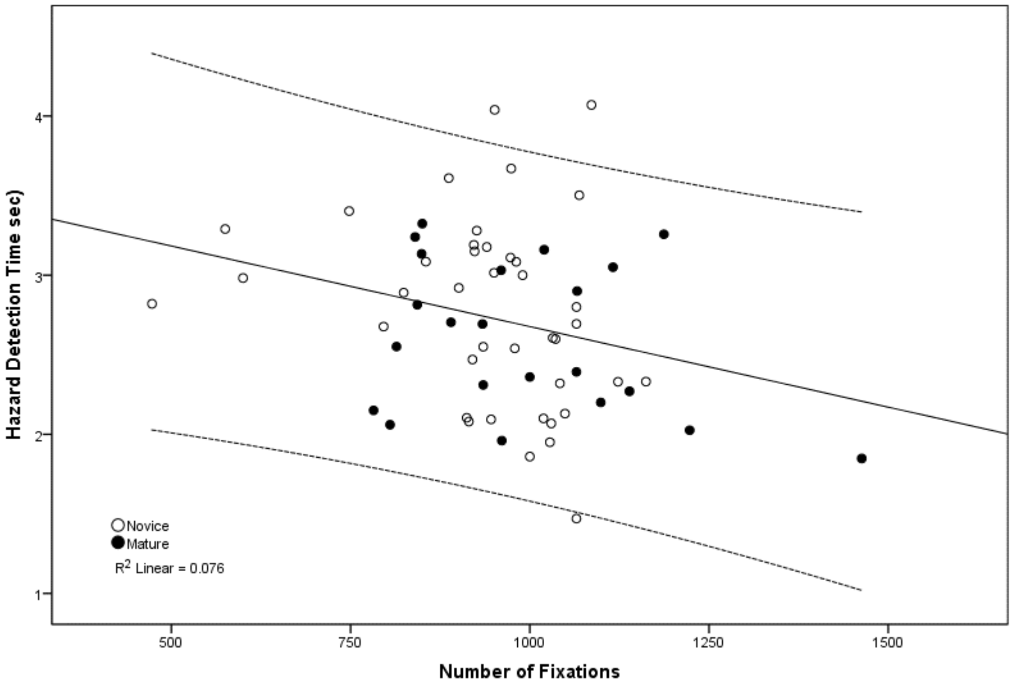

***Figure 56**:* The negative relationship between the Number of Fixations and Hazard Perception time. Markers are used to identify the different driver groups. The solid line represents the linear regression line, and dashed lines represent 95% CI

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[20] Parmet et al., (2015) used the homogeneity as a measure of how similar or different behaviour was between driver groups in a simulator-based study. While their method was used to show homogeneity in speed choice over time, a similar approach could be applied to this instance, where more experienced drivers have similar behaviour, whereas novice drivers have a more diverse range of behaviour based on their range of compitency.

[21] However, this can only be confirmed through the use of eye-tracking, to see whether indeed there are less fixations but visual information being more effectively used to identify hazards.

From a visual inspection of Figure 56, it appears that per fixation, Experienced drivers can perceive more hazards, potentially by extracting more useful information. Considering that the number of fixations is related to both hazard perception time and the number of hazards perceived, further examination of visual search behaviour needs to be conducted. The variability was similar for both Novice and Experienced drivers, suggesting that the number of fixations has less of a role in hazard perception times than the number of hazards perceived. Together, however, this provides evidence that experienced drivers deploy their fixations more strategically to identify hazards.

Fixation Distribution

To this stage in examining drivers' behaviour, the number of fixations and their respective durations have been an essential element to the analysis and interpretation of visual behaviour. The first step was to perform post-hoc cleaning of the data to differentiate trial data related to the primary task (i.e., hazard perception) from the secondary tracking task (e.g., the moving dot). This process involved examining each fixation that returned to the tracking task and removing these from the analysis.

As discussed earlier, the influence of experience and expertise on visual attention and visual search behaviour has been well documented. Concerning the driving task, proficient visual attention, the allocation of fixations strategically has been linked with overall safer driving (Ball et al., 1993). Crundall and Underwood (1998) proposed that novice drivers have less efficient visual search strategies than their more experienced counterparts - evidenced through a narrow breadth of visual search – and that failures of attention related to poor allocation of visual resources can play a significant role in crashes (Trick et al., 2004).

Eye-measures have been used for many years in both assessing cognitive demands (e.g., Ahlstrom and Friedman-Berg (2019) and as a means of determining how drivers extract information regarding different aspects of the road environment (Underwood, 2007). These eye movement measures are highly informative in revealing what features of the road environment are attended to and essential for safe traffic navigation, indicating that there are strong links between eye movements and visual attention (Duchowski, 2003; Velichkovsky et al., 2003)[22]. Posner (1980) was an early pioneer of eye movements as predictive of overt attentional shifts across the visual landscape. Different objects compete for representation and are either reliant on bottom-up saliency of the stimuli or a top-down goal-directed search[23]. Examining the distribution of fixations provides an excellent means of determining how drivers allocate their visual attention across the road environment (Geoffrey Underwood et al. (2002).

Table 21:

The mean x-axis Fixation Distribution between Novice and Experienced Drivers. Standard deviation shown in brackets.

				Driver Group	
Driver Group	**F-value**	**Sig**	**η_p^2**	***<25***	***≥25***
Mean	11.227	0.01**	0.03	963.22 (191.7)	934.93 (253.3)
Significant values: * = p < 0.05, ** = p < 0.01					

The following fixation distributions represent where drivers are focusing their visual search:

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[22] The paper by Velichkovsky et al., (2002) makes a strong case for the role of eye movements in showing the how drivers allocate their visual attention. Their research indicated that in the process of hazard perception, there is a definitive shift in the way fixations move from pre-attentive to attentive accompanied by an increase in fixation duration and a decrease in the number of fixations allocated to other processes. Essentially, hazards captuare fixations upon perception.

[23] This later is the fingerprint that could be used to identify more efficient visual search strategies in experienced drivers. It is likely that novice drivers will be directed more by the saliency of objects in the road environment rather than hazards, especially those of a covert nature.

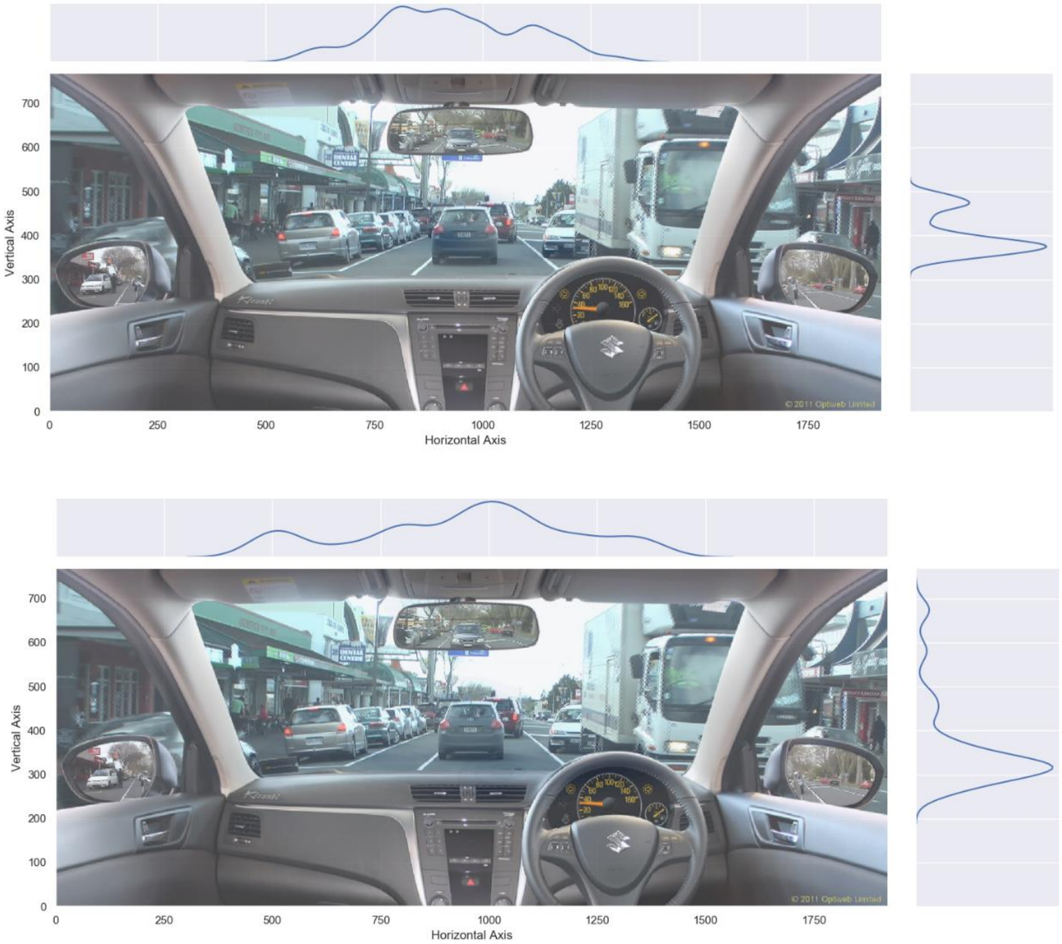

Figure 57*:* The Distribution and Density Mapping of Fixations made by Novice (top) and Experienced (bottom) drivers on Medium Commercial road(Grey St.).The central field shows the Density of Fixations. Each axis shows the frequency of fixations as indicated by the KDE distributions.

Figure 58*:* The Distribution and Density Mapping of Fixations made by Novice (top) and Experienced (bottom) drivers on Light Commercial Road (*Victoria St.)*. The central field shows the density of fixations. Each axis shows the frequency of fixations as indicated by the KDE distributions.

Figure 59*:* The Distribution and Density Mapping of Fixations made by Novice (top) and Experienced (bottom) drivers on a School Road (Knighton Road). The central field shows the density of fixations. Each axis shows the frequency of fixations as indicated by the KDE distributions.

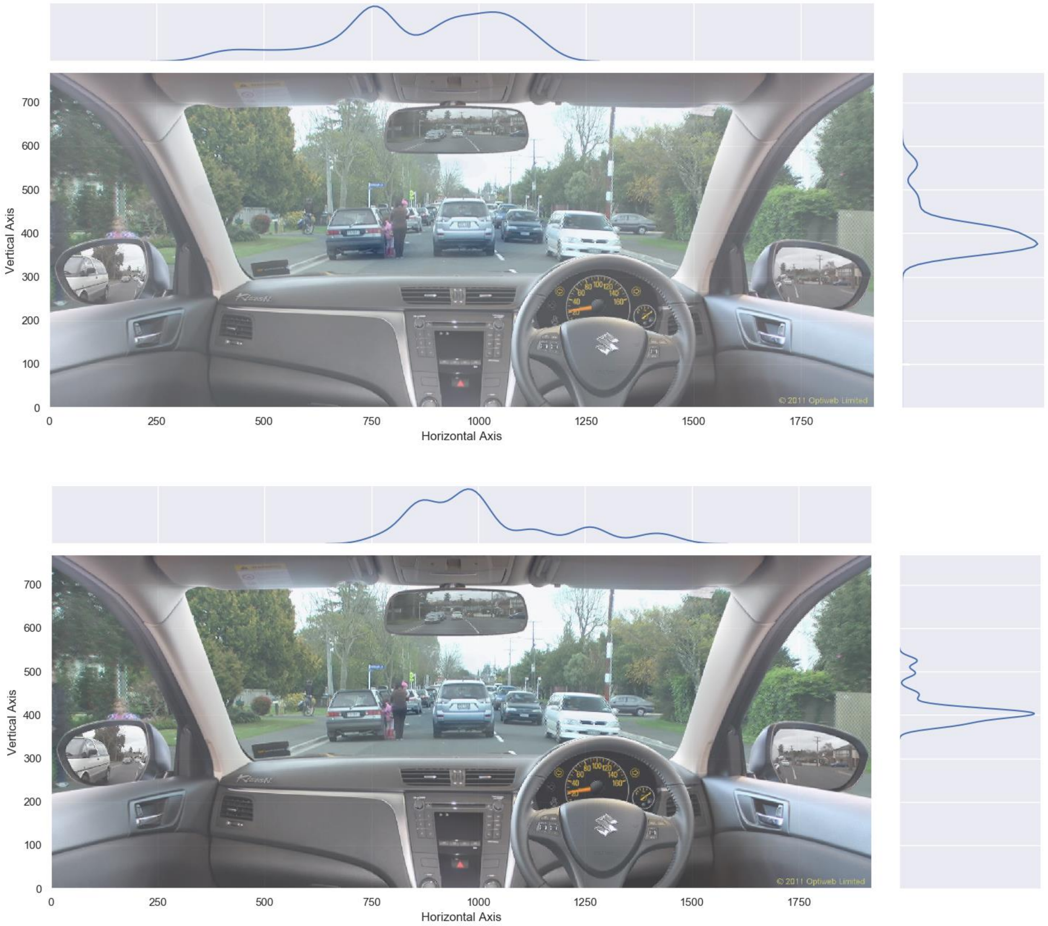

Figure 60: The Distribution and Density Mapping of Fixations made by Novice (top) and Experienced (bottom) drivers on a School Road(Knighton Road). The central field shows the density of fixations. Each axis shows the frequency of fixations as indicated by the KDE distributions.

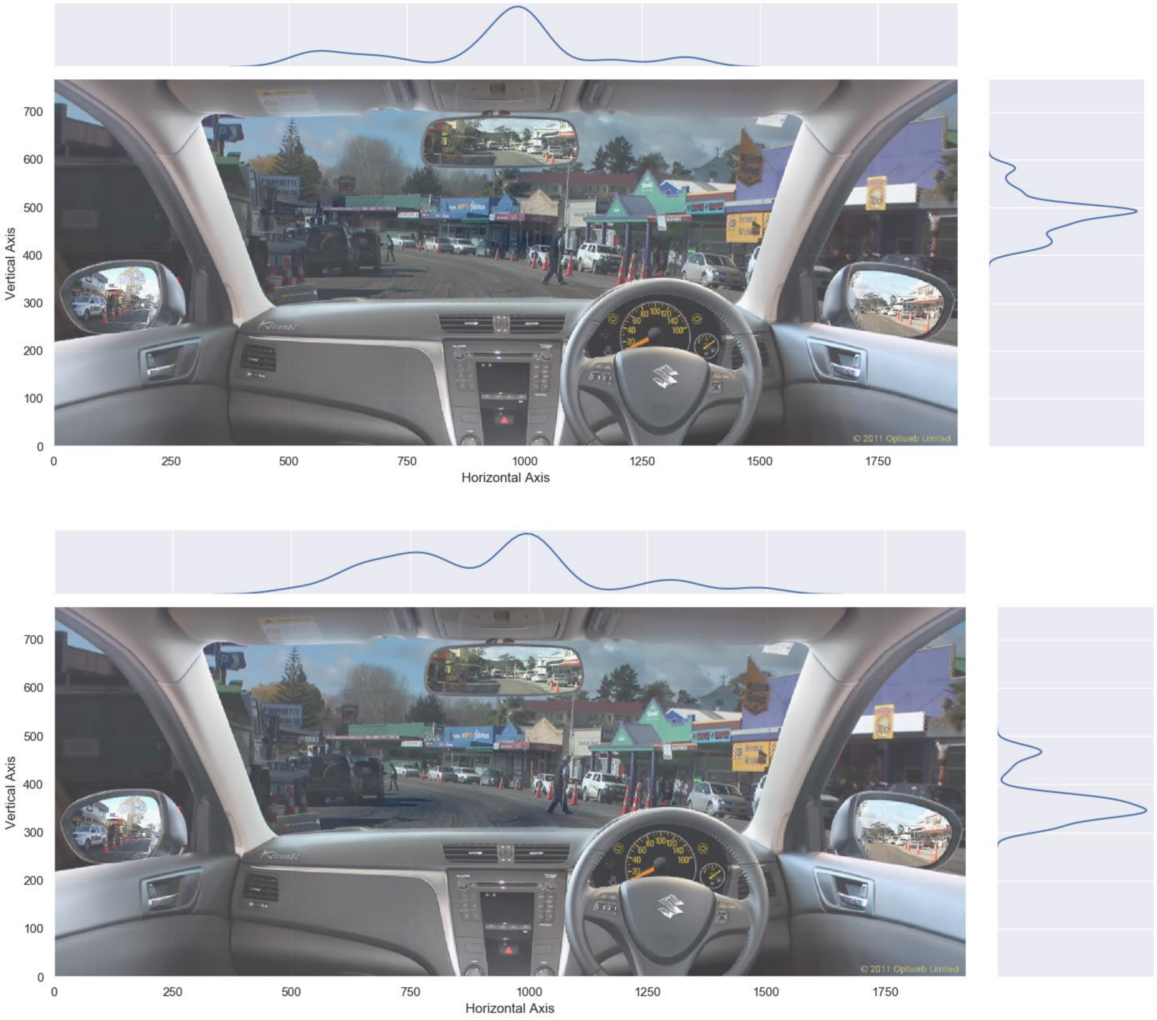

Figure 61: The Distribution and Density Mapping of Fixations made by Novice (top) and Experienced (bottom) drivers on Light-road Construction(Kaikohi). The central field shows the density of fixations. Each axis shows the frequency of fixations as indicated by the KDE distributions.

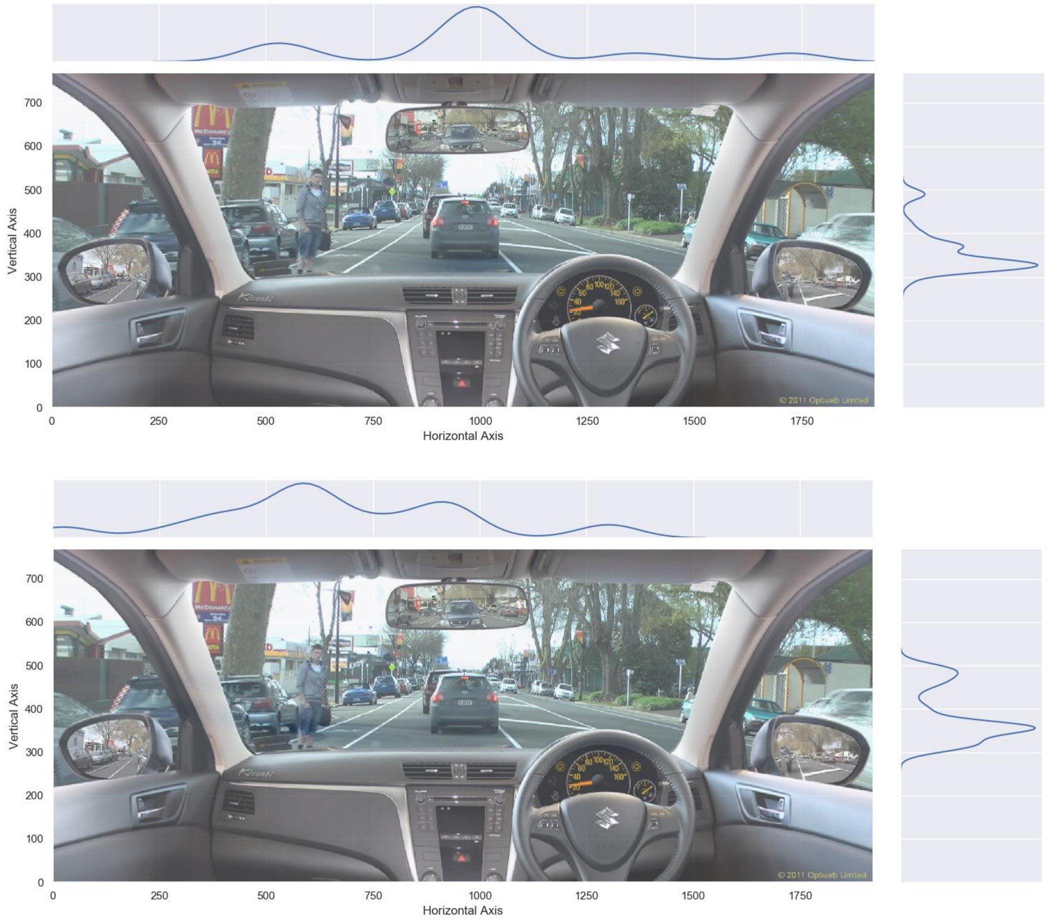

Figure 62: The Distribution and Density Mapping of Fixations made by Novice (top) and Experienced (bottom) drivers on Medium Commercial road (Grey St). The central field shows the density of fixations. Each axis shows the frequency of fixations as indicated by the KDE distributions.

Analysis of the distribution of fixations made by driver groups showed significant differences, similar to those observed in Experiment 1. Notably, novice drivers tend to have a narrower spread of fixations across the horizontal meridian than experienced drivers, suggesting that novice drivers focus more on the centre of the carriageway and less on the periphery. Novice drivers seemed to have a more extensive vertical spread of search than experienced drivers, which could be significant. While the effect of secondary-task carryover is outside the scope of the current study, this may be something worth considering, as there may be detrimental effects in Novice drivers visual search owing to greater visual attention to the vertical meridian (Hills et al., 2018)

Novice drivers typically focused their attention in the centre of the visual field, while more experienced drivers searched in a broader distribution pattern. A common feature of both drivers was the frequent horizontal scan pattern with large central fixation clusters, then a slightly smaller fixation cluster further down the road, indicating that both driver groups search further ahead. What is clear is that experienced drivers allocate more fixations (equivalent to gaze) in attending to visual targets even outside the central field. This indicates that the functional field of view becomes greater with driving experience since experienced participants identified a higher number of hazards.

It also appears that under some conditions, novice drivers limit their search to within the lane-markings, which delimitate the carriageway, and this was found in Experiment 1 to play some role in making speed choice decisions. This finding was suggested that where there were relatively fewer hazards and when there was more capacity for speed variability.

Qualitative Observations of Eye-movement Behaviour

In experiment one, fixation distribution maps were generated to show where participants devoted their visual attention. However, it is essential to acknowledge the limitations between knowing where participants look, and why they looked there (Holmqvist et al., 2011). The following qualitative observations regarding visual search behaviour provides some additional context to support the findings observed in the distribution of fixations – proximate measures of visual search.

Duchowski (2003) discusses the use of *performance* metrics (e.g., usability) being of value in corroborating the commonly used *process* metrics (e.g., fixation duration), which provides valuable insight not easily captured by process metrics alone. Such techniques, which involve combining qualitative and quantitative measures, have previously been used effectively in education and human factors research, and more recently in driving-related research (Lappi & Lehtonen, 2013; Lemonnier et al., 2015).

In using qualitative observations to supplement more traditional metrics of eye-movement behaviours, Lappi et al. (2017) note that using multiple ways to represent observations of eye-movement behaviour "is conducive to giving the reader an overall understanding of the dynamical aspects of the phenomenon: how gaze target selection, and more generally gaze-interaction with the complex natural settings, evolve over time" (p. 2).

Lappi et al. (2017) identify seven unique natural gaze behaviours and how these apply to drivers' behaviour, and the qualitative observations in this section will be discussed generally within the order of these behavioural signatures, which Lappi and colleagues (2017) describe as *laws*. While the observations here may fall into more than one category, as they may involve more than one behavioural signature, they have been located based on the primary type identified:

Law 1: Gaze patterns are highly repeatable and stereotypical (L1)

Drivers did not seem to follow any particular search pattern that was universal across each trial or age and experience group; however, there are some common search-scan sequences. These seem to illustrate differences between novice and experienced drivers, though not all novices displayed poor visual search. Overall, experienced drivers pass swift and staggering glances at peripheral objects and then return their visual attention to the secondary task (L5). The most common search pattern appeared to be a loop extending out to encompass the left-hand roadside, starting and ending with the tracking task (or centre field), or involved a series of apparently planned ‘jump ahead’ glances from distant objects to those nearer (L2). On the other hand, novice drivers tended to maintain search within the limitations of the carriageway and the tracking task. This was similar in many respects to the confined visual search observed in Experiment 1 concerning road-markings. Drivers scan pattern appeared to consist of sequential searches, composed of discrete ‘jumps’ to major areas, then returning to the secondary task. In this respect, novice drivers’ visual search typically moved between the centre-field and other objects, returning immediately to the centre-field again without much additional search.

During moments where the car stopped directly behind another vehicle, experienced drivers continued to broadly scan the roadsides, while novice drivers tended to fixate more on the vehicle ahead, as well as the oncoming traffic in the right-hand (opposing) lane. As the opposing traffic did not pose an immediate risk, this could indicate that novice drivers were concerned with their relative lane positioning and their distance to the vehicles directly ahead. While experienced drivers noticed both the vehicles ahead and other traffic/road users, this appeared to be lower in priority to searching the left-hand for hazards or cues that could foreshadow the likely emergence of a hazard.

When the camera vehicle slowed or came to a stop, this seemed to cue participants to the probable emergence of an immediate hazard directly ahead (which could be a limitation to the task). However, novice drivers seemed to fixate on this while experienced drivers appeared to anticipate the possibility but continued to search ahead. Novice drivers appeared to wait for the immediate hazard to emerge and focus on the secondary tracking task. For example, during the road works sequence (Road Scenario 3), novice drivers anticipated a hazard during the ‘pause’ and quickly identified the man walking across the road; however, this was at the cost in neglecting risks further down the road, particularly the turning vehicle and elderly man crossing the street. Many novice drivers did not notice the road-worker until they were walking directly across the car's path, even though he was visible for some time beforehand.

Additionally, novice drivers tended to devote visual search in tracking the progress of the pedestrian crossing the road at the expense of looking back for other hazards. Many experienced drivers mentioned that the roadworks and the unstable surface could be an additional hazard, though this falls beyond the description of immediate hazards as defined in this experiment[24]. This is certainly a consideration for future research or an extended analysis.

Most drivers did not notice that the speedometer on the dash is functional and generally devoted little attention to the interior depiction of the vehicle and do so only when task demand decreases, such as when the car comes to a halt. Focus, however, was still primarily devoted at these times to the performance of the secondary tracking task. Participants who did notice the dash speedometer generally neglected the reading. Though several participants mentioned their observation of the speedometer in the post-task debrief, no participants noted that the needle moved during the trial (and were surprised to learn that it was functional in the post-trial debrief). Comparison of speedometer readings to participants' speed choices indicates they were not relying on the speedometer reading. Speed choices, as a result, do not seem to be influenced by the speedometer, so this can be reasonably ruled out as a confounding factor. Interestingly, Recarte and Nunes (1996) noted in their study that drivers do not devote much attention to the speedometer. While this is consistent with their finding, a direct comparison should not be made.

Law 2: Gaze is focused on task-relevant objects and locations:

Focus on visually salient stimuli seems to be a decisive factor between drivers with differing hazard perception abilities. The most noticeable and consistent visual phenomenon observed for novice drivers was that they focused on visually salient aspects of the road and traffic situation (e.g., moving objects). In comparison, experienced drivers seem to be more knowledgeable and anticipatory in their visual search behaviour (e.g., checking between cars) and devoted less sustained attention to irrelevant moving objects.

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[24] Analysis into the difference between implicit and explicit hazards, as well as infrastructural characteristics of the road, while of tremendous value, fell outside the scope of the present analysis in this thesis. While this is a limitation to the definition we employed regarding hazards, we remained with the definition as it provided more discrete instances of hazards, rather than the more general definiton of road and traffic related danger discussed in the Literature Review.

One prime example that stands out for its almost ubiquitous nature is the road scene of a coastal village. During the clip, a seagull swoops down in front of the car, moving from the left to the right side of the road. This is followed shortly after by a woman who rushes out from behind a car on the left-hand side. Many novice drivers identified the seagull as a hazard at the expense of not noticing the woman with adequate time to respond. Experienced drivers tended to notice the seagull but disregarded it without becoming distracted from the primary task of searching for hazards on the roadside. This is illustrated in Figure 63:

Figure 63: Illustration of the difference between an Experienced and Novice driver. The Novice driver is distracted by the Bird flying across the path of the vehicle, whereas the experienced driver notices but then returns immediately to search the side of the road.

Novice drivers did seem to be reasonably good at perceiving immediate hazards that were either visually salient (suggesting bottom-up processing), or hazards that were immediately ahead of the vehicle. Interestingly, despite being a visually salient event directly ahead of the vehicle, young drivers did not generally identify a car braking immediately ahead to be a hazard compared to experienced drivers.

One of the most important videos in the task was the school scene (Knighton Roads 1 & 2) which involved the combination of vehicular hazards, pedestrians, braking vehicles, mirror use, and anticipatory hazard perception. As this was such an important road and traffic scenario, these two video clips may be worthwhile focusing on in a shorter version of the hazard perception task.

Young drivers tend to group hazards, such as in the final trial, novice drivers mentioned hazards in groups (e.g., “cars, truck”). In contrast, experienced drivers seem to have a more nuanced approach and mention hazards in a string with the expected action (e.g., “people on side, car turning, truck in the centre, car on left pulling out, parked car”).

Law 3: Individual fixations have interpretable functional roles

Of all drivers tested, only three identified the car pulling in behind the camera vehicle on the second Knighton Road school video. Overall, there is relatively little mirror use between driver groups.

In general, experienced drivers noticed the behaviour of other road users, such as turning vehicles, and routinely searched for ways that other vehicles on the left-hand side might behave. This observation seemed to be highly contextual and seemed to be influenced by the type of road and traffic situation. Novice drivers tended to see the most immediately recognizable aspects of other vehicles (e.g., stop lights). They failed to notice less obvious or partially obscured hazards such as pedestrians preparing to cross the road.

Law 4: If possible, targets are fixated "just in time", with gaze tightly coupled to the information requirements in complex tasks, with gaze typically leading action by about 1 second[25]

There appeared to be some degree of hazard prioritization that differed between novice and experienced drivers. For instance, many experienced drivers will prioritize the child on the roadside over a person shutting the boot. In contrast, novice drivers seemed to prioritize on-road hazards more. It is important to note that not all novice drivers inadequately performed the hazard perception task or visual search.

One important consideration is that some drivers did anticipate that the camera vehicle would stop for other road users, and as a consequence, they would cease to track them. This may be a limitation in the use of video footage and will be discussed more in the limitations section.

Almost every novice driver investigated the turn as the camera vehicle negotiated a corner. This often resulted in visual neglect of features on the left-hand side of the road (e.g., in one scene, a pedestrian is standing to the side with a backdrop of trees). Experienced drivers also were divided in where they looked during this turn. However, there did appear to be a greater amount of smooth pursuit involved with experienced drivers tracking pedestrians.

In one scenario, pedestrians run across the road from the right-hand side, while another pedestrian is exiting a vehicle to the left. Even though both pedestrian(s) are likely to encounter the vehicle as hazards, novice drivers seemed to focus more on the pedestrians running from the right-hand side. As the right-hand pedestrians are on the opposing side of the median, many experienced drivers seemed to devote more attention to the left-hand side of the road. This seems to be another example of the difference in prioritisation between novice and experienced drivers, with experienced drivers focusing on the exiting pedestrian with maintenance glances at the running people, who are visually salient, attracting greater attention from novice drivers.

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[25] This is related to the following Law 5 which describes the intermittent sampling, which can be either guiding fixations interleaved with look-ahead fixations, or in dual tasks, guiding fixations are interleaved with fixations to targets relevant to the parallel task. This is suggested to be due to the way visual information is processed in the brain as discrete as opposed to as a continuous stream.

Concluding remarks on Qualitative Observations

While these qualitative observations are not exhaustive and do not apply to all drivers, they illustrate some distinctions between drivers with differing degrees of experience. It is important to remember that the two groups of drivers are not homogenous, and these observations are some of the more noteworthy differences between drivers. Qualitative observations do seem to assist the interpretation of quantitative findings, and they provide insight into the broader differences in driver behaviour. It is essential that these observations not be removed from their context and are intended to be viewed in conjunction with the superimposed eye-tracking videos that accompany this thesis. The significant differences between drivers appear to be related to both the strategy that is used to search for hazards and how hazards are prioritised. These two aspects of hazard perception have been noted by other researchers and are deserving of consideration in assessing drivers hazard perception ability. Additionally, training in hazard perception can benefit from emphasising these two crucial skills.

Discussion

The most noteworthy finding in this experiment was the strong relationship between hazard perception time and speed choice. The correlation's direction was different from that found in Experiment 2, reflecting the more anticipated relationship between hazard perception and speed choice as anticipated from the reviewed literature – namely, that as hazard perception (time) improves, speed choices would correspondingly decrease. This relationship was expected based on the research conducted by Renge (1998), who determined that as hazard perception improved, there was an improvement in risk-awareness and a reduction of speed. Following the same reasoning, McKenna et al. (2006) found that anticipation training resulted in reduced speed choices by increasing risk awareness for particular scenes where immediate hazards were present. Using a different methodology, Crundall et al. (2010) found drivers reduced speed on approach to perceived hazards. The findings of the current experiment are consistent with the reviewed theories of risk-homeostasis and risk-allostasis, which suggest that as the amount of risk in the environment increases (such as an increase in the number of perceived hazards), there is a corresponding compensatory reduction in speed.

Interestingly, the number of hazards correctly identified did not correlate with statistical significance with speed choice; instead, it is how quickly the hazards were identified. This finding has not been observed previously from a review of the literature. This finding suggests that hazard perception performance may have the most substantial influence on speed choice - and may involve developing hazard perception skills alongside drivers' speed choice habits. This seems to agree with Fuller's (1998) conception of risk mitigation. However, as Lewis-Evans demonstrated, risk ratings seem to increase only after a threshold speed has been met (Lewis-Evans, 2012).

It is essential to consider how the current findings relate to the theory that speed choice is based on habitual behaviour, which De Pelsmacker and Janssens found (2007). Drivers rely on habit concerning speed selection as much, or more than, intentional behaviour. The simplest explanation would be to suggest that the development of habitual speed behaviour develops concurrently with the development of hazard perception skills. This may be seen in the differences in eye-movement behaviour that not only accompanies more advanced hazard perception.

Interestingly, the relationship between the number of hazards perceived and speed choice was non-significant; rather, the time taken to identify hazards was the measure that seemed to correspond to speed choice selection. This may indicate that the relationship between hazard perception and speed choice is mediated by the efficiency of the hazard perception process. The role that the development of hazard perception skills and the corresponding reduction in crash risk takes a considerable amount of experience to develop, during which time other driver behaviours such as driving style may develop as well (Groeger, 2013). The time taken to perceive hazards is vital in safer driving behaviour, and in theory, relates to the efficiency of the underlying cognitive mechanisms that are involved in both situation awareness (Endsley, 1995; Wetton et al., 2013) and risk-appraisal (Kinnear et al., 2013).

When investigating the relationship between hazard perception time and speed choices, there was a significant degree of variability amongst novice drivers compared to experienced drivers, who were clustered much closer together, suggesting that they had more uniform speed choice and hazard perception times. It may be that through accrued experience from driving over an extended period, schemata become more responsive to rapidly appraising risk in the environment (Cohen et al., 1996; Molesworth et al., 2006) and moderating speed consequently. This could explain in part why experienced drivers were more uniformly distributed. Previous research has found a consistent difference between novice and experienced drivers. The finding of a significant difference between novice and experienced drivers in this experiment corresponds well with the reviewed literature. The ability for a hazard perception task to differentiate between drivers of differing experience has been a method of ensuring that the task has ecological validity (e.g., Wetton et al. (2011).

This 'clustering' was also observed in the relationship between the number of hazards perceived and the number of fixations. While both driver groups had similar numbers of fixations, experienced drivers perceived significantly more hazards, suggesting that the fixations were deployed (or 'spent') more efficiently in the perception of hazards. Experienced drivers perceived immediate hazards with more speed and accuracy than novice drivers and indicated that they were searching for covert hazards, as evidenced in their eye-movement behaviour (Geoffrey Underwood et al., 2002). This suggests differences in the schemata used to extract information from the visual environment found in the qualitative observations of eye-movement behaviour.

As with earlier experiments, visual attention was primarily directed to the centre of the roadway, most probably as drivers steer in the direction of gaze (Land & Lee, 1994).

In the present experiment, there were significant between-group differences in eye-movement behaviour, with the fixations of experienced drivers being significantly shorter and more frequent than the fixations of novice drivers. This is in keeping with the reviewed literature and could indicate more advanced cognitive processing of hazards by more experienced drivers (Vlakveld, 2011). Underwood (2007) has noted that efficient visual search strategies are one of the fundamental skills marking the transition from novice to experienced driver (Underwood, 2007).

One indication of increased cognitive load is the dilation of the pupil during the task, which was significantly greater for novice drivers – this could suggest that novice drivers experience higher mental load during the task (Eckstein et al., 2017; Holmqvist et al., 2011; Palinko et al., 2010). It is noteworthy that experienced drivers had lower performance on the secondary 'tracking' task. One explanation is that older participants have less computer experience that influenced their mouse control and subsequent tracking time; however, this is questionable given the average age of 37. An alternative explanation is that this could be a trade-off between cognitive resources devoted to the primary (hazard perception) and secondary task. The more experienced drivers likely have a greater capacity to divert attention from potential distractors toward the more important task of perceiving hazards. There were indications in examining the eye-tracking data that prioritization of visual search is essential for optimal hazard perception.

This is where the role of top-down knowledge becomes essential, as experienced drivers tend to focus their visual attention on areas of the road where hazards are anticipated, whereas novice drivers are influenced more by salient bottom-up aspects of the visual environment (Werneke & Vollrath, 2012; Wickens & McCarley, 2008). suggest that visual attention is based on 'expectancy and value' or 'salience and effort'. Further, it was indicated by examining the initiation of saccades associated with the perception of hazards that experienced drivers could make more rapid assessments concerning the visual scene contents and hazards in particular (Seideman et al., 2018).

As drivers become more experienced, they tend toward expectancy (i.e., the likelihood of seeing an event at a particular location) and value (i.e., the importance or relevance of the event). Eye movements in the current experiment suggest that experienced drivers demonstrate a reduced likelihood to scan the road environment broadly. Novice drivers tend to fixate on the vehicle they are following rather than scan the periphery for anticipated hazards or dedicate time to check mirrors to determine their position in relation to other road users (Konstantopoulos et al., 2010).

One observation made concerning the eye movements of novice drivers is that they quickly search with several successive fixations before returning to the centre field, which demonstrates less flexibility in visual search routines (Crundall & Underwood, 1998). This may be due to novice drivers not developing a complex search schema for hazard perception as they have limited driving experience. In contrast, this pattern of 'search return' will likely not be as inflexible for experienced drivers. This could be because novice drivers may prioritize avoiding collision with the leading vehicle and maintaining lane position over hazard perception and anticipation. Novice drivers search pattern will generally return to the centre-field where they can monitor the leading vehicle and their lane position; while experienced drivers may not need to look directly at a hazard, relying more on parafoveal information

Hazard Perception times and the number of hazards perceived were significantly different between driver groups, with experienced drivers performing better on both hazard perception measures. This data was compared to a larger sample derived from the eDrive training program (Isler & Isler, 2011) and was highly consistent, indicating that the hazard perception measures had a high degree of internal validity (see Appendix 4).

One unexpected finding was that the frequency of mirror use did not differ substantially between novice and experienced drivers, with both groups using the mirrors infrequently. The reviewed literature suggested that experienced drivers will likely look at the rear and side mirrors more frequently than novice drivers (Konstantopoulos, 2009). In this experiment, there was no substantial difference between novice and experienced drivers in relation to mirror use, and this was reflected in the failure of most participants to notice the car pulling in to park visible firstly in the rear-view mirror, then the left-hand wing mirror – of which only 3 participants identified.

Limitations

The first issue concerning this task is that the speeds selected by participants did not differ between driver groups on any of the road scenarios used in this task. This was an unexpected finding, though it may be due to the ceiling effect of limited speed range given the environments. For example, drivers were not given a vast range of available options as far as speed choice as there were often vehicles or pedestrians ahead limiting the maximum reasonable speed, and there were also often vehicles behind (or at least passing), creating a reasonable minimum speed. The footage for each scenario did not meet the criteria used by Horswill and McKenna (1999), which required as few obstructions ahead as possible to allow drivers to accelerate, and this potentially restricted 'free speed' choices. All of the roads used were in the suburban setting, where differences between drivers speed choice have not been found in previous research (Cantwell, 2010; Cantwell et al., 2012). Despite this, the drivers who resided at the faster end of the distribution of speed choices were all novice drivers. This illustrates that not all drivers aged under 25 years old are at high risk, relatively, that the capacity to perceive hazards, appraise risk, and choose appropriate speeds is what differentiates competent from overconfident drivers.

While the selection of roads has shown to differentiate between drivers' in their ability to perceive hazards, a broader range of scenarios and conditions, such as those shown in the previously used video-speed task, could potentially better illuminate the relationship between hazard perception and speed choice. This is because speed choice was also found to differ between driver groups on the different roads and conditions used in the video-based speed choice task. It is debatable whether the hazard perception skills would transfer to rural road settings that lack the abundance of immediate hazards found in urban environments if trained. It may be that there is a benefit to speeds on rural roads by hazard perception training, as this may alter the way drivers notice and appraise risk. An alternative strategy may be to develop a training protocol that focuses on the specific hazards likely encountered on rural New Zealand roads.

Another aspect of this experiment worth considering is that while visual behaviour differentiates between drivers' hazard perception ability, there is no correlation between visual behaviour (i.e., the process measures such as fixation count) and speed choice. This may indicate the inadequacy of variation in the selected roads used in this experiment. For instance, in Experiment 1, a correlation was found between average fixation duration and speed choice on both rural roads under wet and dry conditions.

As with all video-based methodologies, there are benefits and downsides. While video-based methodologies have demonstrated remarkable success across numerous studies (Crick & McKenna, 1991; Evans, 1970) and have demonstrated internal and ecological validity within some contexts (Horswill & McKenna, 1999; Isler et al., 2009), there are also potential disadvantages over more complex simulator environments. Kuiken and Twisk (2001) point out that one such downside is that participants may not fully engage with the task, with young people especially viewing the video scenarios more like a game than a real-world representation. While there are benefits to the use of video as a research tool, such as the high degree of realism, there are also downsides in some instances involving predictability. It is reasonable to expect that the experimenter collecting the footage will act safely and rationally, and this may mean participants become detached from the genuine risks inherent when driving in the real world. This is one disadvantage to the use of video in comparison to more engaging simulators.

Kuiken and Twisk (2001) also note that the driver is not in control of the scenario; hazards can become predictable and lose their impact. Although the genuine difference in eye movements is a good illustration that video tasks are engaging (e.g., Underwood, 2000), there is still the issue where participants may not treat the task in the same way as if they had control over the decisions the driver makes, such as the steering and speed of the vehicle in a simulated environment. In this task, participants' engagement with the task was supported by visual behaviour. However, some scenarios involving the vehicle coming to a stop may cue participants that a hazard is likely to emerge directly in front of the vehicle.

Using a static task rather than a dynamic task (e.g., simulator) has limitations, as drivers cannot continually adjust the vehicle's speed in response to hazards and road scenarios. Due to this, it is hard to be confident that the relationship between hazard perception and speed choice results from a genuine interaction than an artefact of the filmed vehicle speed. This experiment assumes that drivers choose speed based on mostly habitual behaviour elicited by cues found in hazards. However, this cannot be guaranteed as drivers subconsciously make speed judgements and are often not required to monitor and adjust speed in exact speed measures. This is where further testing in a simulator would be of great benefit. Naturally, speed choice varies as the task demands of the traffic environment changes, and the changing risk or task demands would be reflected in participants' speed choice (e.g., Lewis-Evans (2012)). In overcoming that limitation, we considered a method to allow drivers to respond to the perception of hazards by allowing participants to manipulate the rate (e.g., the speed) at which the clip played through the use of foot-pedal. This idea was disregarded, as changing the frame rate of the video clips produces very unnatural scenarios (e.g., pedestrians move awkwardly, quickly or slowly). The alternative would be to film staged scenarios at different vehicle speeds, which participants could select in increments of ±10km/h through the use of a foot pedal. This solution is not ideal, as contrived scenes may inadvertently provide an advantage to one age or experience group over another.

The dual-task aspect of this experiment, though justified, also presents as a potential issue when investigating eye-movement behaviour. Secondary tasks can increase task demand, which can interfere with the capacity for participants to engage fully with the primary hazard perception task. While the secondary task was used to place some loading on cognitive resources similar to what could be expected during real-world driving, it could potentially influence otherwise regular eye movements by introducing fixations unrelated to driving. While the fixations associated with the secondary task were removed from the analysis, simply attending to the secondary task meant that many fixations were devoted to monitoring the moving dot and cursor position, which may have influenced their overall distribution.

Additionally, there is substantial research that drivers tend to steer in the direction they are looking and that this can be achieved by having participants follow a moving dot. In this task, the dot moved randomly, though it could bias perception times (i.e., the dot could be relatively closer or further in relation to where a hazard may appear). Future experiments that do not involve a secondary task or the artificial task demands produced by acting within a hi-fidelity simulator may be worth considering.

The Rationale for Experiment 4

The relationship between hazard perception and speed choice indicates that improved hazard perception may have a subsequent influence on speeds selected by drivers. However, the causal relationship is unknown. For example, maybe driving slower allows more visual inspection of the roadway, whereas a driver may need to rely on gut feeling and intuition at higher speeds. Learning more about the relationship is highly beneficial. This will confirm which side driver education needs to focus on in the future (i.e., education emphasising hazard perception or training drivers in making more appropriate speed choices).

Despite various attempts at reducing drivers' speeds, both through educational campaigns and perceptual countermeasures, speed remains a serious concern. It may be possible to improve speed choice by training hazard perception. The next chapter will focus on the development of a hazard perception training program using road commentary.

Experiment 4

General Introduction

The purpose of this experiment was to examine whether the road commentary used by Isler et al. (2009) could help improve drivers hazard perception skills and result in a subsequent change in speed choices. Road commentary training requires drivers to provide a verbal running commentary of the hazards perceived and possible courses of action in responding to these hazards. Road commentary, as noted by Isler, et al., (2009) may "encourage drivers to actively search for hazards and may improve their situation awareness and lead to a better appreciation of the risks involved." (p. 446). Thus, road commentary may provide a valuable tool to effectively improve young novice drivers' hazard perception and be easily implemented as part of the graduated licensing program.

Another purpose of this experiment was to investigate how road commentary may influence eye-movement behaviour and the corresponding perception of hazards. This experiment is composed of two studies; the first will examine whether road commentary is a viable means of improving hazard perception abilities in drivers. The second study will investigate whether road commentary will influence drivers' hazard perception and have a consequential effect on drivers' speed choices using the combined task used in the previous Experiment 3. Some promising research showed that training in hazard perception using video-based traffic scenarios improved the risk-taking behaviour of young drivers within a short period (McKenna, Horswill & Alexander, 2006). McKenna et al. (2006) found improved hazard anticipation and perception skills using road commentary in a video-based task. Commentary trained participants demonstrated improvements in following distances and gap acceptance, accompanied by fewer self-reported driving violations and instances of speeding. Isler et al., (2008) found that following higher-order training involving commentary, that attitudes to many risky driving behaviours improved (e.g., speeding, close following and overtaking) while also reducing over-inflated levels of confidence in their driving skills (Isler, Starkey, Drew, et al., 2008).

Study A: Does Road Commentary Improve Hazard Perception?

Introduction

For many years, road commentary has been used as a training tool for advanced driver education, and has shown promise as a cost-effective and straightforward training tool for improving hazard perception skills (Castro et al., 2016; Crundall et al. From the reviewed literature, commentary training has been used to improve the hazard perception abilities of both novice (Isler et al., 2009) and experienced drivers (M. Horswill et al., 2013).

Road Commentary can be conducted in different ways and has been applied in driver education for over forty years in a range of different contexts from training novice drivers through to Police who perform advanced high-speed urgent duty driving. These methods can be divided into two general approaches. The first, developed by Cole and Hughes (1984) as a 'think aloud' paradigm, came to be referred to as 'continuous report', where participants comment the entirety of their driving-related contents of awareness. Renge (1980) used this method of commentary to explore where drivers were devoting their visual attention, and involved drivers providing a continuous verbalised stream of consciousness, specifically focused on the driving task.

The second approach, used by Isler et al. (2009), involves participants verbally reporting hazards only when identified, leaving pauses when nothing relevant to the driving task occurs. This type of commentary training is known as 'concurrent verbalisation' (Young et al., 2014). Commentary can be used while the participant is 'online' and actively engaging with the driving task or trained 'offline' before the participant begins the driving task. Horswill (2017) suggests that it usually takes decades of experience for drivers to achieve peak hazard perception skills due to scarcity and poor quality of safety-related feedback. However, Horswill et al. (2013a) demonstrated that these deficits in hazard perception could be potentially bypassed in the space of a few hours of directed training involving road commentary and 'what happens next?' anticipation-based training.

The use of feedback modelled from experts, then self-generating feedback is at the core of Isler's et al. (2009) training approach and is similar to educational approaches first proposed by Wittrock (1974). Wittrock's thesis was that the learner should not be understood as "a passive recipient of information" but rather as an "active participant in the learning process, working to construct a meaningful understanding of the information found in the environment" (p. 720, in Grabowski, 2014). Road commentary could be conceptualised as drivers choosing elements from the road and traffic situation that are important, then integrating these elements into a coherent mental model. Such a mental model is composed of existing knowledge to which new knowledge is fused as the learner engages with information (Fiorella, 2015). According to Wittrock's (1974) theory, "learning can be predicted and understood in terms of what the learners bring to the learning situation, how they relate the stimuli to their memories, and what they generate from their previous experiences" (p. 93).

This is similar in principle to the rationale behind commentary training, a process that challenges participants to engage with the road situation and broadly construct a comprehensive mental representation of the road environment. Prabhakharan and Molesworth (2011) evaluated a training program using simulated driving accompanied by feedback directed at reducing young drivers speeding. The training narrative leads the learner step by step through the story of a crash from the driver's perspective and then later deconstructs the sequence of failures (hazards ignored or violated rules) that led systemically to the crash (feedback). Their study revealed that the group of drivers who received the personalised feedback and narrative training exhibited considerably less speeding behaviour in subsequent driver testing than either the control group or the simplified training group (Fisher, 2006). While Isler's et al., (2009) commentary method does not involve the same degree of examination or feedback into driver's behaviour, the training involves expert commentary to guide the driver's examination of the traffic situation. Additionally, Isler et al. (2009 requested drivers to provide a verbal response to how they would avoid or manage the hazards they had identified. While these responses by participants were not used to provide feedback, this act of verbalising may encourage a greater amount of engagement with the task and the planned management of perceived hazards.

Prabhakharan and Molesworth (2011) describe this process of combined education and practical exercises as a process that develops cognitive structures (e.g., knowledge) that will aid future driving behaviour. These cognitive structures, known as scripts and schemata, amalgamate knowledge and experience to provide a cognitively economical way to process information and plan actions. However, schema can be potentially faulty, which results in poor behavioural outcomes. Prabhakharan and Molesworth (2011) presume that the shortcoming of the graduated licencing system in reducing risky behaviour is that there is a disconnect between the educational knowledge that novice drivers are provided, and the episodic experiences that are acquired through actual driving. In this disconnect, commentary training may help improve novice drivers hazard perception by requiring them to run through mental simulations of the outcome and avoidance of perceived hazards. By using such methods, young drivers can improve their hazard perception within a relatively short time frame (Borowsky et al., 2010; Horswill & McKenna, 2004)[26]. Hence, it is important to assess the influence of road commentary to determine whether novice driver's ability can be fast-tracked to a similar level of competence as more experienced drivers.

Understanding how commentary affects eye-scanning behaviour may reveal how drivers use visual information of the road environment and whether this informs awareness of hazards and the subsequent vehicle speed (Study B). As verbalisation may act as a secondary task, studying drivers' eye movement behaviour may show whether commentary training has adverse effects (Wickens, 2005).

There has been some debate as to the effectiveness of performing commentary compared to merely silently engaging in the hazard perception task (Young et al., 2017). Young et al. (2014) demonstrated that online commentary had a deleterious effect on hazard perception performance, with commentary acting as a secondary task, diminishing the cognitive and perceptual resources needed for the driving task, which had been proposed by Crundall and Underwood (1997). Young et al. (2017) acknowledge that there may still be benefits to using commentary training, noting that their participants had held UK driver licenses for at least a year and potentially much longer, which could influence findings due to the influence of experience.

Vlakveld (2011) raises several important questions regarding the effectiveness of road commentary training that are important to consider. Firstly, whether commentary training merely increases vigilance for unexpected events, and this accounts for improved performance seen in laboratory tasks which does not correspond to the real-world[27]. Additionally, there are questions as to whether

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[26] This not to diminish the importance of the 25 year old age distinction, but there this evidence the drivers accrue a lot of skills within the first three months of driving, some of which relate to hazard anticipation (Day et al., 2018).

[27] Young, Chapman, and Crundall (2014) found that commentary training might influence actual hazard perception during actual real-world driving. This is contrasted with the improvements seen in laboratory situations.

commentary actually alters the cognitive processes that participants utilise when searching for hazards.

Angela Young of the University of Nottingham, notes that fatigue or boredom may be a factor worth considering when investigating training. The positive effects observed through commentary may result from the training group remaining engaged with the driving task, while the control group may become bored or fatigued and subsequently show a reduction in performance, though this effect may be subtle and hard to detect (Young, 2016). An eye-tracker would help show whether both commentary and control groups remain engaged with the hazard perception task through an active search for hazards, and potential measures of arousal (i.e., pupil dilation and blink rate).

The use of an eye-tracker would provide evidence as to whether commentary does indeed alter the underlying cognitive control processes of hazard perception, or whether it merely heightens vigilance to unexpected events. Vlakveld (2011) makes this observation in his doctoral thesis, noting that “[if] an eye-tracker was used in the aforementioned studies, the alternative explanation [of increased vigilance] could have been tested” (p. 199). In this respect, the eye-tracker will provide essential information on how participants search out for hazards, whether commentary alters eye movements and further insight into the underlying cognitive control processes. This would provide evidence of whether participants attend to, and discriminate between, visual stimuli based upon anticipation rather than saliency (Posner et al., 1980).

Despite these potential limitations of commentary as a training method, there is a large amount of research as well as anecdotal evidence that commentary training provides a quick and straightforward method to improve drivers hazard perception and visual search. Hence, it is worth investigating the value in using commentary to improve drivers hazard perception and the potential benefits that commentary may provide on drivers speed choices.

Research Questions

1. What effect does commentary training have on hazard perception measures?

From the reviewed literature, we hypothesise that commentary training is likely to improve novice driver's performance (Isler, Starkey, & Williamson, 2006), and potentially the performance of experienced drivers based on the finding made by Horswill etc. However, it is also possible that commentary may not significantly affect hazard perception performance, which would be hypothesised as the control and training group not significantly differing in performance.

Additionally, there are anticipated differences between novice and experienced drivers. Experienced drivers will likely perceive hazards earlier than novice drivers, with experienced drivers more likely to prioritise specific hazards over others, whereas novice drivers will more likely state them in the order in which they are perceived (Horswill & McKenna, 2004; Underwood, 2007), and with greater accuracy when compared to novice drivers (Isler et al., 2009). Experienced drivers are also more likely to identify potential hazards irrespective of whether these hidden hazards overtly materialise (Vlakveld, 2011). Experienced drivers may potentially comment more on the covert hazards (e.g., cars skirting the roadside) than novice drivers, who will more likely respond only to the overt and immediate hazards present throughout the task[28].

2. What is the influence of commentary training on eye-movement behaviour as opposed to the control groups eye-movement behaviour?

If commentary improves hazard perception, this will likely accompany changes in visual search behaviour in the commentary group compared with the control group. In the previous experiment, different hazard perception skills with greater age and driving experience seem to accompany a more advanced eye-movement strategy, suggesting that eye-movement behaviour plays an essential role in hazard perception.

It is possible that road commentary could act as a secondary task (Cao & Liu, 2013; Young et al., 2014), which would diminish the number of fixations while elongating

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[28] It is thought that this will clearly be supported by eye-tracking data, as search for covert hazards will involve focus on areas where precursors to hazards are likely found, even should no hazard present. Overt hazard search is likely to result in fixations on moving objects that could become hazards, whereas concern for covert hazards will result in fixations on static elements of the scene that might hide a hazard.

their duration for the commentary group in comparison to the control group. However, the cognitive load may remain similar to baseline in the commentary group, even though the number of hazards detected increases. In this case, there could be a change in eye-movement behaviour in the commentary group, though this will likely be similar to more experienced drivers in the control group. This contrast between commentary and experience groups may reveal insights into how road commentary influences driver's behaviour, and potentially resolve the questions posed by Vlakvald (2011) and Young (2016).

Method

Participants

Participants were recruited from the public through advertisements placed on community notice boards in the Hamilton campus suburb. University campus students were recruited through posters placed throughout the School of Psychology and the School of Engineering and an online noticeboard for Psychology Students. A message calling for participants was also placed on Facebook.

Novice drivers were invited to participate in the study if they currently held a New Zealand learner license and began driving within six months of participating in the study. For the recruitment of novice drivers, two high schools in Hamilton were approached and agreed to recruit participants from their respective student bodies, with selection undertaken by teachers, who could release two-four students per class to take part in University Research.

Experienced drivers were required to hold a full drivers licence for at least two years and be aged over 25 years old. Participants were placed into one of two trial sequence groups to ensure that ordering effects could be minimised.

Experienced adult and novice adolescent drivers were allocated into either a training or control (non-training) group by order of participation. The sequence of baseline and post-training assessment videos alternated using an alternating order. The majority of participants identified themselves as New Zealand European (n=38), whereas one participant identified as New Zealand Indian, and three participants identified as New Zealand Maori. Ethnicity was not a factor in the analysis, though this was considered sufficiently representative of a New Zealand sample.

Novice drivers were recruited from local high-school psychology classes from local schools. The novice driver group (n=20) was composed of sixteen male and four female drivers, all with learner licences. The average age of the participants was 16.6 years (SD= 0.6). The average self-reported time since obtaining a learner licence was 11.6 months (SD= 11.7), and the average self-reported distance driven per week was reported as 38km (SD= 38.9).

Experienced drivers were recruited from the student body and the public using advertisements placed at local community centres. The experienced driver group (n= 20) was composed of sixteen male and four female drivers who held a New Zealand full license and were aged over twenty-five years, with an average age of 31.1 years (SD= 2.4). The average self-reported time since obtaining a learner licence was 10.4 years (SD= 1.3), and the average self-reported distance driven per week was reported as 134km (SD= 48.6).

Previous research has indicated that drivers who rate as being more reckless were less responsive to training (Zhang et al., 2018), and therefore psychometric measures of driving attitudes were analysed using a one-way ANOVA to compare differences between training groups. The measures used were self-rated driving skill, Barrett's (1994) Impulsivity Scale (BIS), the Probability of Future Driver Violations (PFDV) by Reason et al. (1990), Driver Attitude Questionnaire (DAQ) by Parker et al. (1995), and drivers self-evaluated ability (SEQ) by Horswill et al. (2004). Results are shown in Table 22. There were no significant differences in psychometric measures between driver training groups.

Table 22:

The Differences in Psychometric Measures of Driving Risk between Control (n=20) and Commentary (n=20) Drivers

				Control		***Commentary***	
	F-value	*p*	η_p^2	M	SD	M	SD
Self-rated Skill	0.253	.62	.007	3.29	1.105	3.24	0.768
DBQ Risk Score	0.036	.85	.001	3.08	0.22	3.07	0.19
PFDV Risk Score	2.861	.10	.078	3.5	0.73	3.2	0.65
SEQ Score	0.378	.43	.018	5.3	0.86	5.1	0.68
Impulsivity	1.020	.32	.028	4.5	1.74	3.9	1.95

Design Outline

This experiment employed a between-subject mixed-measure design. The first between-subject factor was driving experience contrasting novice and experienced drivers, and the second between-subjects factor was contrasting commentary training with the placebo control. Novice drivers were recruited from local high schools and held learner licences for no longer than six months. Experienced drivers were 25 years of age or older and held a full drivers licence for a minimum of 2 years.

This research used a mixed-measures between and within-subjects design to examine the baseline hazard perception ability of novice drivers and experienced drivers (between subjects) and to determine if these skills can be improved in the novice drivers using video-based road commentary training (within and between subjects).

The forty participants were randomly assigned into one of two equally sized groups, with one group receiving road commentary training and the control group receiving a placebo training. The study used a repeated measures design with a baseline and post-training assessment of hazard perception ability for all participants. The dependent measures of hazard perception were the number of hazards correctly identified and the time taken to detect hazards. Measures of eye movement behaviour included the number, location, and duration of fixations as described in previous experiments.

Measures

Immediate Hazards and Perception Times

In measuring immediate hazards, the definition used in previous experiments (2 & 3) , which was proposed by Isler et al. (2009) has been employed in this study (refer to p. 146 for a description). With the advantage of seeing where participants are devoting their visual attention and the hazards they click on, it is possible to measure the relative search times and time from the first fixation to perception as a more precise measure of hazard perception time. The hazards are the same in this task as in the previous Hazard Perception Tasks, and hazard description and window are listed in

Appendix 11.

The Hazard Perception Commentary Task

This experiment was distinctive in that there was no on-screen secondary task, and the experiment was performed using a chin-rest EyeLink 1000 eye-tracker (for which the calibration procedure was identical to that discussed earlier). The Hazard Perception Commentary Task used for the baseline and post-training assessments involved participants viewing five video traffic scenarios for each assessment while searching and identifying any immediate hazards that appeared through the course of the videos. The verbal description of the hazards was recorded as an audio file by computer. The video traffic scenarios ranged in length from 8 to 75 seconds and depicted different hazards found on urban and suburban roads. The videos used in this experiment were identical to those used in the Hazard Perception Dual-task. However, the two longest video clips (Knighton Rd 1, Kawakawa) were bisected to create a total of 10 videos from the original eight video scenarios described previously (see

Appendix 11).

The absence of a secondary task was deemed appropriate for this task, as commentary was considered a cognitively taxing process that uses resources similar to the secondary task. Using a tracking-based secondary task in conjunction with a verbalisation protocol may unduly hinder participants' performance by requiring excessive cognitive load.

Instructions provided to Participants for Road Commentary

Participants were instructed to move a circle on the screen using the mouse, click on hazards as they identified them, and then verbally identify the hazard. The time and number of clicks were recorded by a computer providing the exact time during the video and the exact location of the mouse clicks (x, y coordinates) of the hazards that participants identified. This task was similar to that designed for UK driver evaluation developed by McGowan and Banbury (2004). The number of hazards that were perceived and the hazard perception times could be calculated along with the associated fixation location and duration. The task as presented to participants is shown in Figure 64:

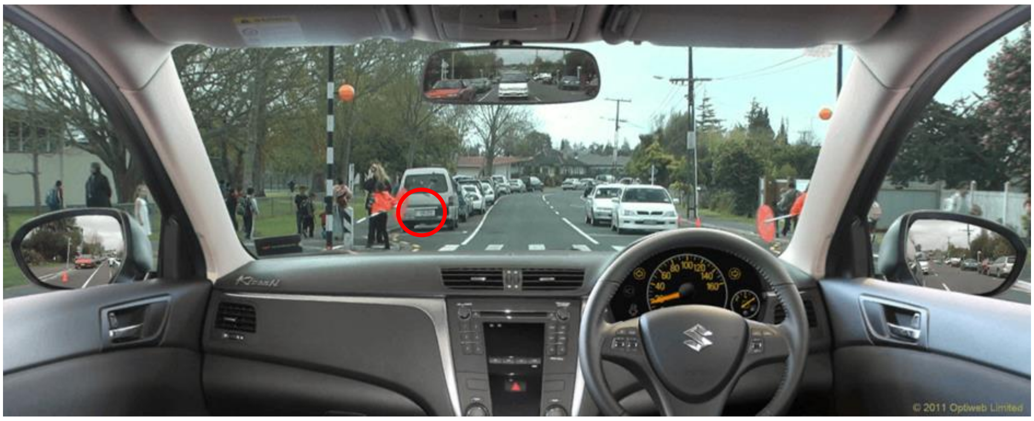

Figure 64: A still image is taken from one of the Hazard Perception Commentary Task(HPC) video scenarios. Participants could move the circle using the mouse to identify the location of immediate hazards by clicking.

The Dependent Variables for Commentary task

The total number of hazards correctly identified, and the time to perceive hazards for each trial were recorded as measures of hazard perception ability. For the hazard perception task, the dependent variables were: a) the number of hazards correctly identified, b) the mean time taken to identify hazards within each trial correctly. The total number of clicks, and the number of clicks on non-hazards were not assessed in this experiment.

The hazard perception task used for the baseline and post-training assessments involved participants viewing five video traffic scenarios for each assessment (ranging from 20-50 seconds duration) while searching and identifying any immediate hazards that appeared through the course of the videos. Participants were instructed to move a circle on the screen using the mouse, click on hazards as they identified them, and verbally identify the hazard. The time and number of clicks are recorded by a computer providing the exact time during the video participants identified hazards and the number of perceived hazards. The verbal description of the hazards is recorded as an audio file by computer. There was no secondary 'moving-dot' task used in this experiment[29]. The video traffic scenarios ranged in length from 8 to 75 seconds and depicted different hazards found on urban and suburban roads. Other instructions given to participants were:

> Your task will be to identify immediate[30] hazards by clicking on them with the mouse as soon as you perceive them. Immediate hazards are hazards such as braking cars, pedestrians walking over the road, cyclists, road workers, etc., which potentially could get into your way so that a driving action would be required (e.g., braking, steering away, etc.).

A 'beep' sound accompanied each mouse click. This task measured the percentage of hazards identified by participants for both the baseline and post-training assessment. For each assessment, there were a total of 20 immediate hazards throughout the five video scenarios. The videos which were used in the experiment were the same as those used in the previous Experiment 3 and 2 in the Hazard Perception tasks.

Commentary Training

The participants selected for training received instructions on how commentary should be performed in the experiment. The participants who received the road commentary training were instructed to provide a running verbal commentary about any hazards they perceived, including potential and immediate hazards. This form of

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[29] Despite the secondary task being included in previous versions of the Hazards Perception Dual Task (HPDT), it was considered that active commentary might serve as a secondary task as noted by Hughes and Cole (1986), and hence no tracking task was used in this experiment.

[30] While this task called for participants to identify immediate hazards, some participants were also vigilant during the commentary training to point out things such as road side signage, as well as areas where hazards (covert) might emerge.

commentary training is known as concurrent verbalisation, as it involves participants providing a continual stream of driving-related contents of conscious awareness. Concurrent verbalisation methods similar to those employed in this experiment have been utilised by many researchers, demonstrating improved hazard perception times and greater vigilance for hazards (Isler et al., 2009); Williamson, 2004). Commentary training has also demonstrated improvements in real-world driving assessments (Mills et al., 1998) and reduction in speeds when approaching hazardous situations (Crundall et al., 2010). While there are other commentary methods, the method employed here provides the greatest amount of information about the drivers' contents of awareness and hazard perception and their strategies in responding to hazards.

The training involved participants' verbally identifying immediate hazards, and expressing how they might alter their driving behaviour (e.g., "I am approaching a school patrol, so I am watching for children crossing and slowing down"). Participants were given the following instructions regarding commentary:

> Road commentary is a training intervention that involved participants verbally identifying real or potential hazards which occur while driving. You will be asked to provide a running verbal commentary about any hazards that you perceive, and how you would respond to them (e.g., slowing using the break). A potential (covert) hazard is anything that may develop into an immediate hazard over time. You will be shown two videos with experts providing a commentary for you to watch, and then the same videos will be shown so you can practice your commentary. This will be followed by twelve training videos, during which you will need to provide commentary.

During the practice trials, participants were reminded to comment on any thought that came to mind regarding the road. There were two practice trials: for the first trial, participants were provided with an example of road commentary performed by a driving expert on a busy urban section of road, and they were required to produce their own commentary on the same section of road. For the second practice trial, participants were required to provide commentary for a second filmed road and listen to the accompanying expert commentary afterwards.

The training session for the participants involved twelve video scenarios, which for each participant was to provide commentary without any expert commentary or feedback. During the training videos, eye-movement data was collected. As some participants could be potentially nervous providing commentary during the 12 training trials, the experimenter was not present in the room, and commentary was recorded using a Dictaphone for later analysis.

Procedure

Participants were provided with an information sheet regarding the experimental setup and the computer tasks. Participants were shown how the eye-tracker worked along with the chin and forehead rest and brief information of how the eye-tracker recorded eye movements. The ethical information regarding participation was presented, which was followed with participants providing informed consent. Participants were seated in front of the monitor. The eye-tracker was adjusted, along with the forehead and chin rest, as shown in Figure 65:

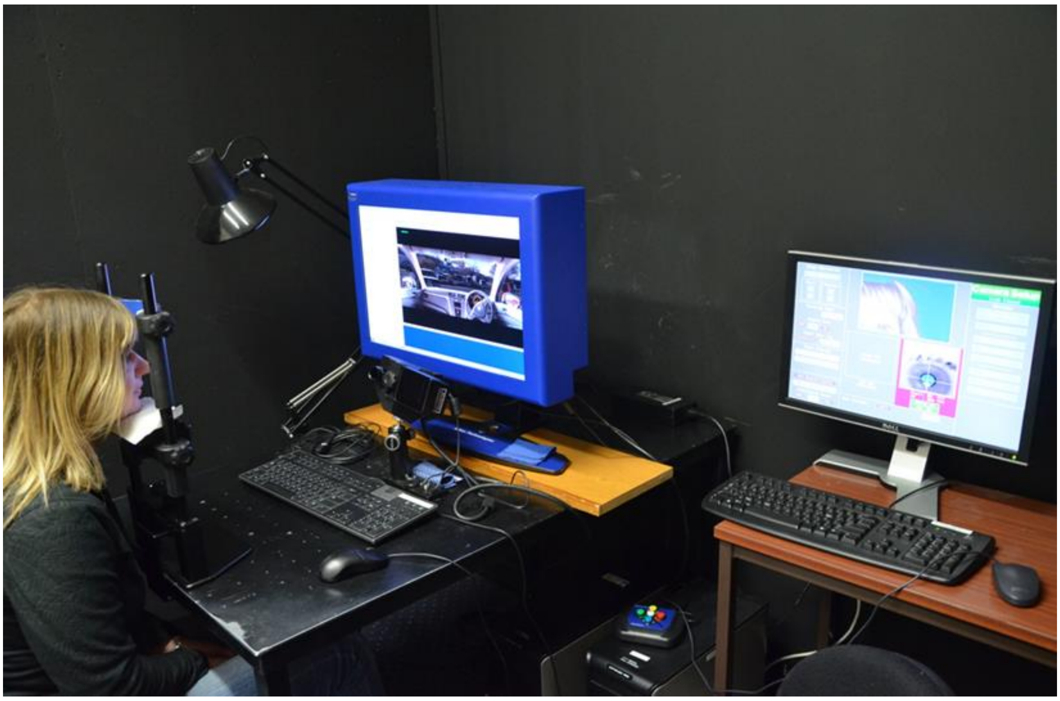

Figure 65: A participant demonstrating the use of the EyeLink 1000 eye-tracker. As the eye-tracker was fixed, a chin and forehead rest was used to ensure that the participants remained as still as possible during the experiment.

Similar to the previous Experiments, participants were provided with a practice run of the hazard perception task to familiarise themselves with the task and be able to adjust their posture to use the chin and forehead rest comfortably. The eye-tracker was calibrated for each participant prior to the hazard perception task commencing. The Hazard Perception Task practice trials involved two video scenarios, in which participants were able to identify hazards verbally and locate them using the mouse. Once participants were identifying approximately 80% of the hazards in these scenarios, the experiment commenced. The baseline assessment and post-training assessments involved a unique set of four of the eight video clips, taken from the Hazard Perception task used in Experiment 2 and 3. Each set of clips contained 20 immediate hazards and were presented to participants in one of two counterbalanced sequences to prevent any bias resulting from ordering.

After baseline assessment, participants who had been assigned to the commentary training group were taken through the road commentary training (as described previously) and then asked to provide a running verbal commentary for each of 12 videos, while an audio recording of the commentary was taken. Participants in the control (no-training) group were instructed to simply watch the 12 videos as if they were the drivers. The post-training hazard perception assessment was the final stage of the experiment. The eye-tracker was calibrated and validated before each stage of the experiment. Additionally, before each trial, a cross-heir would appear, which participants were instructed to look directly at, which was used to correct for any potential drift in eye movement between trials.

After the laboratory-based measures, participants completed questionnaire measures online using Qualtrics™. This was often completed in another lab while other participants were being run through the computer-based measures. After completing the full experiment, participants were given an informal debriefing and allowed to view the data collected by the eye-tracker[31]. Participants were thanked for their involvement and given a $10 gift voucher as an appreciation for their involvement in the experiment.

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[31] As many younger drivers were participating as part of their high-school psychology class, this provided them the opportunity to view a psychological experiment and observe the way eye movements were recorded and how this was thought to be related to safe driving.

Results

Differences between Driver and Training Groups

The initial analysis was to rule out any bias between training groups. In order to determine whether there is an effect of the training, it was essential to initially determine whether the two training groups were significantly different both in hazard perception time and the number of hazards correctly identified.

A mixed two-way 2 (Driver Group) x 2 (Training Group (Commentary, Control)) x 2(Baseline, post-training, repeated measure) ANOVA was conducted on measures of hazard perception time and the number of hazards perceived. The analysis revealed that there was a significant interaction for Driver Group on the measures before and after training, Wilks $\Lambda= 0.720$, $F_{(2, 36)}= 7.008$, $p< 0.01$, $\eta_p^2= 0.280$., as well as a significant effect for the Training Group, Wilks $\Lambda= 0.505$, $F_{(2, 36)}= 21.608$, $p< 0.01$, $\eta_p^2= 0.546$, though no significant interaction effect was identified between Driver group and Training Group, Wilks $\Lambda= 0.852$, $F_{(4, 34)}= 1.650$, $p= 0.206$, $\eta_p^2= 0.084$.

Between-subject effects revealed that there was a significant difference between driver groups before training for the number of hazards perceived, $F_{(1, 37)}= 10.987$, $p< 0.01$, $\eta_p^2= 0.229$, but not for hazard perception times, $F_{(1, 37)}= 1.049$, $p= 0.31$, $\eta_p^2= 0.028$, with experienced drivers perceiving significantly more hazards than novice drivers. For the Training groups, between-subject effects revealed that there was no significant difference between control and commentary groups before training for both the number of hazards perceived, $F_{(1, 37)}= 0.212$, $p= 0.64$, $\eta_p^2= 0.01$, and hazard perception times, $F_{(1, 37)}= 0.408$, $p= 0.53$, $\eta_p^2= 0.011$.

This indicated that while there was a difference between Novice and Experienced drivers before training, there was no significant difference between the Control and Commentary group before training. The lack of between-subject effects at baseline indicated it was unlikely there were any significant differences in ability in hazard perception performance between the control and the commentary group before training commenced.

The Influence of Commentary Training on Hazard Perception

Drivers in the control groups showed a marginal improvement in the post-training assessment regarding the number of hazards perceived and hazard perception times. However, this difference between baseline and post-training assessment was non-significant. Following the training, novice participants assigned to the control group increased the number of hazards they perceived, which approached though did not reach statistical significance (p= 0.057). Novice drivers in the control group also had no significant difference in hazard perception times (p= 0.147) between baseline and post-training. Similarly, experienced drivers in the control group increased in measures of hazard perception between baseline and post-training. However, the number of hazards perceived (p= 0.262) or hazard perception time (p= 0.463) was not statistically significant between baseline and post-training.

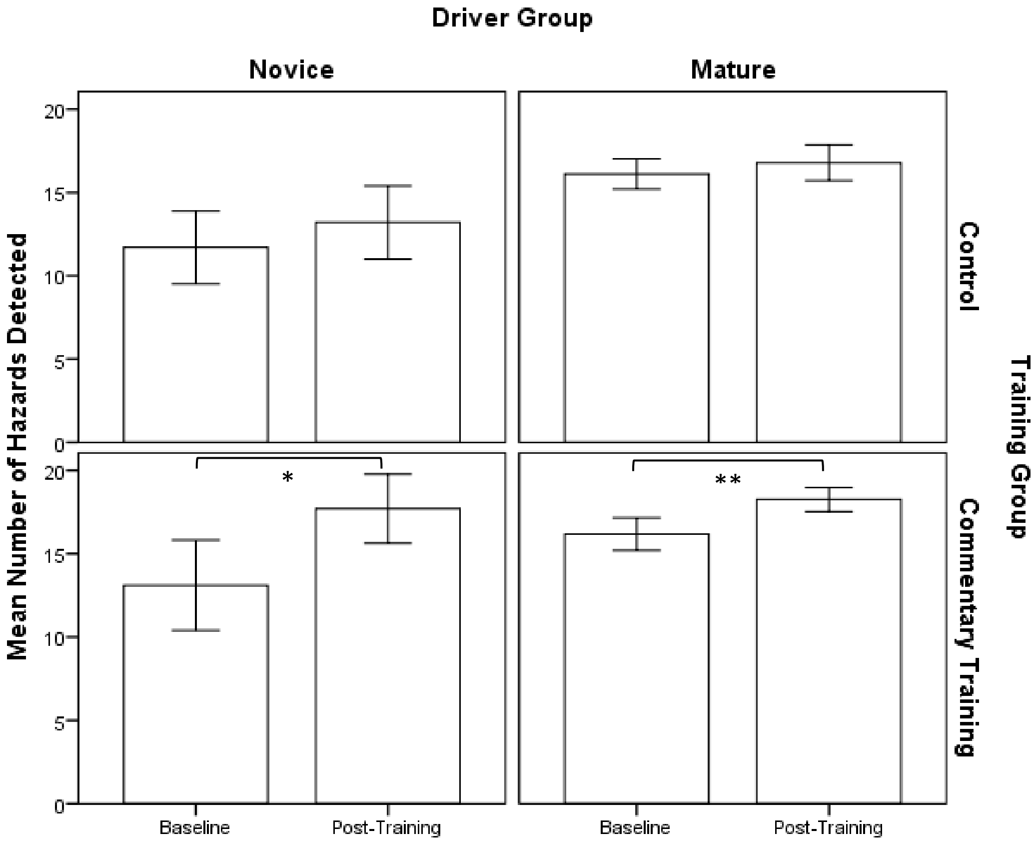


***Figure 66**:* The mean number of hazards identified for the two groups (no training, with training).Visual inspection of the figure shows that road commentary training improved the number of hazards identified, while there was little change visible in the no-training group.

Figure 66 shows the number of hazards perceived was significantly greater for both drivers who received commentary training when contrasted with their control group peers.

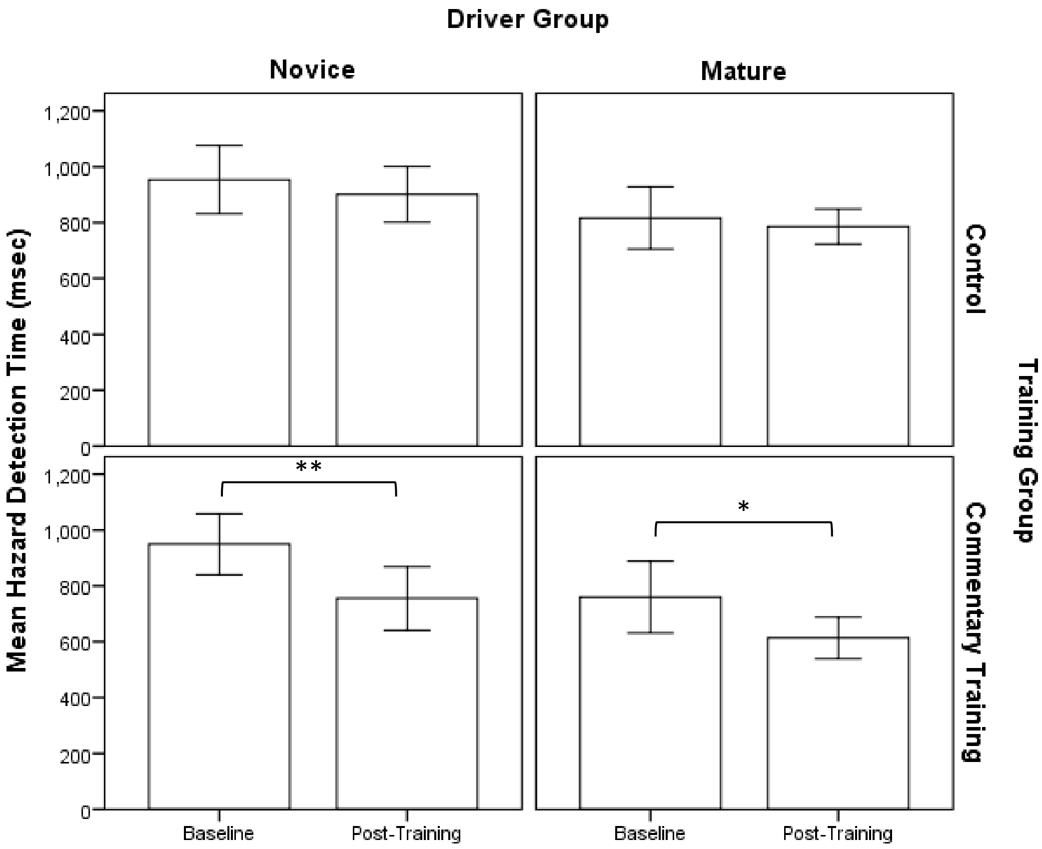


***Figure 67**:* The hazard perception time for the two groups (no training, with training).Visual inspection of the figure shows that road commentary training improved the time taken to perceive hazards, while there was little change visible in the no-training group.

As with the previous findings, Figure 67, shows the drivers in the commentary training group had a reduction in their hazard perception times following the training when contrasted with the control group.

A mixed, repeated measures MANOVA (control/training and novice/experienced as between-subject factors and baseline / post-training as a repeated-measure factor) was conducted to determine whether training had a significant effect on the number of hazards and hazard perception times. The inferential analysis showed no significant effect between the Driver Groups, Wilks Λ= 0.871, $F_{(2,36)}$= 0.184, p= 0.832, η_p^2= 0.010. However, there was an effect between Training Groups, Wilks Λ= 0.668, $F_{(2,36)}$= 8.685, p< 0.01, η_p^2= 0.332, where drivers who received commentary training showed improved hazard perception ability contrasted with drivers in the control group. There was also significant interaction between Training and Driver Groups, Wilks Λ= 0.728, $F_{(2,35)}$= 6.527, p< 0.01, η_p^2= 0.272, with novices in the training group outperforming their peers more so than the mature group.

Comparisons between Control and Commentary Groups

Two mixed one-way ANOVA were conducted to compare the number of hazards detected between baseline and post-training for the commentary and control groups (one for novice and another for experienced drivers, respectively). This revealed that novice drivers who received the commentary training perceived significantly more hazards than their peers in the Control group, $F_{(1, 18)}$= 16.350, p< 0.01, η_p^2= 0.476. Novice drivers also had shorter hazard perception times for those in the Commentary Group, $F_{(1,18)}$= 8.800, p< 0.01, η_p^2= 0.328 contrasted with novice drivers in the Control group.

A one-way ANOVA revealed that experienced drivers in the Commentary Group perceived significantly more hazards following training when compared to drivers in the Control Group, $F_{(1,19)}$= 4.569, p< 0.05, η_p^2= 0.194. There was also a substantial difference in the hazard perception times, with Experienced drivers in the Commentary Group perceiving hazards significantly quicker than drivers in the Control Group $F_{(1,19)}$= 5.615, p< 0.01, η_p^2= 0.228.

Referring to Table 23, novice drivers seemed to benefit more from the commentary training than their experienced counterparts, who did not significantly perceive more hazards after commentary training.

Table 23:

The Number of Hazards (Total n= 20) for Novice and Experienced Drivers, grouped by Control and Training before and following training

		Driver Group			
		Novice		***Experienced***	
		M	SD	M	SD
Control	Baseline Hazards	11.70	3.057	16.11	1.167
	Post-training Hazards	13.20	3.084	16.78	1.394
Training	Baseline Hazards	13.10	3.784	16.17	1.528
	Post-training Hazards	17.70	2.908	18.25	1.138

Table 24 shows a significant decrease in the time to perceive hazards between novice participants who received commentary training compared with novice drivers in the control group. For experienced drivers, there was no significant post-training reduction in hazard perception time for either participants' in the commentary or control groups.

Table 24:

The Hazard Perception Time for Novice and Experienced Drivers, grouped by Control and Training before and following training

		Driver Group			
		Novice		***Experienced***	
		M	SD	M	SD
Control	Baseline Time	953.8	170.13	881.5	144.59
	Post-training Time	901.0	139.70	785.8	81.67
Training	Baseline Time	949.3	152.23	759.9	202.33
	Post-training Time	754.9	159.79	613.4	117.33

The number of hazards perceived in post-training was greater for both groups of drivers, with novice drivers identifying significantly more than baseline compared to their control group counterparts.

Eye-movement Behaviour

Eye-movement data was passed through the same filter as described in Experiment 1 and then viewed by the experimenter to confirm the absence of significant drift or distortion. Significant differences were identified in relation to the training and driver age groups. To ensure that the observed differences between driver groups were not the result of bias in the sample before training, a one-way ANOVA was conducted on the baseline eye-movement behaviour for the two training groups. The ANOVA revealed that the two training groups were similar in their eye-movement behaviour at baseline, $F_{(1,38)}= 0.180$, $p= 0.67$, $\eta_p^2= 0.005$. There was also no significant influence observed in the ordering sequences of the hazard perception clips.

To examine the effect of commentary training on drivers eye-movement behaviour, a repeated-measures MANOVA was performed for all eye-movement measures between the two training groups and age/experience groups. Levene's tests show that variance equality can be assumed for all variables ($p> 0.05$).

A significant effect was found between the training group, Wilks $\Lambda= 0.939$, $F_{(1,38)}= 5.247$, $p< 0.01$, $\eta_p^2= 0.061$, though no significant effect was observed between driver age groups, Wilks $\Lambda= 0.977$, $F_{(1,38)}= 1.938$, $p= 0.08$, $\eta_p^2= 0.02$. There was a significant interaction found between Driver group and Training group, Wilks $\Lambda= 0.884$, $F_{(1,38)}= 10.555$, $p< 0.01$, $\eta_p^2= 0.116$,

Table 25:

*The interaction effects for measures of Eye-movement Behaviour between Novice (n=20) and Experienced (n=20) Driver Group * Training Group in Post-training Assessment*

					Novice		***Experienced***	
	Training	F-value	*p*	η_p^2	M	SD	M	SD
Number of Fixations *	C	10.461	0.05*	.225	276.4	33.34	314.1	31.98
	T	-	-	-	300.8	52.03	332.4	30.35
Fixation Duration **	C	20.034	0.01**	.080	369.2	35.42	319.4	42.36
	T	-	-	-	333.7	37.19	294.13	45.01
Number of Saccades*	C	6.188	0.05*	.015	74.1	24.23	64.8	21.00
	T	-	-	-	69.7	27.17	74.3	29.27
Mean Saccadic Amplitude *	C	12.684	0.01**	.030	5.43	1.150	5.72	1.889
	T	-	-	-	5.70	1.889	4.92	1.004
Number of Blinks	C	0.615	0.43	.002	4.65	3.905	3.41	2.880
	T	-	-	-	6.79	7.99	6.60	6.57
Pupil Diameter	C	10.153	0.01**	.023	1839	450.7	1490	541.8
	T	-	-	-	2188	667.3	1979	345.6

Significant values: * = $p < 0.05$, ** = $p < 0.01$

As can be seen in Table 25, there was a significant interaction between the Training and Driver group for mean fixation duration, mean saccadic amplitude, and the number of blinks per trial. Commentary training appeared to increase the number of fixations for novice drivers significantly. However, it had no significant effect on experienced drivers, with commentary trained drivers having a significantly greater number of fixations than the control group. The mean fixation duration was significantly lower for the experienced commentary trained group contrasted with the control group. Commentary trained novice drivers had longer fixation durations compared to participants in the control group.

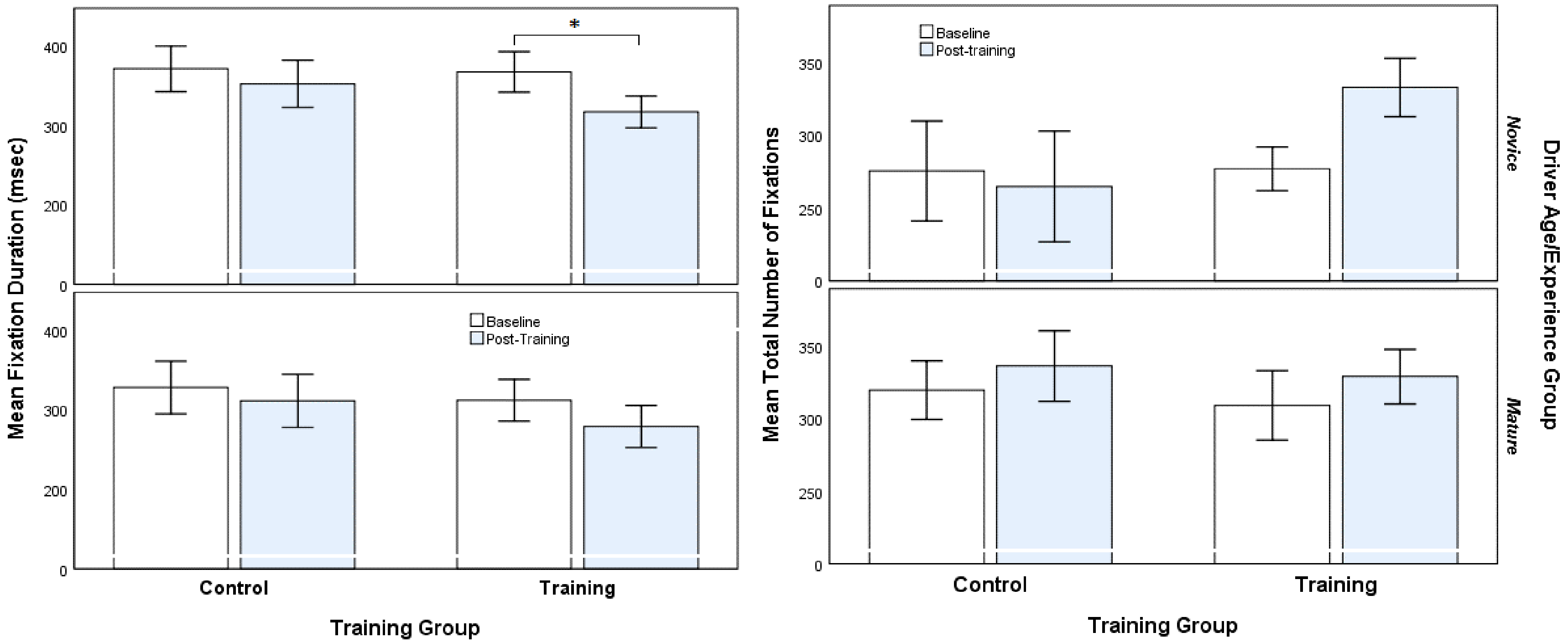


Figure 68*:* The mean number of fixations (left) and mean fixation duration (right) per trial, organized with Novice (top) and Experienced Drivers (bottom), and Training Group with Commentary indicated with stripes. The bars represent 95% CI Significance values are indicated, p< 0.05 *, and p< 0.01 **

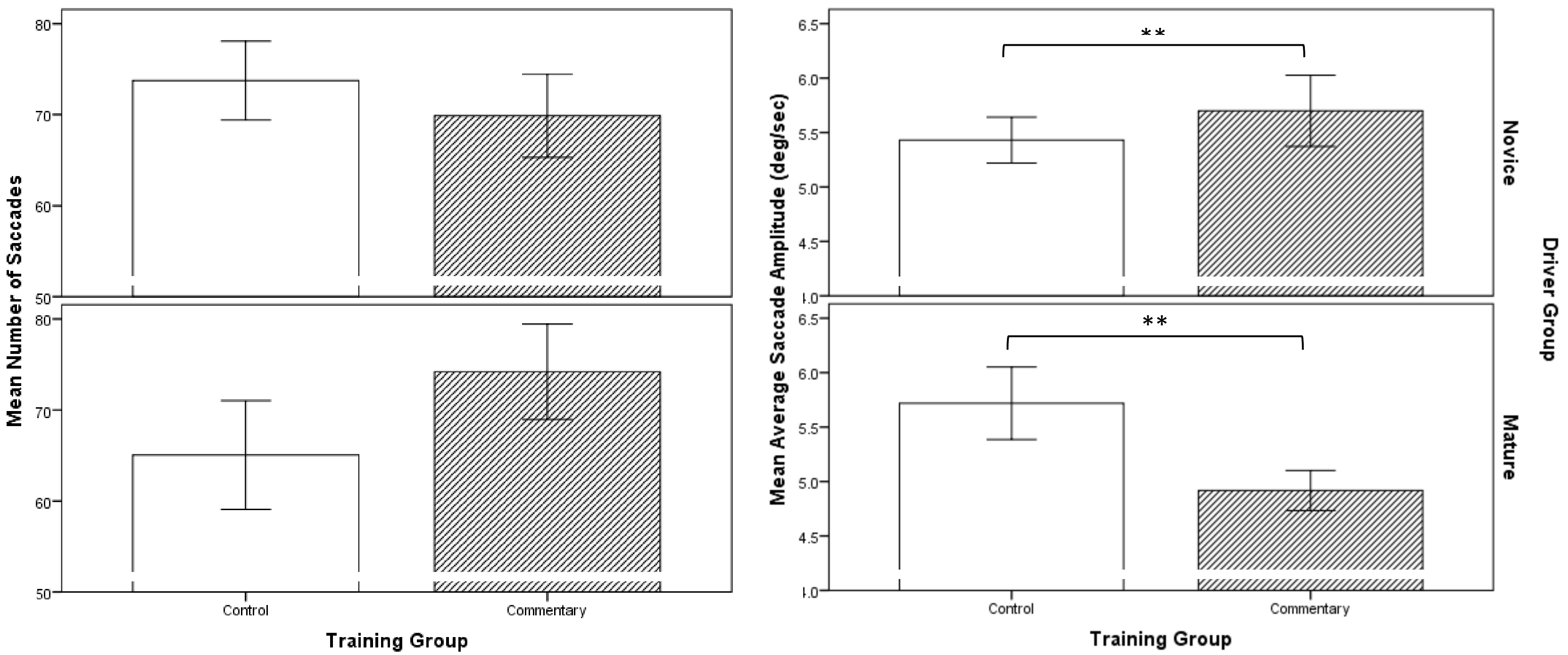


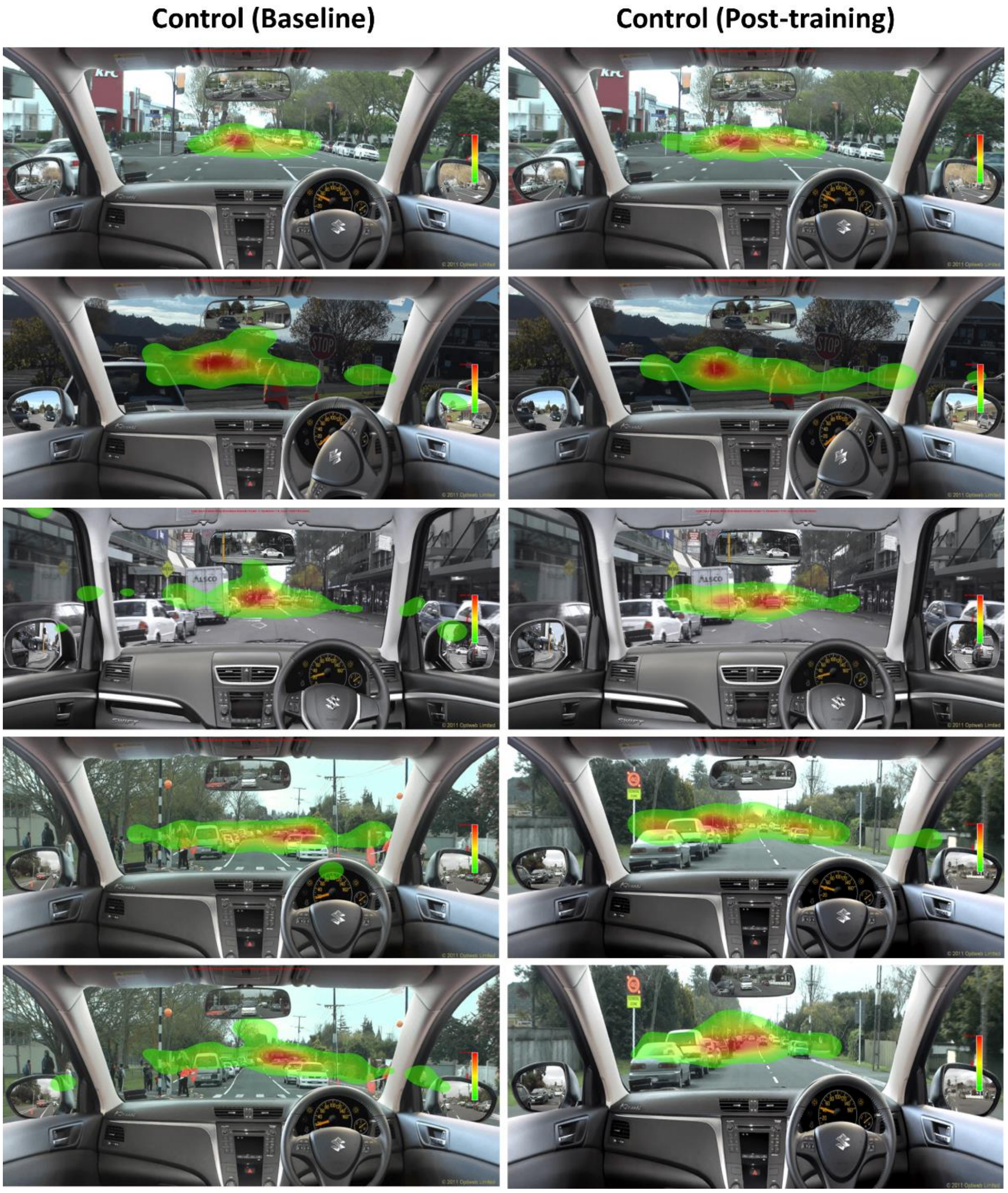
Figure 69: The mean Number of Saccades (left) and mean Saccadic Amplitude (right) per trial, organized with Novice (top) and Experienced drivers (bottom), and Training Group with Commentary indicated with stripes. The bars represent 95% CI Significance values are indicated, $p< 0.05$ *, and $p< 0.01$ **

Distribution of Eye movements between Training Groups

The differences between drivers' visual search behaviour between baseline and post-training assessments is an important consideration. Heatmaps were generated for both training groups, with eye movements from the baseline paired with the same videos from post-training.

Commentary (Baseline) **Commentary (Post-training)**

Figure 70: Heatmap illustrating the fixation behaviour of drivers at baseline (left) and following training (right) for the Commentary training group.


Control (Baseline)

Control (Post-training)

Figure 71: Heatmap illustrating the fixation behaviour of drivers at baseline (left) and following training (right) for the Control group.

Commentary trained drivers have a broader field of view following training compared with the control group. The most significant difference is that the clustering of fixations appears to be greater in the commentary training group, indicating the drivers focused their visual attention differently following commentary contrasted with the control group. One interesting observation is that both groups of drivers were more inclined to use the wing and rear-view mirrors during the baseline compared to the post-training assessment. This may be due to the relative absence of hazards in the mirrors and could indicate that drivers prioritise the search for hazards in the forward field of view as the task progresses.

The training videos were shown to both the training and control group, with the only significant difference being how each training group were to engage with the videos. One group would be required to watch and actively comment on hazards that enter their awareness (commentary group), while the other group was instructed to watch the videos from the driver's perspective. Eye-movement information was recorded as participants watched the videos, and this is shown in Table 28:

Table 26:

Eye-movement Behaviour while producing Road Commentary, contrasted with Control Participants, for both Novice and Experienced Drivers

	Control				***Commentary***			
	Novice		***Experienced***		***Novice***		***Experienced***	
	M	SD	M	SD	M	SD	M	SD
Number of Fixations	74.8	24.23	65.6	20.99	70.4	27.13	75.3	29.29
Fixation Duration	307.5	51.08	361.4	63.69	328.9	62.11	308.8	57.81
Number of Saccades	74.1	24.24	64.8	21.00	69.7	27.17	74.5	29.27
Saccadic Amplitude	5.43	1.150	5.72	1.123	5.70	1.889	4.92	1.004
Number of Blinks	4.65	3.905	3.41	2.880	6.79	7.978	6.60	6.572
Pupil Dilation	892	105.8	724	114.6	1136	186.3	816.5	151.7

Overall, during training compared to control, experienced drivers appeared to increase the number of rapid fixations, though showed a smaller saccadic amplitude than the control group drivers. Novice drivers, on the other hand, seemed to show the opposite behaviour. During the commentary, novice drivers had fewer fixations with longer duration, though they increased the number of saccades compared with the control group (refer to Figures 72 and 73). Both novice and experienced drivers in the commentary group showed a significant increase in the number of blinks, F(1,38)= 14.983, p< 0.01, ηp2= .035 and pupil dilation, suggesting an increased cognitive load as a result of the training. The values shown in Table 28 are presented in Figures on the following page.

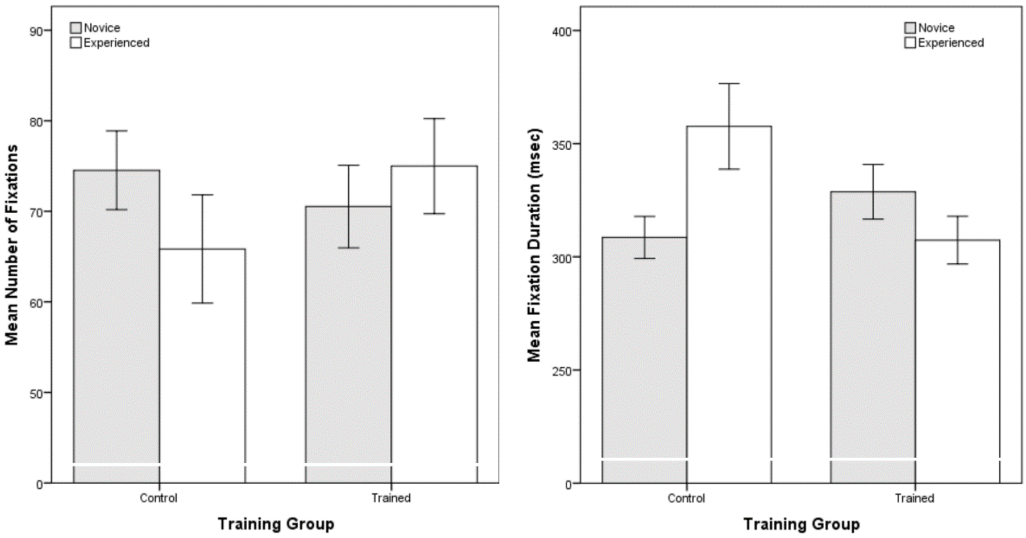


Figure 72: The Mean Number of Fixations (left) and the Mean Duration of Fixations (right), by Driver and Training Groups

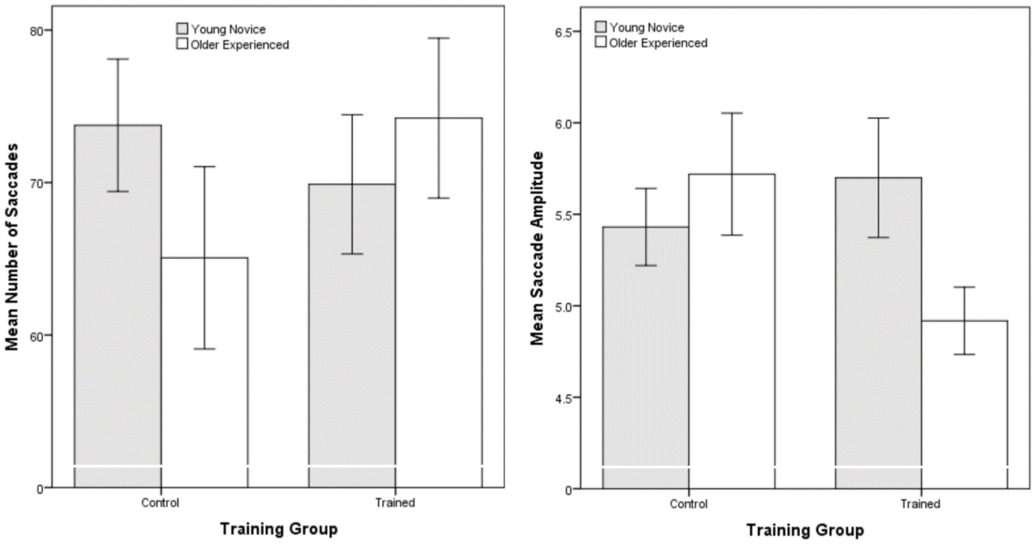


Figure 73: The Mean Number of Saccades (left) and the Mean Saccadic Amplitude (right), by Driver and Training Groups

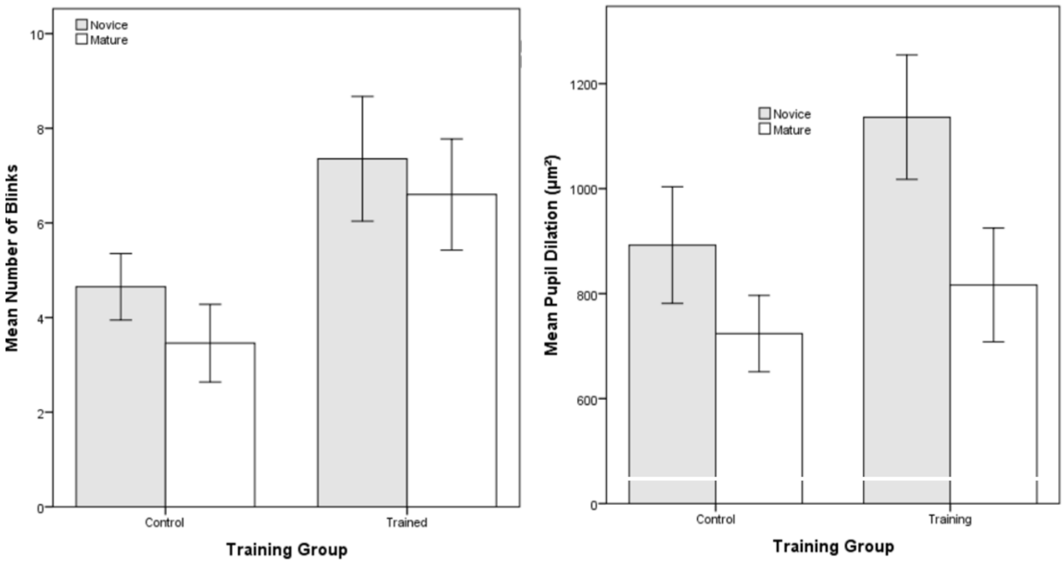


Figure 74: The Mean Number of Blinks (left) and the Mean Pupil Dilation (right), by Driver and Training Groups

Table 27:

*The interaction effects between Driver Group * Training Group for Eye-movement Behaviour during the training task for Control (C) and Trained (T) drivers.*

					Novice		***Experienced***	
	Training	F-value	*p*	η_p^2	M	SD	M	SD
Number of Fixations *	C	6.188	0.05	.015	74.8	24.23	65.6	20.99
	T	-	-	-	70.4	27.13	75.3	29.29
Fixation Duration **	C	35.509	.001	.080	307.5	51.08	361.4	63.69
	T	-	-	-	328.9	62.11	308.8	57.81
Number of Saccades*	C	12.684	.001	.030	74.1	24.24	64.8	21.00
	T	-	-	-	69.7	27.17	74.5	29.27
Mean Saccadic Amplitude *	C	6.153	0.05	.015	5.43	1.150	5.72	1.123
	T	-	-	-	5.70	1.889	4.92	1.004
Number of Blinks	C	.615	.433	.002	4.65	3.905	3.41	2.880
	T	-	-	-	6.79	3.905	3.41	2.880
Pupil Diameter	C	2.397	.130	.130	892	105.8	724	114.6
	T	-	-	-	1136	186.3	816.5	151.7

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Fixation Duration Immediately Preceding Hazard Detection

As a measure of sustained visual attention, the duration of fixations that coincided with the perception of hazards is shown in Figure 75:

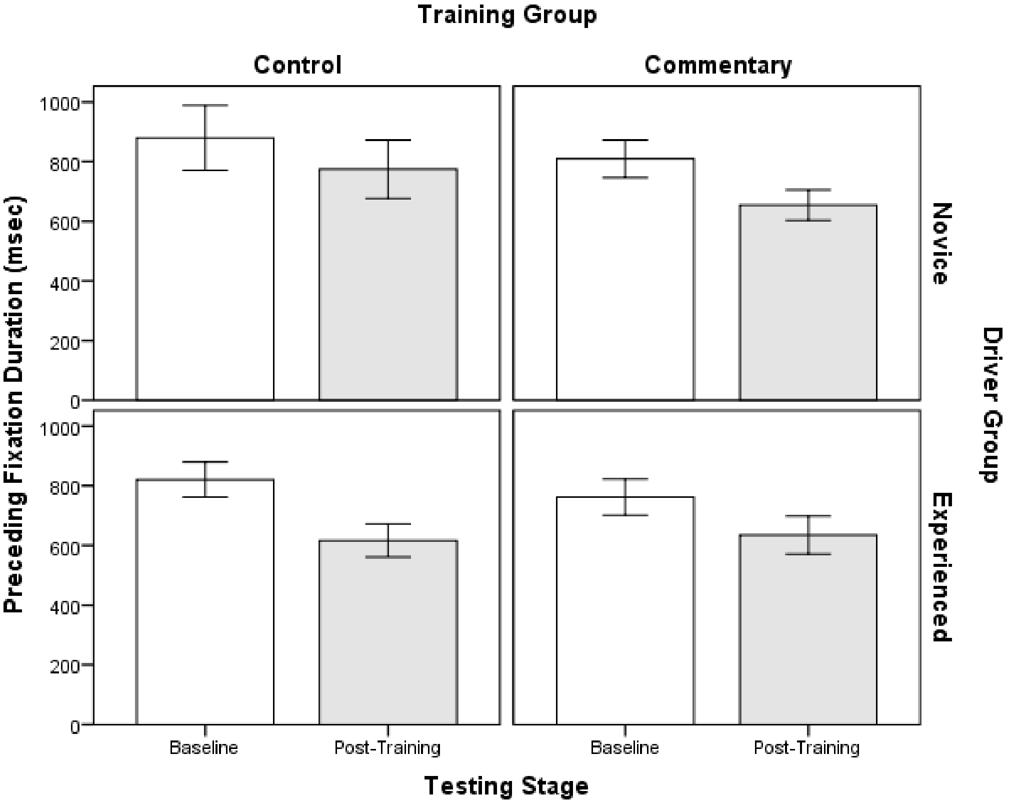


Figure 75: The Duration of Fixations that Immediately Preceding the Perception of a Hazard.

The fixation duration preceding the immediate detection of a hazard (as indicated by a mouse-click) was shorter in post-training trials than at baseline for all groups. The fixation durations were observed to be shorter following commentary for novice drivers but not for experienced drivers, who demonstrated greater hazard perception ability.

A mixed ANOVA with two between-subject factors, 2(Driver Group) x 2 (Training Group) and a repeated measure factor (Baseline vs Post-training), was performed on the fixation durations coinciding with hazard perception, confirming that there was no significant main effect between Driver groups ($p= 0.24$) or between Training groups ($p= 0.52$). However, a significant interaction was observed between Training and Driver Group, Wilks $\Lambda= 0.998$, $F_{(3,36)}= 4.309$, $p< 0.01$, $\eta_p^2= 0.08$.

Post-hoc inferential analysis on the fixation duration between baseline and post-training using multiple one-way ANOVAs, $F_{(1,19)}= 1.932$, $p= 0.16$, $\eta_p^2= 0.008$, showed that novice drivers in the control group did not differ significantly between baseline (M= 879.4, SD= 645.45) and post-training (M=776.1, SD= 518.05). A significant difference was found between baseline (M=809.1, SD=519.35) to post-training (M= 653.9, SD= 407.10) in the commentary group, $F_{(1,19)}= 13.697$, $p< 0.01$, $\eta_p^2= 0.027$, though the effect size was small. It was found that the experienced driver group had shorter fixation durations in the post-training compared with baseline, irrespective of the training group.

Discussion

This experiment investigated developing commentary training for novice and experienced drivers based upon Isler et al. (2009) and measuring effectiveness in relation to hazard perception and eye-scanning behaviour. An initial investigation found that there was a significant difference between the number of hazards perceived during baseline testing between novice and experienced drivers, with experienced drivers perceiving more hazards than novice drivers do before training. As both previous experiments in this thesis, this was anticipated, and evidence from the reviewed literature suggested that experienced drivers should perceive more hazards with greater speed (M. Horswill et al., 2013).

The current study found that road commentary significantly increased participants' ability to identify hazards on video-based traffic simulations. This finding is similar to the reviewed literature, especially that of Isler et al. (2009) who found that commentary training increased the number of hazards that young novice drivers' identified in a hazard perception dual-task. The improvement in hazard perception gained through the use of commentary training has been examined in several studies, and the present findings support its use as part of any driver training programme focussing on higher-level driving skills.

The current study's findings are consistent with those of both Isler et al., (2009) and Horswill et al. (2013a), with commentary training improving the hazard perception performance of both young novice drivers' and more experienced drivers. Commentary trained drivers noticed approximately twenty-percent more hazards and identified hazards on average ~200ms sooner. One consideration was that drivers in the control group did improve, with novice drivers performing better following the control group training, although this effect was not significant. As the sequence of baseline and post-training videos alternated, this is not accounted for by difficulty inherent in the video scenarios and may result from mere exposure to the training scenarios.

Analyses of the fixation data indicated that there were differences between the two training groups regarding the allocation of fixation in distinctly different ways in the post-training assessment. The commentary group demonstrated more fixations devoted to the roadside where hazards are most likely present (Crundall et al., 2010; Crundall & Underwood, 1997). These differences indicate that commenting on the road situation may change the way drivers process the visual scene, with commentary training promoting fixations to hazard-rich areas of the visual scene, and dedicating more fixation duration to the areas of the road where hazards might occur.

When focusing on the fixations that immediately preceded the detection of hazards, these fixations were observed to be more rapid in post-training trials than those at baseline, which suggests that there may be a mere exposure or training-type effect. The fixation durations were observed to be shorter following commentary for novice drivers but not for experienced drivers, who demonstrated greater hazard perception ability. This might partially confirm the findings of Young et al. (2017), who found improved performance in the post-training testing of their control group, suggesting that merely silently performing hazard perception may improve performance over time. However, in this experiment, drivers in the commentary group showed increased hazard perception performance, associated with shorter fixation durations.

Experienced drivers in the commentary group had more frequent rapid fixations than control drivers and had more elongated saccadic eye movements. This could indicate changes to the way participants acquired visual information from the environment while generating commentary. Considering that breadth of the search was not changed, experienced drivers likely used short successive fixations to scan the environment before returning to the centre of the visual field. These findings support Chapman et al. (2002), who found that commentary training produced different visual search patterns in young drivers when combined with hazard anticipation and visual search training. However, it is worth noting that nonspatial secondary tasks (such as verbalisation) have been associated with decreased fixation durations during driving (Nunes & Recarte, 2002). Young et al., (2017) considered that this might be the reason why their commentary drivers had shorter fixations without a corresponding change in hazard perception. In this experiment, hazard perception ability did improve with commentary training, so changes in their visual behaviour are likely related to hazard perception.

In the study by Crundall and Underwood (1998), it was found that novice drivers who drove on several different road environments demonstrated a pattern of inefficient visual search behaviour compared with more experienced drivers who travelled the same route. Isler et al. (2009) speculated that this was due to an inability to redirect attentional resources to hazard perception task or that novice drivers lack the skills needed for efficient search of the road scene. The current study may provide some evidence to suggest that commentary training may promote the more efficient search for hazards, either through improving search strategy or through the allocation of attentional resources to the task of perceiving and responding to immediate hazards. This may address the question raised by Vlakveld (2011); however, further research is required.

While participants were required to identify immediate hazards in their commentary, many went beyond this to identify covert hazards. It was noted that participants seem to prioritise the importance of road environment features differently. Young people seem to assess hazards principally responding to visual salience, whereas experienced drivers make judgements dependent more on situation and context. This might be evidence of more advanced knowledge of the road environment and potential hazards, rather than the largely bottom-up saliency driven attention to environmental features, which novice drivers attend to visually.

Both groups tended to focus ahead of the vehicle rather than attending to the mirrors. The way the two groups attended to the mirrors did not show a statistically significant difference between baseline and post-training. Participants attended more to the central visual field. Previous studies have shown that young novice drivers typically focus their attention on the centre of the visual field (Konstantopoulos et al., 2010), as this is required for the primary driving task of maintaining lane position and avoiding immediate on-coming hazards (e.g., slowing vehicles). It is worth noting that there was no instruction given regarding hazards occurring in the mirrors, and it could be assumed that the use of mirrors in this experiment may not be representative of actual driving behaviour, as the majority of immediate hazards occur within the centre-field.

Both driver groups demonstrated a higher number of blinks during commentary training compared to control drivers. Blinks might be evidence of an increase in the cognitive load required to process the road environment and identify hazards and then verbalise this process. Suppose commentary places additional load onto the primary driving task. In that case, this could be a challenge to implementation, as blink rate evidences a more significant loading on cognitive resources than visual information acquisition. Additionally, on the presentation of hazards, the pupillary response suggests that drivers experienced a physiological response.

Limitations

Several limitations should be addressed in the current study. Firstly, the small sample size might not be sufficiently large to address the high degree of variability observed within groups adequately. As there was a departure from the methodology used in previous hazard perception experiments, validity can only be assumed based on the distinct difference in behaviour between driver experience and age groups.

Secondly, the road commentary task used in this experiment did not employ a secondary dual-task (as was used in other studies, for example, Isler et al., 2009; Crundall et al., 2010). The use of a secondary task created an 'artificial' cognitive demand that is to represent that task demand for actual driving. In simulator tasks, the secondary task would be steering and vehicle control on the virtual road, where the primary task would be hazard perception. Without using a secondary task in this experiment, participants were free to allocate all their cognitive resources to the task of searching for hazards. Therefore, hazard perception performance in this experiment may not have accurately represented the actual hazard perception competency when driving in the real world. This is most notable by the considerably higher number of hazards perceived by both groups and the shorter duration needed to recognise hazards compared with other tasks. However, given these considerations, the secondary task was the most appropriate way to inflate task demand artificially. For instance, a verbal secondary task would interfere with participants commentary production, and a steering task would not work within the framework of using a video-based methodology.

While eye-movement behaviour was recorded during training, and this provided some insight into whether participants were engaged with the task, it remains challenging to determine whether the differences in the training group versus the control group engaged with the task in the same way. There was no significant difference between the control and training groups before training as a measure of control, which suggests that drivers had been allocated to either training group without prejudice. Despite the training videos being the same for both groups, merely asking the control group to view the videos as if they were the driver may affect their level of engagement, despite eye movements reflecting search behaviour. A lack of engagement could diminish the control group's capacity and provide an unequal advantage to more engaged commentary participants.

Crundall and Underwood (1997) mention that verbal overshadowing could have the potential to interfere with visual search behaviour, and this is and further that by requiring drivers to make verbal reports, they may focus attention on non-relevant aspects of the driving task, as noted by Hughes and Cole (1986). As commentary is a verbal process, the results might vary significantly from participant to participant irrespective of the level of competency driving. Novice drivers may struggle to generate commentary with the same fluidity as experienced drivers, as the verbal task may impact more of searching out hazards – hazard perception is likely partially automatized to some degree with experienced drivers. Additionally, verbal overshadowing may play a role in disrupting drivers ability to focus on hazards.

The experimental setup, which involved a chin and forehead rest, may place restrictions on the natural viewing conditions participants might use, limiting the range of visual strategies and presenting all hazards within the immediate front field of view, which could present issues of ecological validity.

Another issue that may be a potential unaccounted variable is the quality of road commentary, which was found to vary substantially between individuals within the training group. While this has not been examined in this current study, it was noted that some participants found commenting on hazards much more challenging than others. While not within the scope of the present study, the analysis of the extent and quality of commentary and the use of covariates in the future analysis may reveal a more accurate picture when it comes to evaluating the effects of road commentary training. Returning to the criticism raised by Vlakveld (2011) of Isler, Starkey, and Williamsons (2009) original task, a longitudinal approach, as well as an additional training group, could provide a great deal of important information. An additional participant group of initial control subjects then go on to perform commentary would provide insight regarding both the long-term effectiveness of commentary as training and the role of simply viewing traffic scenarios. This could help determine whether observed changes were the result of altered cognition and not merely increased visual sampling of objects

Finally, it is important to consider that participants listened to expert commentary in the commentary training and were then required to self-generate a similar commentary. Participants then repeated the process in reverse before going into the twelve self-produced commentary videos. This approach is not dissimilar from what is referred to as “feed-forward training”, where participants are instructed where to look, and subsequently, they tend to dedicate much more attention to those locations compared with drivers who are not provided with instruction (Sadasivan et al., 2005).

Study B: Does improving Hazard Perception influence Speed Choice?

In the previous experiment, there was a notable improvement in drivers hazard perception time under the commentary training condition for both novice and experienced drivers, which has also been observed by other researchers in the reviewed literature (M. Horswill et al., 2013). The development of hazard perception and efficient visual search strategies is one of the fundamental skills marking the transition from novice to experienced drivers (Horswill & McKenna, 2004; Underwood, 2007) and is a driving skill related to reduced crashes likelihood.

Road commentary is a simple training technique and was demonstrated in the previous study to improve drivers hazard perception using video-based traffic scenarios, with similar findings to the research conducted by Isler et al. (2009). Furthermore, improvements to drivers hazard perception performance were accompanied by changes in visual search behaviour, similar to Chapman, Underwood, and Roberts (2002). Given the observed relationship between speed choice and hazard perception observed in Experiment 3, it was hypothesised that improving hazard perception through road commentary may also improve drivers' speed choices. It might be possible that improving hazard perception with commentary may lead to a subsequent reduction in drivers' speed choice, with previous research supporting this possibility.

The potential benefits of improved hazard perception are a possible change in drivers' speed choices, likely in response to greater awareness of risk. Isler, Starkey, Drew, et al. (2008) found that among other training methods, commentary improved hazard perception within a group of young novice drivers and was accompanied by a reduction in drivers' speeds in a real-world setting (i.e., driving on a race-track). Renge (1998) found that drivers reduced speed after training, which improved hazard perception, which has also been observed in hazard anticipation tasks (McKenna et al., 2006). Mills et al. (1998) found commentary training improved hazard perception and response times in on-road driving assessment ratings, and this finding is supported by Crundall et al. (2010), who found commentary resulted in increased responsiveness to hazards, including a reduction of speed when approaching hazards.

Introduction

Several decades of research has demonstrated that training speed adaptation is notoriously challenging to educate and is managed mainly by enforcement through policing. While efforts have been made with varying degrees of success, speed is still the greatest contributing factor to fatal crashes (Accident Compensation Corporation & Land Transport Safety Authority, 2000). Australian researchers Kloeden et al. (1997) analysed crashes in Victoria and New South Wales. They noted that excessive vehicle speed is potentially misjudged by other drivers, which reduces the available driver reaction times and the effectiveness of braking or counter-manoeuvres while dramatically increasing the energy released upon impact. Such crashes may be the result of under-developed hazard perception (McKnight & McKnight, 2000).

The relationship between speed choice and hazard perception may be mediated by the ability to search the road for hazards effectively. For instance, when a driver is travelling at a high rate of speed, there is less time available to acquire visual information and respond to potential hazards before encountering them (Aarts & van Schagen, 2006). Parmet et al. (2015) argue that poor hazard anticipation may be the root cause of poor speed management when young drivers display inferior speed management strategies in the presence of potentially hazardous traffic and road situations.

In the reviewed literature, there has been a strong theme that educational programs that focus on hazard perception have a subsequent reduction in speed choice. Isler and Starkey (2008) tested this concept in a longitudinal study, the Frontal Lobe Project. Amongst other things, they tested the influence of driver education, focusing on higher level skills such as hazard perception and situation awareness. After an extensive training program, they observed that novice drivers showed improved performance and reduced speeds on a track. Using the road commentary training used in Study A, this second study explores the potential for commentary-based training to improve the critical relationship between hazard perception and speed choice. This corresponds to changes in visual search behaviour.

Research Question

Does improving Hazard Perception through Road Commentary have a positive-safety influence on Speed Choices?

There is an indication in the literature that advanced hazard perception is related to more appropriate speed choices, and if the findings from Experiment 3 are reasonable, then it would be expected that there should be a subsequent reduction in speed as hazard perception improves. By training hazard perception, the hypothesis is that there would be a corresponding reduction in speed choice, as measured using the previously developed combined task from Experiment 3.

Method

In this experiment, the role of commentary training on hazard perception and speed choice was examined using the Hazard Perception & Speed Choice task developed for Experiment 3 and the commentary training that tested in the previous study. In order to accomplish this, twenty-two participants volunteered to return from previous participation in Experiment 3 to be retested, with half participants receiving commentary training developed in the previous study.

In the previous experiment, the training participants actively engaged in commentary, while the control group were asked to watch the videos as if they were the driver. This experiment will use the same training method, using the same clips, with the combined Hazard Perception and Speed Choice task used in Experiment 3 as the instrument used to measure participants behaviour. This study examines the relationship between hazard perception and speed choice and the effects of commentary training on visual search behaviour using road commentary training.

Participants

Participants who had volunteered and completed the hazard-speed computer task used in Experiment 3, and had indicated their interest in future research were invited to return to participate in this study, which was conducted approximately six weeks after the original experiment. Twenty-two participants returned, with 10 novice participants (M= 22.4 years, SD= 1.26; 5 male, 5 female) and 12 experienced (M= 28.5 years, SD= 3.26; 5 male, 7 female) from Experiment 3 volunteering to repeat the same computer-based combined Hazard Perception Speed Choice task. Ten participants received commentary training before repeating the computer-based task (M= 25.7, SD= 2.61; 5 male, 5 female). The other 12 participants (M= 26.8, SD= 4.97; 5 male, seven female) observed the same videos used for the commentary training but did not receive training so that they repeated the task as a control group.

Baseline assessment bias:

There was no significant difference between gender and training groups concerning baseline speed choice or hazard perception measures. However, there was a significant difference in baseline with driver groups, with novice drivers choosing faster speeds than experienced drivers and having shorter hazard perception times, which is discussed in the results section. There were no significant interaction effects identified between gender, training, or driver groups.

Hazard Speed Computer Task

The laboratory task used in this second commentary experiment was the Hazard Perception Speed Choice task developed for Experiment 3. Participants were required to watch eight different traffic-related videos and asked to perceive immediate hazards by pressing the mouse and verbally stating the hazard identified as quickly as possible while simultaneously tracking a randomly moving dot using a mouse. Following each video, participants selected the speed they considered ideal for that road condition using a digital speedometer. The head-mounted eye-tracker (SR Research EyeLink II) was used to record participants' eye movements, and the eye-tracker was fitted and calibrated before the task in a similar way to Experiment 1 and 3.

Procedure

Similar to the previous study, participants in the training group received road commentary training, which involved watching two videos while listening to expert commentary and then were required to reproduce commentary for the same two videos to familiarize themselves with the training. Participants in the training group were then required to produce verbal commentary for the twelve training videos used in the previous experiment. Participants in the control group were asked to watch the videos as if they were the vehicle's driver but did not provide any commentary. Both groups then repeated the computer task. Unlike the previous study, participants were not using an eye-tracker during the training session.

Participants' data were paired with the data recorded from the first time (baseline) they had run through the combined task. Additionally, participants were asked some brief demographic questions related to driver history.

Results

The values for the different measures related to hazard perception and speed choice were calculated and matched for baseline and post-training assessment - and are presented in Table 28. Hazard perception measures improved for both training groups, referring to Table 31; baseline measures indicate that there were no significant differences within driver groups (i.e., novice drivers did not significantly differ between training groups, suggesting that they were similar in their ability). However, there was found to be significant differences between driver groups in both pre-training assessments.

Following training, there was an improvement in the hazard perception times for both groups of drivers in the commentary training group compared with drivers in the control group. The baseline and post-training descriptive and inferential statistics are shown in Table 28:

Table 28:

The Measures of Hazard and Speed Behaviour for Novice (n=10) and Experienced (n=12)

					Novice		***Experienced***	
		F-value	p	η_p^2	M	SD	M	SD
Baseline	Number of Hazards	0.131	.721	.007	33.2	3.85	32.5	4.98
	Hazard Perception Time **	12.418	0.01**	.383	3.19	.357	2.71	.284
	Mean Speed Choice **	15.063	0.01**	.430	31.9	3.03	27.2	2.76
Post - Training	Number of Hazards	0.634	.435	.031	35.0	2.71	36.6	3.10
	Hazard Perception Time *	5.804	0.05*	.225	2.71	.325	2.38	.309
	Mean Speed Choice	0.987	.332	.047	27.4	4.61	25.8	2.67

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Referring to Table 28, no significant difference was identified between the Driver groups regarding the number of hazards perceived. However, hazard perception time was significantly different between novice and experienced drivers in both baseline and post-training[32]. Speed choice was significantly different between groups at baseline but did not differ between Driver at post-training assessment. There was no identified interaction effect observed between the Training and Driver groups.

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[32] This was an anticipated effect, as in Experiment 3, experienced drivers generally had faster hazard perception times than novice drivers.

The measures of hazard perception and speed choice were graphically represented in Figure 76:

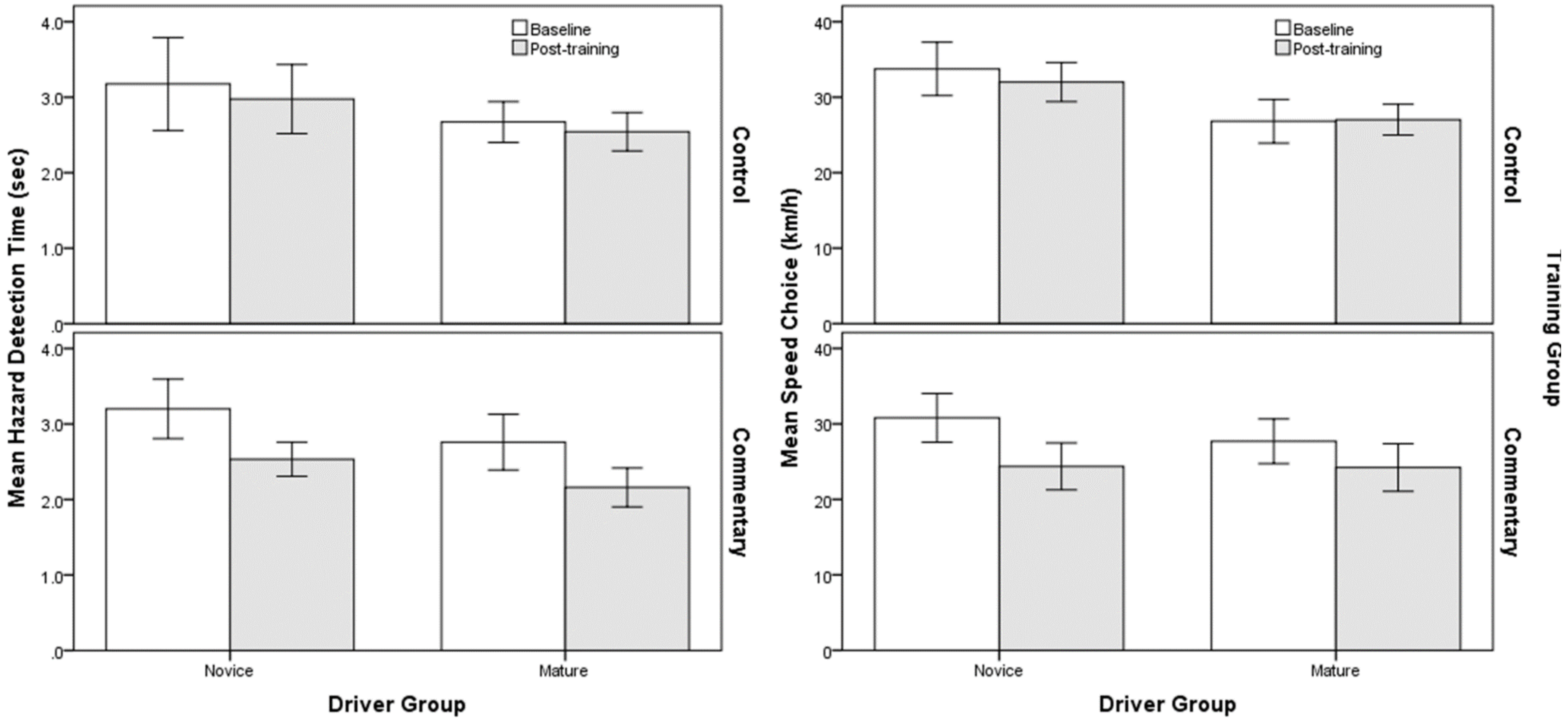

Figure 76: Mean Hazard Perception time (left) and mean Speed Choice (right) for the first and second trials of Trained (above) and Untrained Drivers (below).Error bars indicate 95% confidence intervals.

Figure 76 indicates that the Training group who received the commentary training had slower speed choices and reduced hazard perception time following training assessment and in contrast with the control group.

The Effects of Commentary Training:

The difference between baseline and training for the control and commentary training group was calculated and is shown in Table 29. There is a general improvement in all measures in the post-training assessment, which was anticipated considering participants had previously performed the task.

Table 29:

Hazard Perception and Speed Choice before and after training

		Baseline		***Post-Training***	
		M	SD	M	SD
	Number of Hazards	33.8	4.21	36.00	2.68
Control	Hazard Perception Time	2.85	.401	2.70	.344
	Mean Speed Choice	29.3	4.42	28.8	3.16
	Number of Hazards	31.67	4.37	35.09	3.18
Training	Hazard Perception Time	2.94	.397	2.36	.281
	Mean Speed Choice	29.4	3.11	24.3	2.64

A mixed two-way 2 (Driver Group) x 2 (Training Group (Commentary, Control)) x 2(Baseline, post-training, repeated measure) MANOVA was conducted on measures of hazard perception time, the number of hazards perceived, and speed choices. The analysis revealed that there was a significant effect for Driver Group on the measures before and after training, Wilks Λ= 0.412, $F_{(2, 18)}$= 7.627, p< 0.01, η_p^2= 0.558., as well as a significant effect for the Training Group, Wilks Λ= 0.579, $F_{(2, 18)}$= 3.874, p< 0.05, η_p^2= 0.421, with drivers in the commentary group improving in hazard perception ability, and selecting slower speeds following training when compared with the control group. However, no significant interaction effect was identified between Driver Group and Training Group, Wilks Λ= 0.758, $F_{(2, 18)}$= 1.700, p= 0.207, η_p^2= 0.242.

The analysis revealed no significant difference following training between Training Groups in relation to the number of hazards perceived $F_{(1,18)}$= 1.472, p= 0.241, η_p^2= .076. However, following training, drivers in the commentary group had quicker hazard perception times, $F_{(1,18)}$= 25.20, p< 0.01, η_p^2= .583 compared with drivers in the control group. Commentary trained participants' were also found to have significantly slower speed choices, $F_{(118)} = 9.251$, $p < 0.01$, $\eta_p^2 = .339$, compared to their control group counterparts.

Within-subject effects were identified for both the Training Group, Wilks $\Lambda = 0.331$, $F_{(2, 18)} = 10.760$, $p < 0.01$, $\eta_p^2 = 0.669$, and Driver Group, Wilks $\Lambda = 0.634$, $F_{(2, 18)} = 3.471$, $p < 0.05$, $\eta_p^2 = 0.366$, though no significant interaction within Training and Driver Group, Wilks $\Lambda = 0.980$, $F_{(2, 18)} = 0.108$, $p = 0.95$, $\eta_p^2 = 0.020$. There was a significant within-subject effect for the Training Group, both for the hazard perception times $F_{(1,18)} = 25.20$, $p < 0.01$, $\eta_p^2 = .583$ as well as speed choice, $F_{(1,18)} = 9.251$, $p < 0.01$, $\eta_p^2 = .339$, with commentary trained drivers showing a significant improvement in both the time taken to perceive hazards, as well as slower speed choices following training as compared to baseline. While a within-subject effect was identified for Driver Group, there was no significant difference between baseline and post-training for measures of hazard perception ability, with speed choice approaching but not reaching statistical significance, $F_{(1,20)} = 4.193$, $p = 0.54$, $\eta_p^2 = .173$.

The Relationship Between Speed Choice And Hazard Perception Time:

The relationship between hazard perception measures and speed choice was of interest, as previous experiments had indicated a relationship between hazard perception time and the speed at which participants chose as ideal.

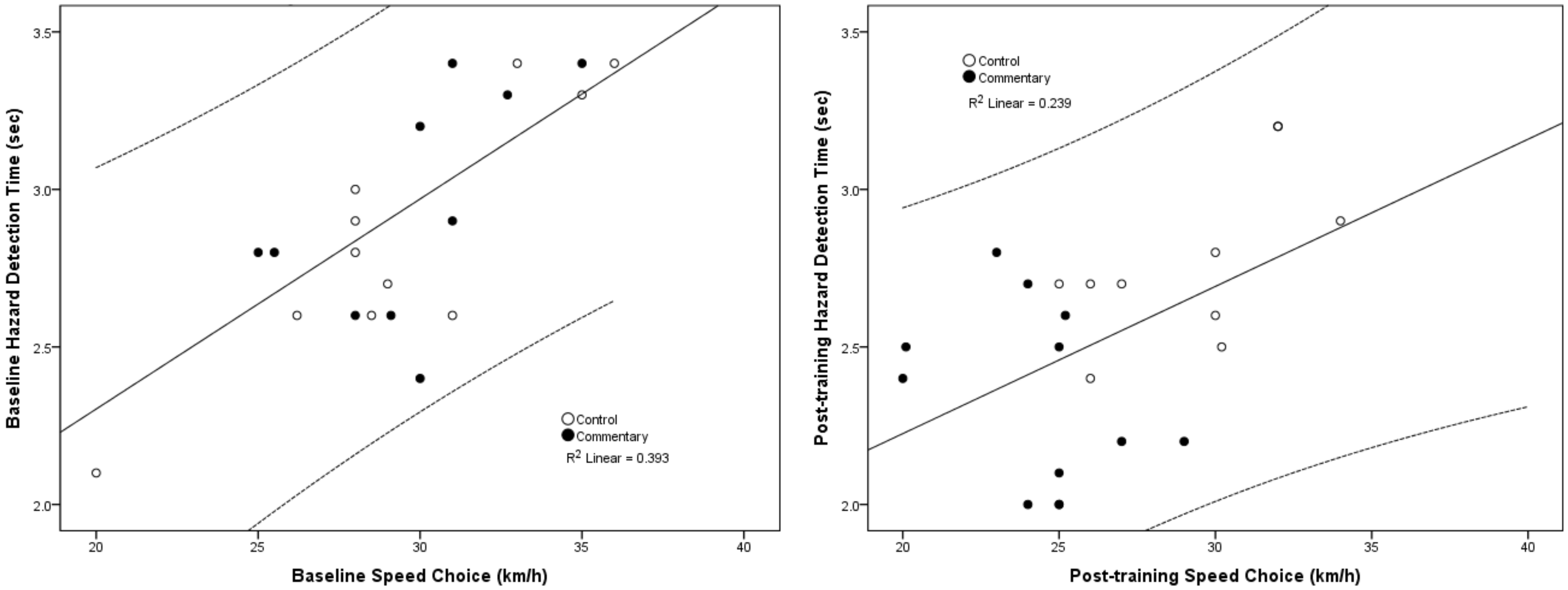

Figure 77: The relationship between Hazard Perception Time and Speed Choice for Baseline (left), and Post-training assessment (right).

Participants who received commentary training are represented as dots. 95% CI are shown as the dotted line.

The relationship between speed choice and hazard perception was analysed using Pearson correlations. There was no significant correlation between speed choice and the number of hazards perceived in either baseline ($p= 0.418$) or post-training ($p= 0.293$) assessments. However, there was a significant correlation identified between speed choice and hazard perception time both at baseline ($r= 0.698$, $p< 0.01$) and post-training ($r= 0.584$, $p< 0.01$), which was consistent with the findings from Experiment 3. Notably, there was greater homogeneity in the baseline assessment, and three drivers from the control and one driver from the commentary group were outliers with faster speed choice and longer hazard perception times.

Analysis from Eye-tracking Data

Eye-tracking data were collected from 16 of the participants, with 4 participants indicating signs of unreliable data in post-training, which was excluded from the analysis.

The eye-tracking analysis revealed that overall, in the repeated task, that road commentary trained drivers had longer fixations per trial (M= 314msec, SD= 32.3) compared to control drivers (M= 295msec, SD= 31.9), which was significantly different between Training groups, $F_{(1,15)}= 5.435$, $p< 0.05$, $\eta_p^2 = 0.361$. The mean number of fixations was significantly lower following training for drivers in the commentary group than the control group, $F_{(1,15)}= 7.903$, $p< 0.05$, $\eta_p^2 = 0.280$).

Table 30:

The Measures of Eye-Movement Behaviour for Control (n= 7) and Commentary Training (n= 9) Groups at Baseline and Post-Training

					Baseline		***Post-training***	
	Training	F-value	*p*	η_p^2	M	SD	M	SD
Number of Fixations	C	7.406	0.01**	0.346	200.43	71.942	245.86	63.326
	T	-	-	-	236.44	52.247	205.89	48.403
Fixation Duration	C	5.504	0.05*	0.282	322.00	100.816	296.3286	84.27
	T	-	-	-	342.78	83.681	229.8889	71.893
Number of Saccades	C	3.934	0.067	0.219	827.43	133.448	881.14	101.29
	T	-	-	-	894.00	73.273	1065.31	113.05
Mean Saccadic Amplitude	C	9.739	0.01**	0.410	6.693	1.8217	6.629	1.629
	T	-	-	-	6.562	1.4683	9.400	1.704
Number of Blinks	C	10.928	0.01**	0.438	16.43	12.313	18.00	12.08
	T	-	-	-	16.22	9.576	25.44	12.58
Pupil Diameter	C	0.759	0.398	0.051	734.8	271.109	629.00	105.192
	T	-	-	-	758.9	410.351	847.00	185.376

Significant values: * = $p < 0.05$, ** = $p < 0.01$

Differences between visual search behaviour:

Road commentary trained drivers appeared to have a broader distribution of visual search and seemed to focus more on ‘hazard rich’ areas compared to participants with no training.

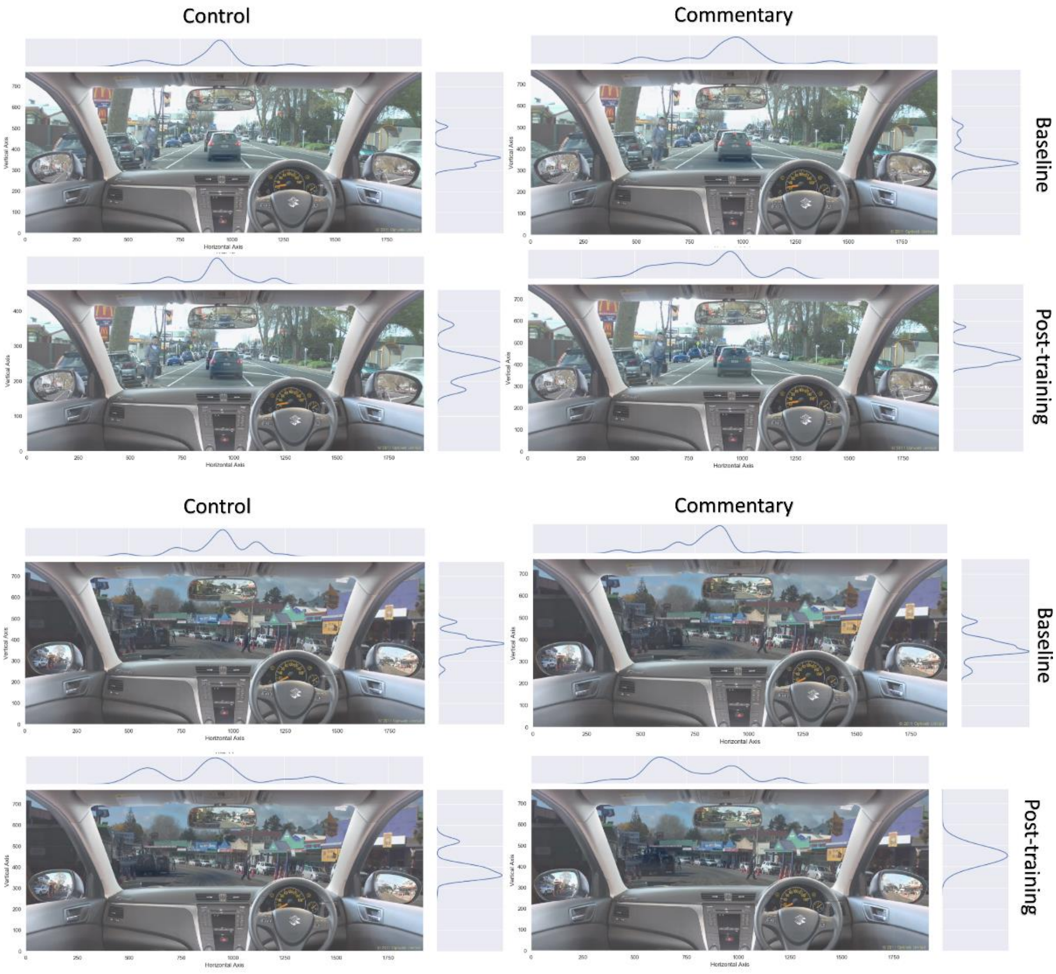

Figure 78: The Distribution and Density Mapping of Fixations made at Baseline (top) and Post-training (bottom) for both Control (left) and Commentary (right) drivers. The top frames are from the Light Commercial scenario, and the bottom frames are from the Construction road scenarios.

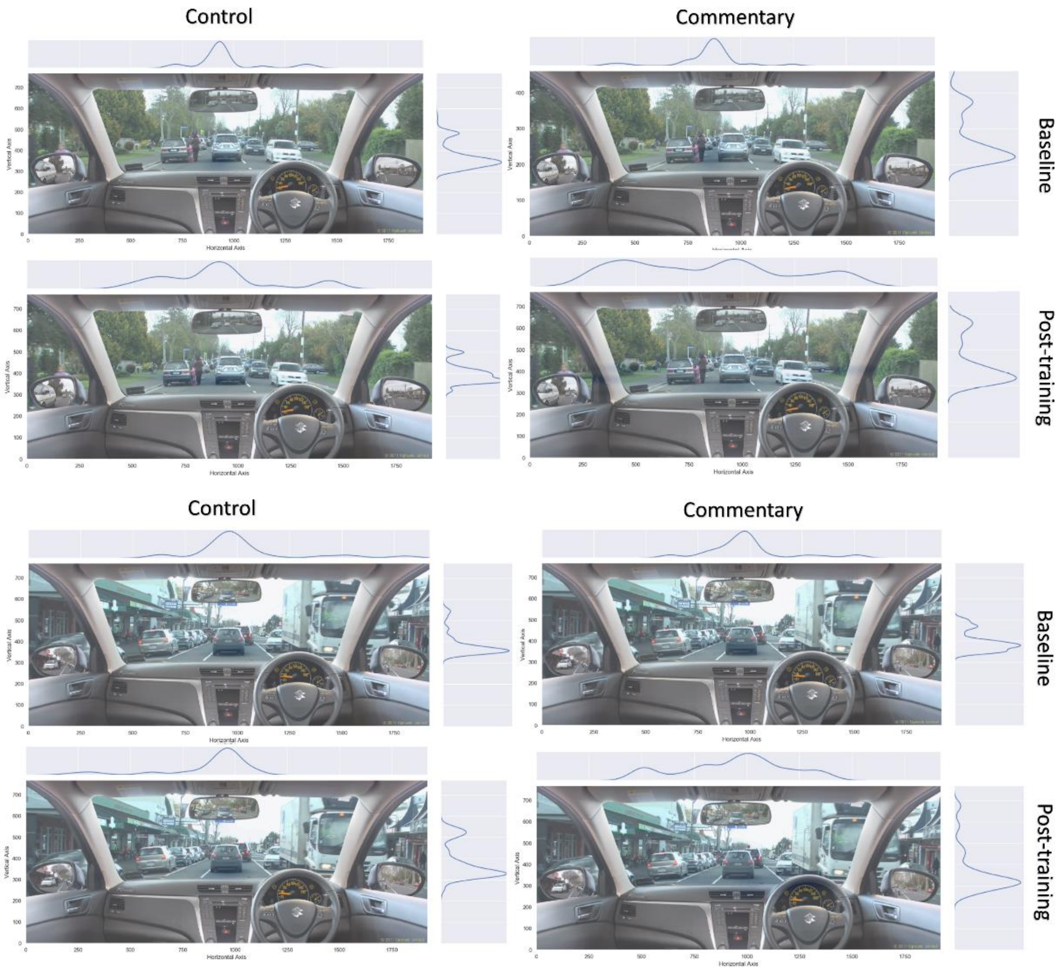

Figure 79: The Distribution and Density Mapping of Fixations made at Baseline (top) and Post-training (bottom) for both Control (left) and Commentary (right) drivers The top frames are from the School scenario, and the bottom frames are from the Heavy Commercial road scenarios.

There are differences for both Control and Commentary drivers in the post-training assessment from observing the distribution of fixations (Figure 78 and Figure 79). Generally speaking, commentary trained participants had a broader field of search in the post-training evaluation when contrasted with baseline measurement.

Discussion

The present study was designed to determine the effect of road commentary on drivers speed choice, with the hypothesis that drivers who improved their hazard perception skills would show a speed reduction. This hypothesis was confirmed, with drivers who performed road commentary showing a significant decrease in chosen speeds following commentary training than the untrained control group who did not show a significant difference in speed choices between baseline and post-training assessments. This finding confirms previous research by Crundall et al. (2010), who noted that drivers with more advanced hazard perception reduced speed on approach to hazards. This finding was also noted to be similar to the study by McKenna et al. (2006), who noted that drivers who had received hazard perception training selected slower speeds when hazards were present in the traffic situation

Initial observations were similar to Experiment 3, showing that the number of hazards perceived by participants had no significant relationship with their speed choices. However, the relationship between hazard perception time and speed choice showed a high statistical significance level both at baseline and post-training. This finding confirms the association between hazard perception times and speed choices observed in Experiment 3. Surprisingly, no differences were found in the number of hazards perceived between either driver age or training group, with a non-significant albeit marginal improvement in the post-training assessment for all drivers.

Novice drivers who received the commentary training selected slower speeds compared to the baseline assessment, which seemed to be related to an improvement in hazard perception times, confirming the findings from the previous road commentary study. This may result from improved search behaviour and may be related to anticipation of hazards or an increase in the awareness of risk, based on where commentary trained drivers focused compared to baseline. Commentary drivers search a broader area of the road compared to controls and baseline. As found in the previous study, they appeared to anticipate hazards by focusing their visual search to areas of the road where hazards are likely to occur, which suggests anticipation of hazards. Novice drivers benefited from the commentary training in relation to hazard perception time, but not to the same extent in the number of perceived hazards.

Experienced drivers also seemed to show improved responsiveness to hazards, and there is evidence to suggest that commentary training is beneficial to experienced drivers (Horswill et al., 2013). Experienced drivers showed a significant improvement in the number of hazards perceived, as well as a reduction in hazard perception time, and it may be that commentary encourages drivers to allocate more attention on where hazards are likely to present based upon existing knowledge (Prabhakharan & Molesworth, 2011). The potential that baseline experience could influence experienced drivers more than novice drivers, given experienced drivers possess more hazard-related knowledge, may explain the significant improvement in hazard perception and speed choice. Suppose the cognitive processes of experienced drivers were significantly affected by the training. In that case, this provides some evidence that commentary training does more than increase vigilance for hazards, though this cannot be thoroughly established from this study.

Experienced drivers did not seem to reduce speed, though they had slower speeds than novice drivers overall, and this was consistent with speed choices made in the previous experiment. Charlton and Starkey (2017b) noted that participants grouped roads based in part on prior experience and the presence of pedestrians and school-aged children. Prior schemata related to the road type and potential hazards could be the strong determinant of speed selection and may explain why there was not a significant change in the speed choice between baseline and post-training assessments, which is in keeping with the findings made by Prabhakharan and Molesworth (2011).

Commentary training did seem to come with an apparent increase in cognitive load. This is not unexpected, as dual-task interference has been extensively studied and is anticipated when multiple tasks compete for limited higher-order resources (Wickens, 1982; Wickens & McCarley, 2008). Despite the commentary training being ‘offline’, the number of fixations decreased under the commentary condition, indicating a ‘tax’ or increased demand on cognitive resources. Both pupil diameter and blink rate support this suggestion and agree with the reviewed literature (Holsanova, 2008). This was unexpected, as, in the previous study where the commentary training was developed, training seemed to come with increased fixation count and a reduction in fixation duration, despite the increased load during training. One explanation for this is the difference in the hazard perception task. The commentary training task in the previous study did not have a secondary tracking task, which potentially released otherwise devoted cognitive resources entirely to the perception of hazards. In this experiment, the secondary tracking task could have potentially interfered with the commentary being generated.

Furthermore, the previous study involved a more extended break between training and post-training assessment, affording drivers more time to integrate the practice into their mental model before post-training assessment[33]. The increase in cognitive load observed may indicate that commentary training is better suited for situations where the learner is not directly controlling a vehicle, such as driving as a passenger or as an online or computer-based training tool.

Overall, this study suggests that road commentary training might be useful in improving hazard perception skills while improving the speed choices of drivers, though further research needs to be conducted to determine the robust nature of this effect.

Commentary trained drivers had slower speed choices and faster hazard perception times. The number of hazards perceived did not significantly improve for either driver group. Speed choice was strongly correlated with hazard perception time but was not related to the number of perceived hazards. Eye-tracking data revealed commentary trained drivers allocated more visual attention to regions of the road where hazards were more likely to present. However, this was associated with longer fixations as well as a decrease in the total number of fixations compared to control measures. The improvement in hazard perception time was suggestive that road commentary training might be useful in improving hazard perception skills and improving the speed choices of drivers' towards safer driving.

In this experiment, evidence supports Experiment 3 that hazard perception time is related to drivers speed choices, with the same relationship in the correlation. This experiment indicated that improving hazard perception may result in reduced speed choices, and this relationship may be causal. According to Chambliss and Schutt (2018), to establish causality, establishing a causal effect requires a plausible causal mechanism that has reasonable explanatory power and an empirical association between the independent and dependent variables (correlation). Additionally, causality requires temporal ordering, such as the dependent variable not changing before the independent variable; and contextualisation, that is, the setting where the change occurs, and non-spuriousness, which is essentially the control for other external factors that could influence the findings. On the assumption of all things being equal, the training group significantly improved in hazard perception measures

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[33] It is possible that the increased cognitive demand observed in this task is a result of a training 'hang-over', though as no eye tracking was used on the training portion of this experiment, this cannot be easily determined.

and had a slower choice of speeds. Firstly, there is a reasonable mechanism to explain this effect found in models of risk and speed choice and previous experimental evidence from both Experiment 3 - that a greater number of hazards elevates the perceived risk, which is compensated by a reduction in speed. Secondly, there was an observed relationship between hazard perception time and speed choice, which correlates independent of age/experience or gender; and that improving hazard perception accompanies reduced speed choices.

The caveat that ‘all things being equal’ is always necessary when considering causal relationships, so that change to the independent variable results in a change to the dependent variable when all other variables are controlled or accounted for. Ensuring this criterion is met is essentially impossible in the field of psychology, as there are always interpersonal and intrapersonal factors that cannot be controlled in the same way that a physicist or chemist can manipulate (Rohrer, 2018).

The proposed relationship that we suggest is that visual search behaviour is related to hazard perception, as visual information informs that process. Hazard perception influences speed choice by adjusting the level of perceived risk, and as hazard perception improves, drivers detect greater risk in the traffic situation and reduce their speed accordingly.

Practical Considerations regarding Commentary Training

There are, however, some practical issues in applying commentary training to driver education. In a comprehensive review, Helman (2009) highlights the possibility that concurrent verbalisation is related to a reduction in drivers performance, owing to its secondary task nature. It may be difficult for trainees to alternate between the commentary task and the higher priority driving task. Young et al. (2014) identified that ‘online’ (concurrent) commentary training negatively influenced drivers' hazard perception performance. Young et al. (2014) performed two experiments. The first involved participants’ performing ‘live’ commentary contrasted with a silent untrained group. The second involved a shorter ‘clipped’ commentary training to reduce task demands. The results did not suggest any change in the accuracy of hazard perception in the commentary group compared with the control group, but response times to hazards were slower for those in the commentary group. While the commentary group demonstrated shorter fixation times, no significant effect on time to first fixate on hazards was unaffected (Young et al., 2014).

They speculated that this prolongation of hazard time was due to the duration of the verbal report interfering with attentional resources, and this has sound theoretical foundations (Huettig et al., 2012; Ranney et al., 2001). Young, Chapman, and Crundall (2014) suggest that commentary interferes with the primary task at one or several stages in drivers cognition. Despite this, however, a wealth of research suggests commentary has a positive effect on hazard perception. However, there is a need for considering the potential for task demands on drivers performing concurrent commentary[34].

Limitations

The findings in this report are subject to at least three limitations. First, the design of the experiment involved a recall of participants who had already experienced the task, which could introduce the potential for the recollection of particular hazards, which could explain the improvement in hazard perception time and speed choice. As the project used a convenience sample of students willing to participate again, inherent biases were potentially introduced. Although these participants were not debriefed comprehensively, unlike the Experiment 3 group, there is still the possibility that participants may have been made aware of the nature of the study in the period between participation.

There was also a small sample size which may not be representative of the general population. For instance, caution must be applied with a small sample size, as the findings might not be transferable to the broader driver education demographic. Though the two training groups were assigned at random, and only provided with the instruction in relation to commentary, there is still the possibility that there was some form of priming or influence of the experiment, which could present with a small sample. However, given that the commentary trained participants showed a significant difference to the untrained participants in post-training assessment compared to baseline assessment, there is likely to be an effect from the commentary

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[34] The hazard perception task used throughout this thesis has involved a degree of verbal report, which itself may have an influence on task performance, and this cannot be discounted. Comparison was made between the hazard times for the data acquired from eDrive Solutions Ltd. (Isler & Cockerton, 2003; Isler & Isler, 2011), and this showed similar results in hazard perception time for each immediate hazard, suggesting the effect of verbal report may not be as prominent an issue.

training over mere exposure or explicit awareness of what is expected (i.e., from the debriefed students), though this cannot be ruled out completely. The general improvement in the number of hazards perceived and hazard perception times for the untrained control group suggests some exposure effect.

Additionally, there is the potential that experienced drivers were able to incorporate the previous ‘baseline’ experience of the video scenarios into their cognitive episodic memory, which may explain the improvement observed. It is noteworthy that the baseline study findings had not been discussed with participants before the post-training assessment. One of the key indicators of behavioural differences can be found in observing the eye-movement behaviour of participants, with emphasis on the differences between the two groups. While the additional load of having to perform commentary alongside the secondary task may influence speed choice in a more dynamic simulator, it is unlikely to influence this experiment based on how speed is selected. However, observing hazards may change the perception of risk, which could influence speed choice. Further research into this field is required in relation to the role of commentary training, hazard perception and speed choice in a more advanced simulator which is a closer representation to real-world driving and moment by moment decision-making.

A final limitation comes from the research findings from Zhang et al. (2018), who found that training interventions were only effective for careful drivers. Careless drivers, by comparison, were found to be less influenced by training. While carelessness was defined as a combination of aggression and sensation-seeking, which in this experiment is likely to balance between groups, it could be worth measuring in future research. The addition of psychometrics could prove to be significantly valuable in determining which drivers benefit from commentary training, as this could allow more focused training towards individuals who are more or less benefited by driver education.

Summary and Future Research

In the current experiment, it was found that a simple commentary based training intervention could be useful in improving both novice and experienced drivers hazard perception, with a subsequent reduction in speed choice. This finding is of significance as if commentary can simultaneously improve hazard perception as well as reduce speeds. The implementation of a training method based on commentary training would be of immense value. While the generalisability of these results is subject to certain limitations, much more research is required to ensure the relationship between hazard perception and speed choice and the scope and application of the commentary training method. Despite this, road commentary could be used as a training method alongside other existing techniques to improve driver safety and assist drivers in reading the road and making more appropriate speed choices.

General Discussion

The main aim of this thesis was to establish a greater understanding of the relationship between hazard perception and speed choice. The extensive literature review concluded that choice of speed is one of the leading contributing factors in drivers crash likelihood. Given this, drivers could easily control the amount of risk they are willing to accommodate in the natural course of driving (Fuller, 2005, 2008) simply by selecting appropriate speeds.

Young novice drivers, in particular, are vulnerable, being twice as likely as experienced drivers to be involved in a speed-related crash (Ministry of Transport, 2009), and generally demonstrate under-developed hazard perception ability (McKnight & McKnight, 2003). Horswill and McKenna (2004) suggest that hazard perception is the most likely trainable source of any skill gap between novice and experienced drivers. This is accompanied by the development of more efficient visual search strategies (Crundall, 2016; Underwood, 2007). Despite the importance of understanding the relationship between hazard perception and speed choice, they are typically studied separately (Elander et al., 1993). As there has been relatively little research published on hazard perception's role in drivers speed choices, this thesis was designed to fill this critical gap in the literature. The key findings will be discussed in this section.

Summary of Key Findings

Hazard Perception Time is Related to Drivers' Speed Choices

The most significant finding to emerge from this thesis was identifying a causal relationship between hazard perception time and speed choice. This finding is distinguished from previous research in that hazard perception times play a central role instead of the number of hazards drivers identified. All reviewed prior research had found relationships between drivers' speed choice and the number of hazards perceived (e.g., Renge, 1998), or a reduction in speed following training in hazard perception (Isler, Starkey, Drew, et al., 2008; McKenna et al., 2006). While these previous studies have shown that there may be some connection between these two factors, this is the first study, to the best of our knowledge, that drivers' speed choices are directly related to the time taken to perceive hazards. Hazard perception time (or latencies) has been generally regarded as a more valid measure of drivers' hazard perception ability and is a strong predictor of drivers crash likelihood (A. Quimby & G. Watts, 1981). The examined relationship indicates that the ability to appraise risk efficiently through the perception of hazards is a central consideration when drivers make speed choices.

Hazard Perception is Related to Drivers' Visual Search

The present study confirmed previous findings and added empirical evidence suggesting that hazard perception was directly dependent on drivers' visual search, which was demonstrated in both the distribution and number of fixations associated with hazard perception time. This also confirms previous research, which has found that visual behaviour significantly differs between novice and experienced drivers. Rapid perception of hazards could be related to a drivers awareness of situational risk, and the efficiency in processing visual information may be critical to how quickly drivers perceive hazards (Crundall & Underwood, 1998; Konstantopoulos, 2009).

It was found in this thesis that experienced drivers searched strategically for roadside features, and this included searching for both overt and covert hazards. Novice and experienced drivers' visual search strategy were comparatively limited in its breadth, suggesting that experienced drivers placed greater value and expectancy on 'hazard rich' regions of the road, maximizing the amount of useful information a driver retrieved from the visual scene (Lappi, 2014; Lemonnier et al., 2015). It was observed that attention to roadside features and pedestrians were significant focal points for experienced drivers' attention. In contrast, novice drivers devoted their visual attention less strategically and not to areas where a potential hazard may emerge. This finding does not mean that novice drivers neglected hazard-rich regions entirely. Rather, novice drivers looked to where hazards were already readily apparent, whereas experienced drivers looked to where hazards were anticipated to appear, even if they did not materialise (Underwood, 2007; Crundall, Underwood, & Chapman, 2013; Konstantopolous, 2010).

Improving Hazard Perception Modifies Speed Choice Behaviour

Another significant finding was that following road commentary, drivers whose hazard perception improved made slower speed choices. Although these findings are based on a small sample of participants, the findings provided reasonable evidence that drivers who received commentary training not only improved in their hazard perception but also selected slower speeds. This finding could be interpreted as reinforcing the findings made by McKenna, Horswill, and Alexander (2006), who noted that drivers who underwent anticipation-based training also selected slower speeds under traffic scenarios that contained hazards. More generally, this finding has some profound implications for road safety education, as training in hazard perception may assist drivers in making more appropriate speed choices. Furthermore, improving the perception of hazards may help to add credibility to road speed limits as drivers become aware of greater amounts of risk.

Risk Appraisal varies with Driving Experience

Although risk was not directly measured, the present study provides a strong indication that novice drivers were less sensitive to certain aspects present on the road and traffic situation, suggesting less awareness of risk. This was not only shown by novice drivers' choice of faster speeds across different road conditions and types compared to experienced drivers but was also confirmed through evaluation of novice drivers limited visual search behaviour (G. Underwood et al., 2002). Novice drivers selected faster speeds on more risky roads, whereas experienced drivers selected more appropriate speeds and searched the road for hazards (Underwood, 2007; Crundall, Underwood, & Chapman, 2013; Konstantopolous, 2010).

It is well known that different road characteristics influence drivers speed choice, and while these generally are not regarded as 'hazards', they certainly fall within the definition as features of the road and traffic environment that increase the danger of which the driver must be mindful (Mills et al., 1996). Examining these risk factors may be valuable in assessing a driver's ability to manage dangerous traffic situations. These are important considerations for future research devoted to understanding how these factors influence drivers' speed and their place in driver education.

Road Markings Influence Drivers' Visual Search Behaviour

The present study provides additional evidence with respect to the influence that specific road markings have on drivers' visual search behaviour, beyond merely influencing their speed choices. Drivers appeared to focus their visual attention within the confines of the lane markings, and this effect was particularly evident for novice drivers. This finding supports previous research showing that fixed road characteristics can influence drivers' perception of risk and consequent speed choice (Elliott et al., 2003). Based on this observation, it is important to consider that road markings play an influential role in how drivers approach the road and traffic situation (Davidse et al., 2004; Mourant & Rockwell, 1972) and how this may affect their driving behaviour.

Road-markings seem to be an essential feature in traffic safety (Charlton & Baas, 2006) and this finding has several significant implications for how roads are designed and the use of markings to influence drivers behaviour which will be discussed later. However, the current findings suggest that lane markings can create an unrealistic sense of ease for drivers who neglect important cues that occur on the sides of the road and events happening in the distance that may evolve into hazardous situations. Novice drivers, in particular, may fail to notice these factors and adjust driving behaviour, which may potentially lead to a crash (Chapman et al., 2002; Konstantopoulos et al., 2010; McKnight & McKnight, 2000).

Significance of the Findings and Research Contribution

Validation and Usefulness of Video-Based Techniques

This thesis demonstrated that video-based approaches are a reliable experimental methodology in an age where, increasingly, research is conducted in vehicle simulators that employ computer-generated scenarios. Video has several advantages over simulators in that video can be easily recorded across a diverse range of different conditions with relative ease. Furthermore, video is cost-effective and versatile compared to more advanced simulators that rely on less realistic computer-rendered scenarios and are generally geographically fixed to laboratories. This study has provided support for the validated video-based methodology developed by Horswill and McKenna (1999). It contributes a reliable research tool for measuring speed choice in a New Zealand context under different situations involving weather conditions and lane-markings. The combined task has been shown in this thesis to measure drivers' hazard perception ability reliably.

Another advantage is that video-based methods provide a useful tool for driver education. The use of a video-based commentary task in this thesis was found to enhance both novice and experienced drivers' hazard perception skills (M. Horswill et al., 2013; Isler et al., 2009). This finding has numerous practical applications in driver education and assessment, as video-based tools can be provided under a range of conditions, including classroom and online driver training (Isler & Cockerton, 2003).

Methodology is an Essential Consideration when examining Speed Choice and Hazard Perception

This thesis has established that it is essential to gather hazard perception and speed choice measures within the same setting. It was found that when hazard perception and speed choice data were acquired using separate tasks involving different road scenarios, the relationship between these two measures was the reverse to what was hypothesised. This could explain why there has been a lack of research findings on the important relationship between these two important driving skills (Elander et al., 1993; Wetton et al., 2011). It was found that when speed choice was measured immediately after participants were presented with hazards, their speed choice strongly related to perception times. This finding is significant in that it may be only when drivers are made aware of hazards at the same time and under the same conditions do speed choices reflect how drivers respond. This could explain why speed choice has been related to hazard perception following training (Isler, Starkey, Drew, et al., 2008; McKenna et al., 2006).

Implications for Road Safety

The findings of this thesis have several implications for road safety. As observed in this study, hazard perception can be trained with relative ease, and this is in agreement with previous research by M. Horswill et al. (2013) as well as Crundall et al. (2010) and Isler et al. (2009). This contrasts with speed choice, which is challenging to modify with training and is usually reliant on enforcement or perceptual countermeasures to manage. However, drivers can choose inappropriate speeds and still be driving legally under the speed limit, which exposes them to higher crash risk. Developing habitual behaviour on a limited range of roads does not allow drivers to accommodate the diversity of New Zealand road conditions. This has enormous implications for how driver education is conducted concerning speed in New Zealand.

Driver training needs to emphasise the importance of hazard perception for immediate hazards (as we examined in this thesis) and covert hazards that fall within the broader definition of aspects of the road that increase the danger to the driver. Speed Choice is related to a driver's ability to correctly appraise risk, described by Deery (1999) as the subjective experience of risk in potential traffic situations. This description of the ability to detect risk has considerable overlap with many definitions of Hazard Perception (e.g., Helman, 2009). This definition encompasses aspects of the traffic and road situation that can be easily overlooked, such as vehicles on the roadside, the influence of road condition, and markings.

As observed in the speed choice task, the impact of road marking on drivers visual behaviour can be quite pronounced. It seems visual search influences speed choice, with markings and roadside features being important features when making judgements, similar to the effect of road weather and lighting conditions. There are some essential applications here to the way that roads are designed. Design principles need to convey as much information as possible to the driver so that they automatically select an appropriate speed and steering behaviour for the roadway without depending on road signs or enforcement.

Limitations

The main limitation of this research is that risk was not directly measured. Perception of risk related to drivers' speed choice in the literature (Fuller, 2010) was the primary way drivers would be influenced by the perception of hazards. As noted, previous research has observed the presence (Renge, 1998) or absence (Wetton, et al., 2011) of a relationship between hazard perception and risk. While it is reasonable to assume that risk is a viable means by which speed choice connects to hazard perception, further research is required in demonstrating this presupposition. In the literature review, a case was made for the important connection between speed choice and risk, and how risk may be an important factor in the role hazard perception plays in drivers' behaviour. A significant limitation in this experiment was that risk was not directly measured. While it is possible to use speed choice as a proxy measure for risk, this is limited as it is not a direct measure of risk awareness or risk-taking proclivity.

While useful for clear on-road risks, the definition of immediate hazards may not fully acknowledge the importance of other road factors that fall under the broader definition of hazard being something that increases the risk for the driver. Although immediate hazards are a reasonable measure of drivers' ability, it was noted that other aspects to the road and traffic situation could influence speed choice, which could be considered as hazards that still discriminate between drivers with varying degrees of experience. Evidence for this was observed for experienced drivers who identified covert or potential hazards, and the potential role that foreshadowing has on speed choices should be considered in future research. As suggested, one such method would be to classify identifiable risks from an expert perspective and then determine what subtle elements are taken into account when participants make speed choices.

Due caution is always warranted in relying upon eye-tracking data, and results need to be interpreted with care. There is evidence suggesting that participants watching video have greater variability. This is not always representative of natural behaviour as video-based tasks do not require a driver to determine the lane position or direction of the vehicle. Determining where a driver focuses their visual search does not guarantee that the participant deliberately extracts information from the scene. However, as Crundall and Underwood (2011) note the link between what the eye is looking at and what the viewer is thinking about is still very robust.

Future Research

This thesis has addressed several critical areas in the field of road safety research. The findings of this thesis have several important implications for both the future of driver training and education and potential applications to current New Zealand transportation policy. With these real-world applications resting on findings from this laboratory-based thesis, it is essential that future research work to ensure their validity.

The finding of a relationship between speed choice and hazard perception is of central interest and deserves considerable further examination of this relationship needs to be conducted to both verify and learn more about this exciting finding. A natural progression of this work is to analyse how drivers hazard perception influence speed choices in the real world. While validating the results in a simulator would provide greater control across participants, and allow for the precise measurement of changes in speed when participants encounter hazards, moving this research to a real-world context seems to be a more advantageous approach when considering the practical applications to driver education. Therefore, the next step in extending this research into a more complex experimental setting is highly dependent on what outcomes we expect. A simulator would be beneficial in further understanding of the role of eye-movement behaviour in hazard perception and speed choice. However, given the decreasing cost of eye-tracking, there is great value in moving to naturalistic settings and exploring the potential for commentary-based training to reduce speed choice while enhancing hazard perception skills.

Further research needs to closely examine the links between hazard perception and risk, and how these factors interrelate and influence speed choice behaviour. While the role of risk in drivers speed choice is a well-studied subject, there is relatively sparse evidence to suggest that hazard perception relates to risk. This may in part be owing to the way that perception of risk is examined in the laboratory setting. Typically, researchers have asked drivers to rate risk on a Likert scale, or to adjust a lever to indicate increases and decreases in risk (e.g., such as the task pioneered by Watts & Quimby, 1979). While these methods are practical for evaluating risk at a conscious level, they may be insensitive to risk perception if drivers experience risk as a feeling or somatosensory response (Slovic et al., 2004). Evidence suggests that this may be the case, explaining why several studies have not found a relationship between risk and hazard perception ability.

Additionally, with road commentary as the means of improving hazard perception, there is the opportunity to study and potentially begin to explain why road commentary seems to work for some participants and not as well for others. Addressing the effectiveness of commentary as a driver education tool would be an essential avenue for research. However, given that it has shown the potential to improve hazard perception and speed choices within a laboratory context, commentary could provide a simple but effective tool in the New Zealand driver education toolbox.

The Potential Role of Emotional Wellbeing

While it is outside the scope of this thesis, there is evidence that the driver's state of mind has a considerable bearing on their ability to drive safely. As noted in a literature review, speed is often studied in relation to driver's attitudes, beliefs, and values, which are commonly associated with driving style. However, Isler and Newstead (2017) found that those individuals with higher emotional wellbeing have safer driving behaviour. This raises the intriguing possibility that poor emotional wellbeing may adversely affect driver hazard perception skill and their style of driving. Furthermore, young drivers may be more vulnerable to psychological effects on driving behaviour. A preliminary evaluation found that drivers' well-being might positively influence their hazard perception skills and subsequent speed choices. While these early findings are outside the scope of this thesis, there is potential for further analysis of the existing data along with future research into the moderating role of emotional well-being on driver performance and corresponding safety.

Implications for Practice

This thesis highlights the importance of making roads 'readable' by the driver and possessing credible speed limits. As noted, driving is an intensely visual process (Rogé et al., 2004), and hence conveying the most information to the driver in the least taxing means is vital in reducing crash rates. While there is a significant need to develop, improve, and maintain our current infrastructure, it remains essential to continue developing ways to improve drivers' hazard perception abilities. In New Zealand, novice drivers generally have poor hazard perception ability. Not all experienced drivers have optimal hazard perception skills either, and this should be a significant consideration that accompanies changes to roading. Drivers often rely on personal judgements and habitual speed behaviour, which reflects the awareness of the risk perceived in the traffic environment. Hence, training needs to be developed to provide clear and appropriate information related to speed choices. Moreover, drivers need to be educated to detect the situational risks that are often not considering in the traditional approach to hazard perception training.

Conclusion

In conclusion, this thesis revealed that hazard perception time, arguably the most crucial measure of driving skill, is associated with speed choice, and this relationship seems to be causal. This finding has implications for both driver training, as well as transport policy. More efficient visual search that accompanies rapid detection of hazards can be influenced by a range of road characteristics and the traffic situation; this needs to be considered when developing New Zealand road infrastructure. While appropriate speed is subject to the driver's perception and management of risk, this places further emphasis on drivers' ability to appraise the traffic situation correctly and roads being designed to convey information about appropriate speeds automatically to the driver.

In creating safer journeys, training hazard perception can reduce the number of preventable crashes and positively influence drivers' speed choices. Drivers' choice of more appropriate speed is of enormous benefit to decrease the road toll and reduce fuel consumption and emissions while smoothing out drivers' travelling speed in reducing traffic congestion. The fact that speed choices can be improved by training hazard perception is of great value in future road safety initiatives aimed at preventing speeding and could help decrease the number of crashes in New Zealand and globally.

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Appendices

Table of Appendices

Appendix 1: Ethical Applications

This research was conducted in line with University of Waikato Ethical Guidelines concerning human testing (University of Waikato Handbook on Ethical Conduct in Research, 2009). Ethical applications for human testing was approved by the Psychology School Ethics Committee, with amendments or addendum submitted when required for adjustments in procedure or extension of data collection. Testing was authorized for a period of three years from the date of ethical approval.

Ethics application reference numbers were 2011:21, 2012:46, 2013:15, 2015:21, 2017:09, with amendments to 2011:21 approved in July 2015

Participants were briefed concerning their rights as participants under the department ethical guidelines and were informed about the nature of the experiment with an opportunity to enquire regarding the research. Participants gave written consent before undergoing testing. Participants enrolled in first-year psychology papers were given course credit for their involvement towards their final grade. Participants were presented with a $10 MTA voucher in appreciation for their involvement.

Participants who requested a summary were emailed a breakdown of research findings, and were given the opportunity to obtain a complete copy of this report from the Faculty Thesis Library and online Research Commons.

Appendix 2: Information Sheets and Participant Information

The following are the information sheets that participants were provided accompanying ethical approval forms. Instructions given to participants is described in the General Method.

Standard Ethical Information for Participants

What will happen to my information?

All information received from you will remain strictly confidential, and will not be made available to anyone in a way that will identify you. Your information will be immediately stored on a computer using an anonymous identification number, so even the researchers will not be able to connect your data with your identity. After data collection from all participants, the analysis of the data and an electronic summary will be emailed to participants would like to see the findings.

What can I expect from the researchers?

If you decide to participate in this project, the researchers will respect your right to:

- Ask any questions of the researchers about the study at any time during participation;
- Decline to answer any particular questions or carry out any of the tasks;
- Withdraw from the study at any stage and request your data be excluded or destroyed;
- Provide information on the understanding that it is completely confidential to the researchers. All forms are identified by a code number, and are only seen by the researchers. It will not be possible to identify you in any articles produced from the study;
- Be provided with an electronic summary of the findings if you would like;
- Be kept aware of future publications, newspaper or journal articles related to our research.

Who can I speak with about my participation in this project?

If you, or anyone you know is interested in taking part in this research please contact either:

Steve Cantwell (scant@waikato.ac.nz)

Dr Robert Isler (r.isler@waikato.ac.nz

This research has been approved by the School of Psychology Research and Ethics committee. If you have any concerns about the experiment, please contact the convenor: *NAME, EMAIL*

Experiment 1 Information Sheet

What is this study about?

You are being invited to participate in a research project that examines the way age and experience influence driver behaviour. I am primarily focused on the way drivers perceive the road and choose appropriate speeds for road conditions.

This research will be conducted at the University of Waikato, and it is hoped that the findings from this experiment will lead to future crash interventions and improvements to driver training which will be of benefit to all New Zealand road users.

Am I eligible to take part?

You are eligible to take part in this study if you hold a New Zealand learner, restricted or full drivers licence and are 16 years or older.

What am I being asked to do?

If you agree to take part in this study, it will involve one session of approximately 60 minutes. There will be a tasks involving viewing filmed roads on a computer monitor, then selecting your preferred speed for each road using a computer. This will be followed by online questionnaires related to your personal driving behaviour and demographic information (age, gender, etc.). The computer based task will involve a special eye-tracking camera that records where you are looking, and uses a chin rest so that you are sitting in consistent position throughout the experiment. We will endeavour to ensure your comfort throughout the entire experiment, and you a free to pause or discontinue the experiment at any stage.

To show our appreciation for your involvement in this research, you will receive either 2% course credit (if you are enrolled as a first year psychology student, the experiment will be a useful learning experience) or a $10 voucher.

Experiment 2 Information Sheet

DRIVERGE
UoW YOUNG DRIVER SPEED SAFETY RESEARCH GROUP

What is this study about?

You are being invited to participate in a research project that examines the way the factors age and experience influences driver behaviour. We are primarily focused on the way drivers perceive hazards on the road; choose appropriate speeds, and how this relates to attitudes and beliefs about road usage.

This research will extend the findings of the DRIVERGE research project, and is being conducted in the *Applied Cognitive Psychology* lab at the University of Waikato. We believe that the findings from this research will greatly benefit all New Zealanders, and lead to future crash interventions and improved driver training.

Am I eligible to take part?

You are eligible to take part in this study if you hold a New Zealand learner, restricted or full drivers licence and are 15 years or older.

What am I being asked to do?

If you agree to take part in this study, it will involve one session of approximately 60-90 minutes. The experiment involves a number of computer-based tasks related to hazard perception and speed selection, carried out in the Applied Cognitive Psychology laboratory (I-block) on the Hamilton Campus. You will also be asked to complete several questionnaires related to your personal driving behaviour and demographic information (age, gender, etc.) If you are interested in participating, please email us, and a researcher will arrange a suitable time with you to take part in the study. You may need to provide your own transport to the University of Waikato. To show our appreciation for your involvement in this research, you will receive either 2% course credit (if you are enrolled as a first year psychology student, the experiment will be a useful learning experience) or a $10 MTA fuel voucher.

Experiment 3 Information Sheet

What is this study about?

You are being invited to participate in a research project that examines the way the factors such as age, experience, and emotional wellbeing influence driver behaviour. We are primarily focused on the way drivers perceive hazards on the road; choose appropriate speeds, and how this relates to attitudes and beliefs and emotional wellbeing.

This research will be conducted by Steve Cantwell from the University of Waikato under the supervision of Assoc. Prof Robert Isler and Dr. Nicola Starkey, and it is hoped that the findings from this research will greatly benefit all New Zealanders, and hopefully lead to future crash interventions and improvements to driver training.

Am I eligible to take part?

You are eligible to take part in this study if you hold a New Zealand learner, restricted or full drivers licence and are 15 years or older.

What am I being asked to do?

If you agree to take part in this study, it will involve one session of approximately 30-45 minutes. There will be a number of tasks involving hazard perception and speed selection carried using a computer, and also some questionnaires. There will also be several questionnaires related to your personal driving behaviour and demographic information (age, gender, etc.), as well as attitudes and beliefs surrounding driving, and measures of emotional wellbeing and mindfulness. For this, you will need to arrange transport to be at the University of Waikato to meet with a researcher at a pre-arranged time. To show our appreciation for your involvement in this research, you will receive either 2% course credit or a $5 voucher.

Experiment 3 Post-experiment Debrief

The purpose of this study is to investigate whether emotional well-being plays a role in the likelihood of crash involvement. Vehicle crashes take a huge toll on not only those involved directly, but also on the economy. One of the highest risk populations is young drivers aged under 25 years old. However, there is emerging interest in the role that personal mental well-being plays in vehicle crashes, as unhappy drivers have slower reaction times and are more likely to miss important visual cues (Zimasa, Jamson, & Benson, 2017). Poor hazard detection is a leading cause of crashes (McKenna, Horswill, & Alexander, 2006), so it is critical that we train drivers to scan the road more broadly with their eye's and detect hazards sooner (Underwood, Crundall, & Chapman, 2002). Research has shown that the frontal cortex of the brain is responsible for 'executive processes' such as working memory and attention as well as emotional regulation (Dahl & Spear, 2004), and this is related not only to personal well-being, but also safe driving practices (Isler, Starkey, Drew, & Sheppard, 2008). There may be good evidence that poor mental well-being is related to limited attention, which could lead to crash involvement (Fredrickson, 2001).

This study looks to investigate a range of different aspects of driver behaviour, namely a) the relationship between personal well-being (IV) and hazard detection (DV) performance, b) the relationship between hazard detection (IV) and speed choice behaviour (DV), and c) the differences in eye-movement behaviour (DV) between novice and experienced drivers (IV). Principally however, the key objective is to further explore the concept of whether happy drivers are safer drivers.

We expect to see that in keeping with Zimasa et. al., (2017) that drivers with more positive mental well-being have more effective hazard perception, and that they scan the road more broadly with their eyes (Zimasa et. al., (2017). Additionally, we expect that there is a relationship between hazard perception and speed choice, with faster detection of hazards related to slower speeds, and lastly, that novice drivers will scan less of the road than experienced drivers (Underwood, Crundall, & Chapman, 2002).

Thank you again for taking part in this study. We hope that you have learnt more about how driving research is conducted in a laboratory setting using eye-tracking technology to observe where visual attention is allocated, as well as the importance of both mental well-being and hazard detection in producing safer drivers. If you have any further comments or thoughts, feel free to contact Steve at sjc29@waikato.ac.nz

IV: Independent variable

DV: Dependant variable

Experiment 4 Study A Information Sheet

What is this study about?

You are being invited to participate in a research project that examines the way the factors age and experience influences driver behaviour. We are primarily focused on the way drivers perceive hazards on the road; choose appropriate speeds, and how this relates to attitudes and beliefs about road usage. Furthermore, we will be investigating the use of 'commentary training' as a means of improving drivers hazard detection.

This research will be conducted by Steve Cantwell from the University of Waikato under the supervision of Assoc. Prof Robert Isler and Dr. Nicola Starkey, and it is hoped that the findings from this research will greatly benefit all New Zealanders, and hopefully lead to future crash interventions and improvements to driver training.

Am I eligible to take part?

You are eligible to take part in this study if you hold a New Zealand learner, restricted or full drivers licence and are 15 years or older.

What am I being asked to do?

If you agree to take part in this study, it will involve one session of approximately 30-45 minutes. There will be a number of tasks involving hazard perception and speed selection carried using a computer, and also some questionnaires. There will also be several questionnaires related to your personal driving behaviour and demographic information (age, gender, etc.) For this, you will need to arrange transport to be at the University of Waikato to meet with a researcher at a pre-arranged time. To show our appreciation for your involvement in this research, you will receive either 2% course credit or a $5 voucher.

What is Road Commentary?

Road commentary is a training intervention that involves participants verbally identifying real or potential hazards that occur while driving (or viewing footage of driving). For this task, participants are asked provide a running verbal commentary about any hazards they perceived including potential as well as immediate hazards. A potential hazard is defined as a hazard that may develop to an immediate hazard over time.

Experiment 4 Study B Information Sheet

Experiment 4B was an extension of Experiment 3, and involved the information sheet used in that experiment, along with the description of Commentary Training found on the Experiment 4 Information Sheet. The following email was sent to participants who indicated in a questionnaire that they were interested in returning to complete the experiment a second time following training. These participants were not provided the post-experimental debrief information from Experiment 3.

Dear *Participant*,

Thank you for expressing your interest in taking part in the continuation of the research that you participated in involving hazard detection and speed choice. I wanted to get in contact and extend the invitation for you to participate in the follow-up study that will examine how driving behaviour is affected by watching filmed traffic scenes. The filmed scenes will take approximately 20 minutes to view, and you may be asked to comment on certain aspects of the films.

The experiment is identical to the experiment you participated in beforehand and uses the same measures, including eye-tracking, and should take about the same amount of time to complete, with the addition of the time needed to view the videos. This study will continue to advance our knowledge into the use of video as a tool in driver education.

If you are interested in participating, feel free to email or call, and we can arrange a time that suits your schedule. I look forward to hearing from you, and thank you again for your prior participation.

Kind regards,

Steve Cantwell

PS – For enrolled psychology students, course credit is not available for this semester. However, it is possible to add course credit to any psychology paper that you do next semester so long as they accept research participation credits.

Appendix 3: Additional Validity of the Speed Choice Task

As with Experiment 1, the speed choices for the urban and rural road types and conditions were calculated, shown in Figure 1. As there appeared to be significant within and between-subject effects, inferential testing using repeated-measures ANOVAs explores the speed choices for all drivers related to the different road types and conditions (presented in Tables 32 and 33).

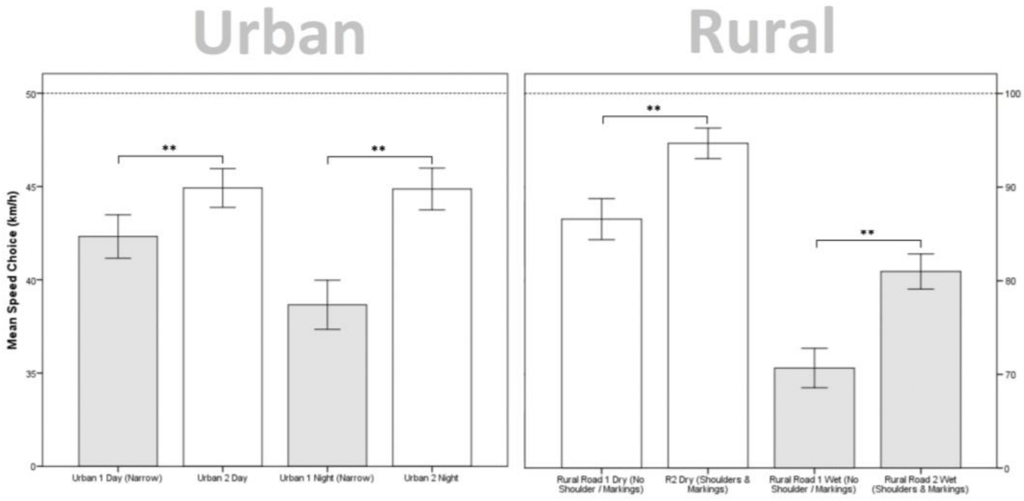

Figure 80: The mean overall speed choice for both Urban and Rural road scenarios. The graph legend displays the road condition for both road scenarios. Speed Limit indicated by the dotted line. Error bars represent 95% Confidence Intervals (CI). All between and within (shown) subject effects are significant with $p < 0.01$

What is immediately noteworthy is that the speed choices made in Experiment 2 were highly consistent with those made in Experiment 1 (refer to Table 31). Furthermore, the results demonstrated a similar difference in speed choices between road type and condition as found in experiment one, with drivers selecting faster speeds for day time (urban) and dry (rural) conditions (see Table 32), and selecting slower speeds on the more *'difficult'* roads (see Table 33), which was consistent with the measure of sensitivity found in Experiment 1.

Table 31:

Speed Choices from Experiment 1 (n = 48) compared with Experiment 2 (n = 136)

			Experiment 1			***Experiment 2***		
Environment	Type	Condition	M	SD	SE	M	SD	SE
Urban Roads	1	Day	40.0	7.844	1.206	42.3	6.125	0.587
	-	Night	37.6	8.222	1.286	38.6	6.609	0.666
	2	Day	44.1	12.100	1.890	44.9	6.856	0.525
	-	Night	43.9	6.630	1.028	44.8	7.775	0.566
Rural Roads	1	Dry	82.7	10.470	1.642	86.5	12.928	1.108
	-	Wet	68.2	10.421	1.652	70.6	12.417	1.064
	2	Dry	92.4	9.910	1.558	94.6	9.6357	0.826
	-	Wet	79.9	8.756	1.734	80.9	11.052	0.947

These figures are close to those reported by the Ministry of Transport (2019), the Rural Dry 2 speed measured is remarkably close to that of the MoT for Waikato drivers at 93.9km/h. The mean speed for Urban Roads by drivers in the Waikato was 50.5km/h.

The speed choices between the road conditions were found, indicating that driver preferred slower speeds under night driving for Urban Road 1 (narrow with no median) but not for Urban Road 2 (left-hand margin and median). Speed choice was slower for the wet condition on both of the Rural Roads 1 (without shoulders and marking) and 2 (with shoulders and markings) compared to the dry condition.

Table 32:

The difference in Speed Choice between Road Conditions (for each Road Type)

Environment	***Type***	***Condition***	***F-Value***	***Sig.***	***Part.*** η^2	***M***	***SE***
Urban Roads	1	Urban 1 Day	70.894	0.01	0.344	42.3	0.587
	-	Urban 1 Night	-	-	-	38.6	0.666
	2	Urban 2 Day	0.019	0.89	0.001	44.9	0.525
	-	Urban 2 Night	-	-	-	44.8	0.566
Rural Roads	1	Rural 1 Dry	505.90	0.01	.789	86.5	1.108
	-	Rural 1 Wet	-	-	-	70.6	1.064
	2	Rural 2 Dry	332.07	0.01	.711	94.6	0.826
	-	Rural 2 Wet	-	-	-	80.9	0.947

When road type (e.g., With shoulders and markings) was compared, as with Experiment 1 the speed choices were different between the two urban roads, and the two rural roads were consistent with Experiment 1. This indicated that the measure was sensitive in differentiating between the road characteristics that influence speed.

Table 33:

The difference in Speed Choice between Road Types (for each Condition)

Environment	***Type***	***Conditions***	***F-Value***	***Sig.***	η_p^2	***M***	***SE***
Urban Roads	1	Urban 1 Day	33.180	0.01	0.197	42.3	0.587
	-	Urban 2 Day	-	-	-	44.9	0.525
	2	Urban 1 Night	161.216	0.01	0.544	38.6	0.666
	-	Urban 2 Night	-	-	-	44.8	0.566
Rural Roads	1	Rural 1 Dry	93.778	0.01	0.409	86.5	1.108
	-	Rural 2 Dry	-	-	-	94.6	0.826
	2	Rural 1 Wet	239.75	0.01	0.639	70.6	1.064
	-	Rural 2 Wet	-	-	-	80.9	0.947

Comparing Speed between Novice and Experienced Drivers

Consistent with the approach used in Experiment 1, the speed choices were first examined between the two age/experience groups. As there was a substantial difference in age between driver groups, this served as a useful distinction between the amount of driving experience of 'novice and 'experienced' drivers before examining drivers age and experience in more detail. The speed choices of both groups are shown in Figure 81:

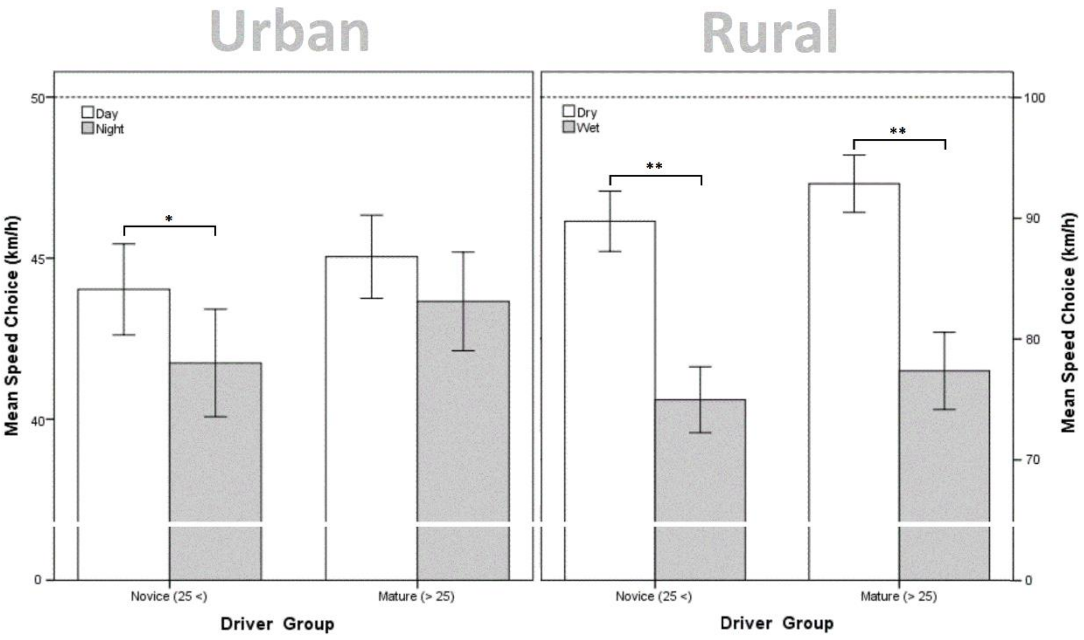

Figure 81*:* The Mean Overall Speed Choice for both Urban and Rural Road Scenarios, by Driver Group. The graph legend displays the road condition for both road scenarios. Speed Limit indicated by the dotted line. Error bars represent 95% Confidence Intervals (CI). Significance values are indicated, $p < 0.05$ *, and $p < 0.01$ **

Visual inspection of Figure 81 indicates that there are differences between road conditions for both driver groups, with drivers selecting slower speeds under the night condition compared to the day on urban roads, and wet compared to dry condition on rural roads. There also appear to be differences between driver groups in the speed choice for the urban night, and both the rural road conditions. What is noteworthy is that the experienced driver group tends to select faster speeds compared to novice drivers, in contrast to the previous experiment (Exp. 1).

A two-way mixed repeat-measures ANOVA was performed for both Urban and Rural Road Environments, 2(Driver group) X 2(Gender) X 2(Condition) showed that there was a significant effect between the speed choices for driver age groups, Wilks Λ= 0.856, $F_{(6, 128)}$= 2.077, $p< 0.05$, η_p^2= 0.144, though no significant effect between gender, Wilks Λ= 0.916, $F_{(6, 128)}$= 1.124, p= 0.350, η_p^2= 0.084. There was no interaction between age and gender, Wilks Λ= 0.919, $F_{(6, 128)}$= 1.078, p= 0.384, η_p^2= 0.081.

Between-subject effects revealed significant differences between the speed choices of novice (M= 40km/h, SD= 6.15) and experienced drivers (M= 43km/h, SD= 5.18) for the urban night road condition, $F_{(1,134)}$= 5.032, $p< 0.05$, η_p^2= 0.037, and rural dry road condition, $F_{(1,134)}$= 4.646, $p< 0.05$, η_p^2= 0.034, with, experienced drivers selected slightly faster (M= 93km/h, SD=8.2) speeds than novice drivers (M= 89km/h, SD= 11.1). Planned within-subject contrasts revealed a significant difference between day and night condition for novice drivers, t(68)= 4.515, $p< 0.01$, and for dry and wet conditions, t(68)= 16.502, $p< .01$. Planned contrasts revealed significant differences between night and day speed choices for experienced drivers, t(48)= 2.915, $p< 0.01$, and wet and dry rural conditions, t(48)= 13.889, $p< 0.01$.

The mean speeds for each of the five driver groups were calculated and is shown in Table 34:

Table 34:

The Speed Choices for each Urban Road Condition and Type for the Five Driver Age/Experience Groups.

			Driver Group				
Environment	***Road Type***	***Condition***	***Novice Learner***	***Novice Restricted***	***Novice Full***	***Full <25***	***Full >50***
Urban Roads	1	Urban 1 Day	40.1 (8.17)	43.6 (4.72)	41.5 (8.99)	42.4 (5.59)	44.4 (4.75)
	-	Urban 1 Night	35.4 (7.37)	38.3 (7.41)	38.4 (8.87)	40.4 (6.31)	41.4 (7.64)
	2	Urban 2 Day	43.5 (7.69)	44.1 (4.87)	45.1 (7.12)	46.1 (5.47)	46.1 (4.56)
	-	Urban 2 Night	43.5 (7.63)	43.7 (5.96)	45.5 (8.25)	45.5 (5.05)	46.3 (5.04)
Average	1&2	Urban Day	41.8 (7.47)	43.8 (4.01)	43.3 (7.38)	44.24 (5.16)	45.2 (4.32)
	-	Urban Night	39.5 (6.95)	40.9 (5.93)	41.9 (8.16)	42.9 (4.78)	43.8 (6.06)

Table 35:

The Speed Choices for each Rural Road Condition and Type for the Five Driver Age/Experience Groups.

			Driver Group				
Environment	***Road Type***	***Condition***	***Novice Learner***	***Novice Restricted***	***Novice Full***	***Full <25***	***Full >50***
Rural Roads	1	Rural 1 Dry	76.5 (14.68)	87.5 (13.03)	88.9 (9.86)	93.2 (9.27)	87.6 (11.28)
	-	Rural 1 Wet	63.4 (13.99)	71.7 (11.48)	71.7 (10.28)	75.7 (10.58)	71.6 (12.91)
	2	Rural 2 Dry	88.3 (12.72)	96.7 (9.59)	96.9 (6.98)	97.6 (5.48)	93.9 (8.79)
	-	Rural 2 Wet	75.5 (13.38)	81.7 (11.07)	83.7 (7.98)	84.8 (9.33)	79.4 (10.98)
Average	1&2	Rural Dry	82.4 (12.17)	92.1 (10.25)	92.9 (7.67)	95.4 (6.66)	90.7 (9.13)
	-	Rural Wet	69.4 (12.77)	76.7 (10.64)	77.7 (8.39)	80.3 (9.36)	75.5 (11.61)

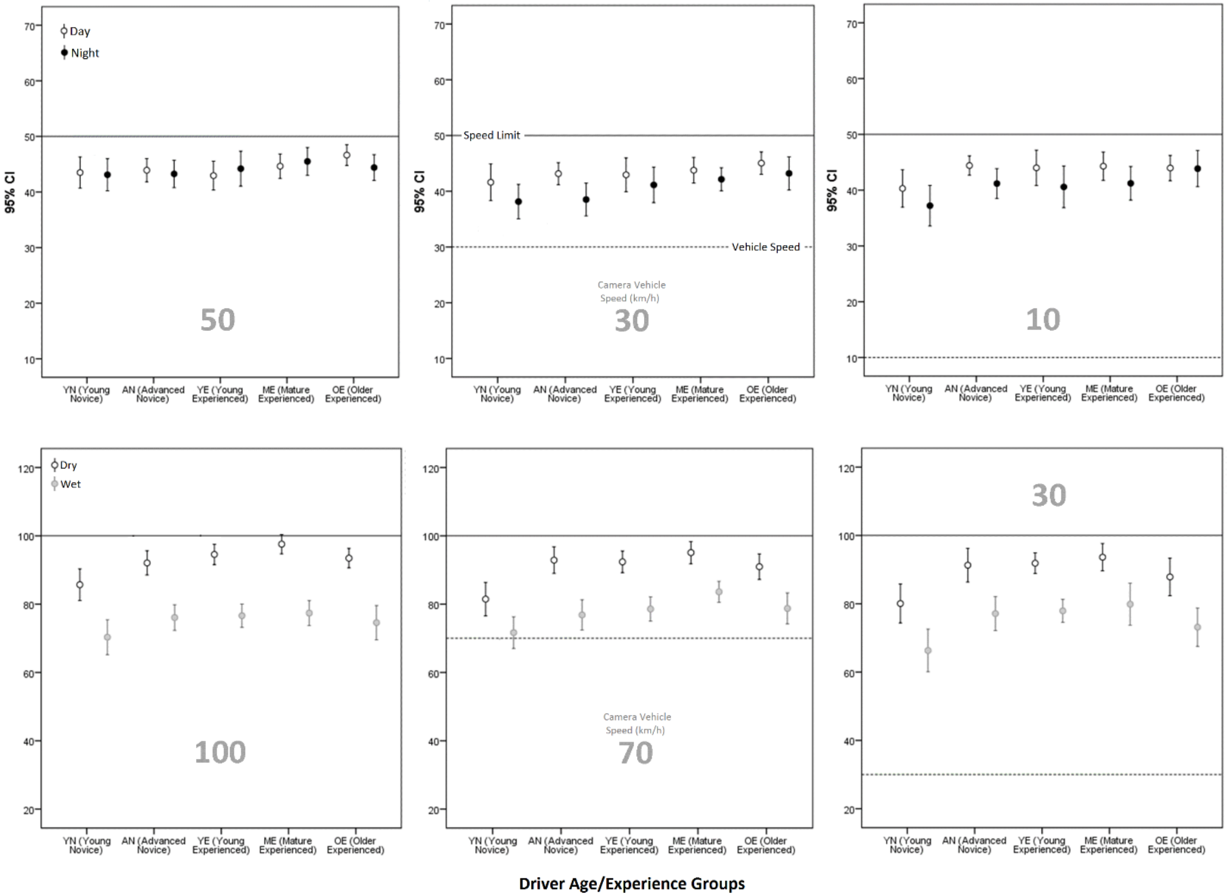

Figure 82: Comparison between different camera vehicle speed conditions for both Urban and Rural road environments for each of the driver groups, shown in relation to the different vehicle speeds. The top frames show day and night speed choices on Urban Roads, and the bottom frames show dry and wet speed choices for Rural Roads

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The differences between speed choices made by the five driver groups can be seen in Figure 82. From initial inspection, speed preferences are consistent across the three different camera vehicle speeds for each road environment – suggesting that the speed at which the camera vehicle was travelling had little influence on the speed at which drivers preferred for either environment. Generally speaking, drivers were more conservative in the speed preference in either night and wet conditions compared to day and dry conditions, with the latter being the more favourable condition for higher speeds.

Appendix 4: Validating Experiment 2 Hazard Perception Times using the eDrive™ Data Set

One crucial question that remains is whether there is ecological or external validity regarding hazard perception times in this experiment. Other research into hazard perception often presented perception times within 1-2 seconds (e.g., Crundall et al., 2012) with few studies presenting hazard perception times greater than 4 seconds. Across all eight hazard perception trials, the average hazard perception time within this thesis sample (N = 19) was 3.12 seconds (SD = .499) with a range of between Min = 2.13 and Max = 4.07. In order to validate the hazard perception times within this study, there is a considerable set of external data available from the eDrives program (Isler & Cockerton, 2003; Isler & Isler, 2011), which has used the same video clips as this study.

It is, therefore, possible to compare the pre-training hazard perception times from the eDrive sample (n = 6800) to determine whether the response times in this research have similar statistical properties. An analysis was conducted to determine whether the distribution and mean hazard perception times and the number of hazards perceived were similar to those found in this experiment. Firstly, the eDrive data was mapped to correspond to each immediate hazard (40 hazards across eight video scenarios), and the descriptive statistics were calculated, and this is shown in Figure 83.

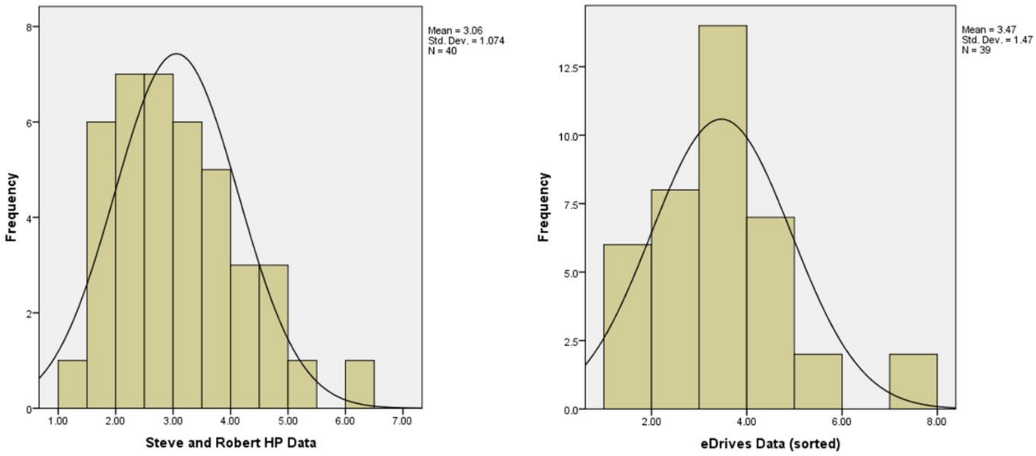

Figure 83: The distribution of Hazard Perception times for both the Hazard Perception tasks used in this thesis and those taken from the eDrive™ driver education program from 2016 data

For the current experiment, the mean hazard perception time was 3.06 seconds (SD = 1.07), and the external data from eDrives the mean hazard perception time was 3.47 seconds (SD = 1.47). Given that the internal and external mean hazard perception times are similar and have similar distributions, there is reasonable confidence that the hazard perception times for this experiment are reflective of those of the general population, and that the way hazard windows are measured is the reason for the enlarged hazard perception times in relation to other research.

Appendix 5: Difference between Driver Experience Groups (Discounting Age)

As there were a number of learner and restricted-licence drivers who were over the age of 25 years, groups were created based on how much driving experience and the licence type held. Inexperienced drivers were those drivers who held a learner or restricted licence. Experienced drivers were those drivers who held a Full licence and had been driving for at least 2 years.

If several reasonable assumptions are made regarding group allocation: (a) that a driver who has 6-9 months of total driving experience is essentially a learner even if they had just recently received their Restricted licence in the past (which was inconsistent reporting unless they had just received their license before the law change); and (b) that drivers over 25 who have been driving 5 years or over, egardless of license, are equivalent to Full licence, then the between-group difference becomes significant, with the main effect $F_{(3,85)} = 5.745$, $p < 0.05$, $\eta_p^2 = 0.174$.

The finding would seem to contradict the 2nd experiment, which showed that Novice Learner drivers were the slowest group, not that fastest. However, in Experiment 2, the Novice Learner (NL) group were recruited from Highschool students, with an average age of 16.5 years (SD= 2.09) with an average of 6 months driving experience. In Experiment 3, we used convenience sampling from University students, which means that these ‘novice learner’ drivers in Experiment 3 have an average age of 19.7 years (SD= 1.78) with an average driving experience of 2.5 years (SD= 1.65), four times the reported near-misses, and twice the distance driven per week compared to Exp. 2.

Using data from Exp. 3, drivers’ speed choices were plotted in relation to hazard perception times in a scatterplot, and this is shown in Figure 84:

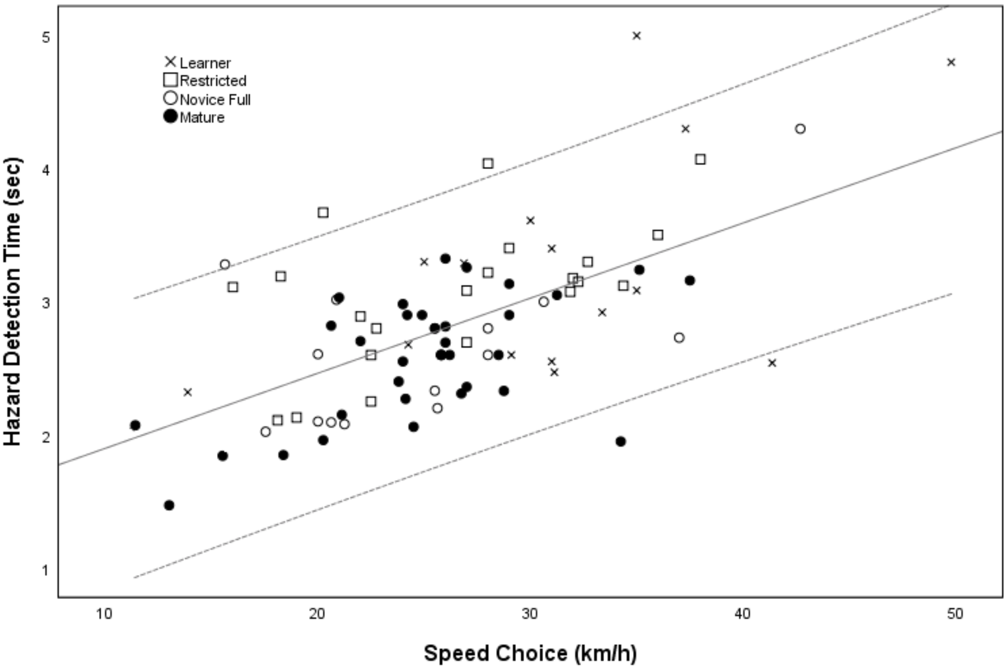

Figure 84: The relationship between Hazard Perception Time and Mean Speed Choice. The hollow circle represents the inexperienced driver group, and the solid circle (grey in box plot) represents the experienced driver group. The continuous line represents the linear regression line, and the dotted line represents 95% CI. Box-plots are also included to show the distribution of Hazard perception time (vertical axis) and Speed Choice (horizontal axis).

Figure 84 shows that Learner and Restricted licence drivers had longer hazard perception times, and generally chose faster speeds than the older and more experienced driver groups. Furthermore, when analysis was conducted based upon driver age and experience based on several assumptions, there were differences in age and experience groups for Number of Hazards Perceived, $F_{(3,82)}$= 10.371, $p < 0.01$, η_p^2= 0.275., and Hazard Perception times, $F_{(3,82)}$= 7.494, $p < 0.01$, η_p^2= 0.215.

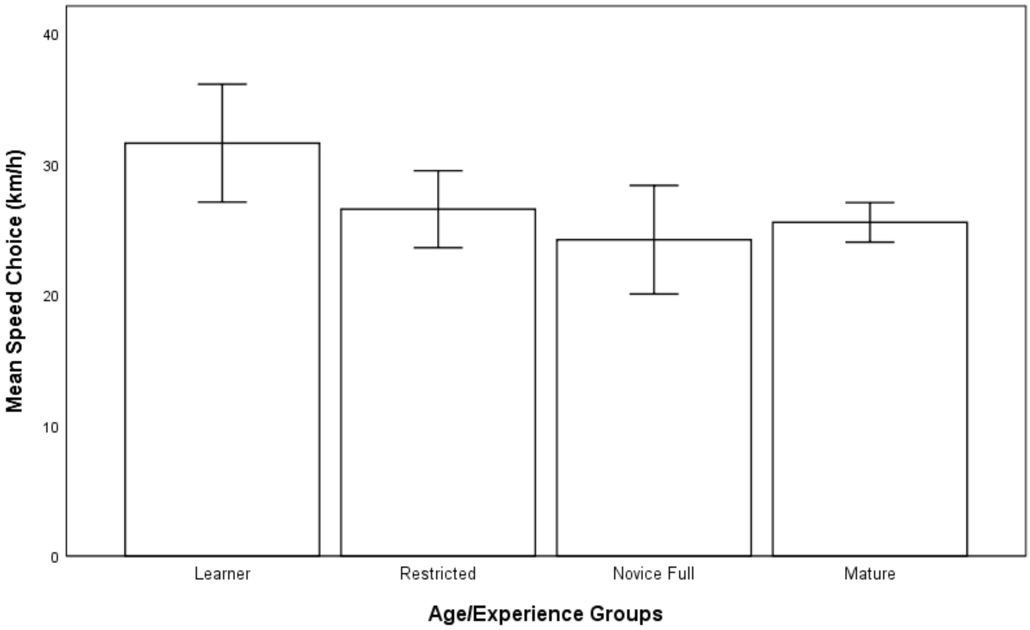

Figure 85: The Speed Choices (km/h) made by the four-driver age/experience groups in Experiment 3

A one-way ANOVA was conducted to examine the differences observed in the speed choices between driver groups. Significant main effects were observed between driver groups for the speed choice $F_{(3,82)} = 3.957$, $p < 0.01$, $\eta_p^2 = 0.174$. Bonferroni corrected post-hoc pairwise differences between driver groups are presented in Table 35 (Speed Choice), Table 36 (Number of Perceived Hazards), and Table 37 (Hazard Perception time):

Table 36:

Pairwise comparisons in Speed Choice by Driver Age/Experience Group

				Driver Groups		
Group	***n***	***Mean***	***SD***	***Novice Learner***	***Novice Restricted***	***Novice Full***
Novice Learner	16	32.44	6.455	-		
Novice Restricted	20	26.39	6.920	0.10	-	
Novice Full	13	24.54	8.346	0.05*	0.95	-
Experienced Full	37	25.55	5.128	0.01**	0.91	0.99

Table 37:

Pairwise comparisons in Number of Hazards Perceived by Driver Age/Experience Group

					Driver Groups		
Group		***n***	***Mean***	***SD***	***NL***	***NR***	***NF***
Novice Learner	NL	16	28.75	6.728	-		
Novice Restricted	NF	20	25.95	4.729	0.32	-	
Novice Full	NF	13	32.38	4.113	0.19	0.01**	-
Experienced Full	MF	37	32.94	4.142	0.05*	0.01**	0.98

Table 38:

Pairwise comparisons in Hazard Perception Time by Driver Age/Experience Group

					Driver Groups		
Group		***n***	***Mean***	***SD***	***NL***	***NR***	***NF***
Novice Learner	NL	16	28.75	6.728	-		
Novice Restricted	NF	20	25.95	4.729	0.64	-	
Novice Full	NF	13	32.38	4.113	0.05*	0.05*	-
Experienced Full	MF	37	32.94	4.142	0.01**	0.05*	0.95

Appendix 6: Young Driver Statistics

Research has shown that crash rates of the 15 ½ years old drivers are particularly high during the first month of restricted licensure, with about 8 times the risk of the supervised period and decline rapidly by about 50 % over the next 6 months (De Craen et al., 2007; Lewis-Evans & Lukkien, 2007). A newly qualified driver is significantly more at risk in a road traffic accident than the same driver ten years later (Underwood, 2007). Despite these objective data, New Zealand is the only jurisdiction in the OECD apart from the United States of America, that allow teenagers currently to get a restricted driver's license at 15 ½ years of age.

According to the literature concerning young driver behaviour and accident involvement, there are several approaches to understanding the young driver problem. One way is to analyze accidents and accidents distributions through in-depth accident investigations or comprehensive statistical analysis. Another approach is to analyze the psychological, social and educational processes which are related to or attributed to the development of a driver. Analysis of accident statistics has given some evidence that several and context- and individual-related factors may contribute to the high crash risk of young drivers. From the context-related perspective, relevant risk factors include night-time driving (Williams, 2006), low compliance with seat-belt laws (Williams, 2006), speeding (McKnight & McKnight, 2000) and distraction by frequent cell-phone use (Charlton, 2009; Foss et al., 2009) amongst others. Engström et al. (2003) mentioned single, loss-of-control and left-turn accidents where young drivers are over-represented, but also overtaking and negotiating bends can be found in literature as typical accident reasons for this group of drivers (RoSPA, 2002).

Other reasons for the high accident involvement are alcohol, sleepiness, non-usage of seat belts and badly adapted speed (as already mentioned above) (Engström et al., 2003).

As mentioned earlier, young novice drivers are worldwide at high risk of death or injury. Teen drivers (16-19 years old) have crash rates that exceed those of drivers of any other age group, with 16-years olds having the highest crash rates of all (Mayhew et al., 2003). In 2007, of the thirty countries that contributed to the OECD traffic crash database, New Zealand had the second-highest population-based crash fatality rate for the 15 – to 24-year old age group (OECD, 2006) . The Ministry of Transport provided recent statistics regarding young driver crashes. In 2008 young drivers (those aged 15-24) were involved in 124 fatal traffic crashes, 787 serious injury crashes and 3,800 minor injury crashes. Of these crashes, the 15 to 24-year-old drivers were at fault in 106 of the fatal crashes, 632 of the serious injury crashes and 2,915 of the minor injury crashes, resulting in 122 deaths, 808 serious injuries and 4,262 minor injuries.

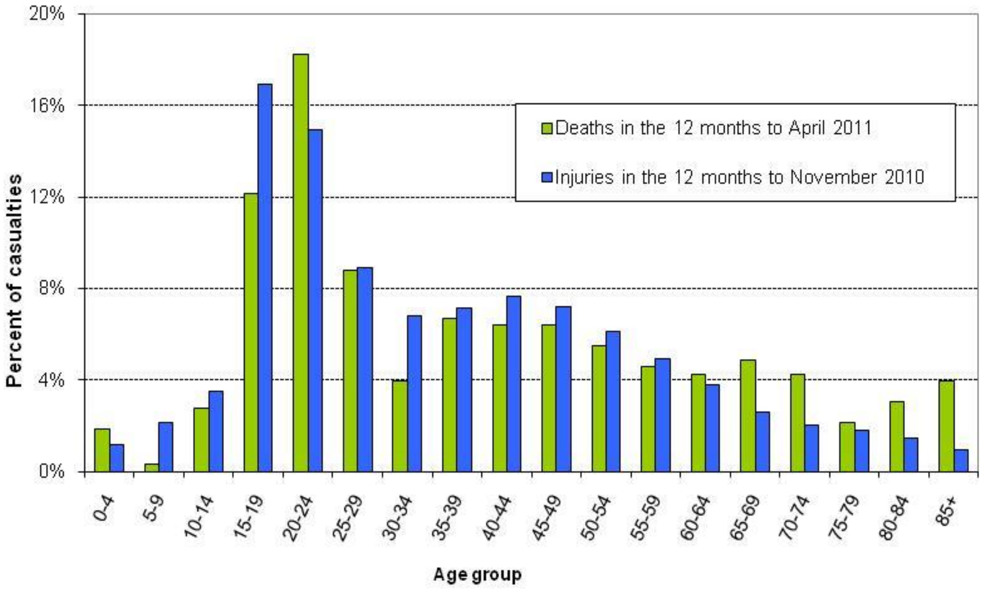

Figure 86: Ministry of Transport statistics of crash injuries and deaths by age group (Ministry of Transport, 2011)

The total social cost of the crashes in which 15 to 24-year-old drivers were at fault has been calculated at $1.1 billion, which equates to almost one-third of the social cost associated with all injury crashes. Male drivers in the 15 to 19-year-old age group are approximately eleven-and-a-half times more likely to crash (per 100 million kilometres driven) than male drivers in the lowest risk age group of 55 to 59 years. Female drivers aged 15 to 19 have a lower crash risk than males of the same age but are still nearly eight times more likely to crash (per 100 million kilometres driven) than female drivers in the lowest risk group of 55 to 59 years. Male and female drivers in the 20 to 24-year-old age group are approximately three to five times more likely to crash than the lowest risk of 55 to 59-year-old drivers of the same gender.

Recent figures show that 15 to 19-year-old drivers make up just seven percent of all licensed car drivers. Between 2006 and 2008, 15 to 19-year-old drivers accounted for 15 percent of all drivers involved in minor injury crashes, 16 percent of those in serious injury crashes, and 13 percent of drivers involved in fatal crashes. Similarly, 20 to 24-year-old drivers make up approximately nine percent of licensed car drivers but, between 2006 and 2008, they accounted for 14 percent of drivers involved in minor injury crashes, 15 percent of those in serious injury crashes, and 13 percent of drivers involved in fatal crashes. Of all young drivers (15 to 24 years old) involved in fatal crashes between 2006 and 2008, 73 percent were male. Males accounted for 71 percent of young drivers involved in serious injury crashes, and 64 percent of those involved in minor injury crashes over the same period. Alcohol, drugs, and speed are the major contributing factors for young drivers involved in fatal crashes.

Young drivers are more than two and half times as likely to have speed as a factor than drivers over the age of 25. Crashes that involve drivers losing control of their vehicles are a major feature in crashes involving young drivers. Thirty-nine percent of 15 to 24-year-old drivers involved in fatal crashes were in single-vehicle loss-of-control or run-off-road crashes, compared to twenty-one percent for older drivers. In addition, many head-on crashes also involve drivers losing control of their vehicles (Ministry of Transport, 2009).

Appendix 7: Does Knowing vs Estimating the Speed of the Vehicle influence Speed Choices?

One intriguing question that has been raised is whether knowledge of vehicle speed plays a role in the speeds drivers choose to travel. For instance, the implementation of speed indicating devices along the roadside has been somewhat effective in altering drivers speed choice temporarily, and it is also worth noting that knowledge of vehicle speed means a driver has a good concept of the how fast the vehicle is travelling which may influence their comfort and consequently cause them to reduce speed.

Cantwell et al. (2012) considered how estimated speed might relate to speed choice in a video-based task. These researchers suggested there could potentially be an unknown influence caused by drivers adjusting their ideal speed to compensate for an overestimation of the vehicle speed. Horswill and McKenna (1999) note that visual (e.g., 'speed adaptation effect' Denton, 1976) and audio cues can significantly influence the accuracy of speed perception, and potentially subsequent subjective feeling of risk. This question needs to be addressed in developing an ecologically valid laboratory-based instrument.

While this is a somewhat naïve approach to understanding the dynamic factors involved in speed choice, the general rule of drivers tending towards the 85 percentile as the safest general vehicle speed might play an important role. Another possibility is that drivers rarely inspect their speedometers while driving, and so knowing the actual vehicle speed without having to divert their eyes from the road could be helpful – and support the idea of augmented windshields that display the drivers' speed without them having to divert their attention from the road.

Does knowing vs estimating the current speed of the vehicle influence the speed choice?

The perception of speed may influence speed choice, though it is also possible that judgements, mainly rule-governed judgements, are made independent of perceived speed. In the context of the present experiment, the author has found that this vital question does not appear to have been answered in the road safety literature but emerges from previous research using video-based speed tasks. Nevertheless, drivers perception of vehicle speed has been well explored (Elliott et al., 2003), and there is some indication that the differences between perceived and ideal speed may influence drivers subsequent speed selection (Goldenbeld and Van Schagen, 2007), though no concrete hypothesis can be drawn at this stage.

The effects of Vehicle Speed Awareness on Speed Choice

One of the questions raised in previous research was whether awareness of camera vehicle speed affected participants' speed choice. The experiment was designed so that one group of participants would be aware of the camera vehicle speed - as indicated on the speedometer - when making their speed choice. The other group would be unaware of the speed, and would be required to estimate the vehicle speed before making their speed choice.

The group estimating speed had 22 participants, while the group that was aware of the vehicle speed had 20 participants. Groups were gender-balanced, with the age of both groups approximately equal (Unaware: Age = 29.32, *SD*= 1.818; Aware: Age = 28.50, *SD*= 1.528). Self-rated skill did not significantly differ between these groups.

Figure 88 shows the speed choices of both awareness groups:

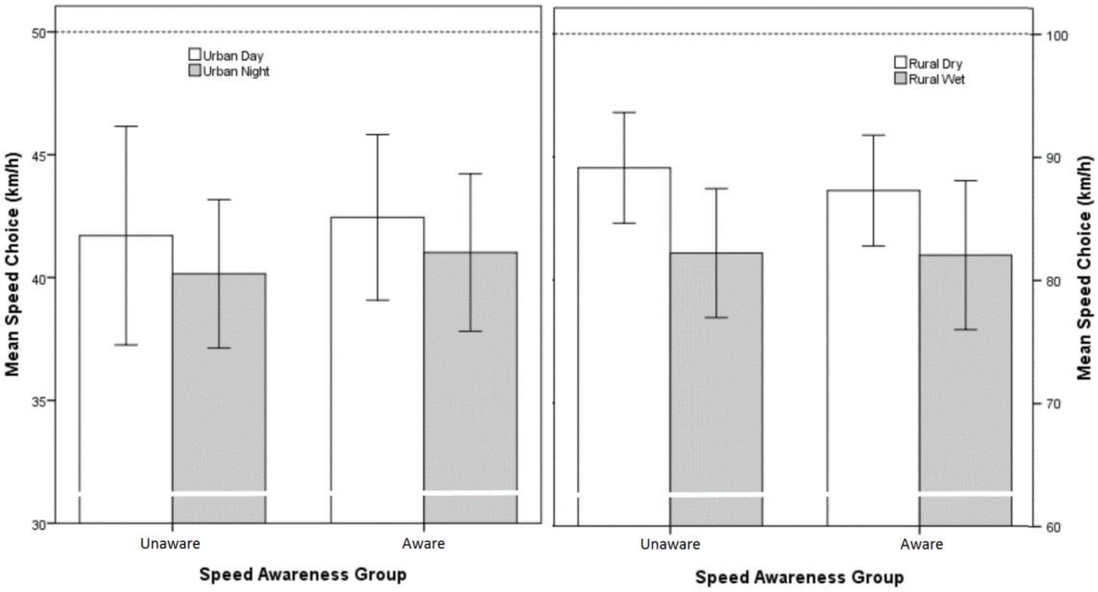

Figure 87: The mean speed choice for both Urban and Rural Road scenarios (when combined), grouped according to speed-knowledge groups. The graph legend displays the road condition for both road scenarios. Speed Limit indicated by the dotted line. Error bars represent a 95% CI.

Visual inspection of the figure revealed that there appeared to be little difference is speed choices made by those participants who were aware of the vehicle speed compared to those who were unaware. This finding was confirmed using inferential statistics, with no significant effect being found for either urban or rural condition. Further analysis did not reveal any significant gender or driver group effect.

A 2(Age Group) x 2(Awareness group) ANOVA did not determine a significant effect in speed choices. Both awareness groups made similar speed choices across the roads and conditions between groups, irrespective of whether participants were aware of the vehicle speed, with both groups making similar speed choices across the roads and conditions. The results from the inferential analysis for knowledge of vehicle speed for each road type and condition are shown in Table 38:

Table 39:

The results from the inferential analysis for knowledge of vehicle speed.

					Estimates		***Aware***	
Environment	***Road***	***F-Value***	***Sig.***	η_p^2	***M***	***SD***	***M***	***SD***
Urban Roads	U1 Day	0.478	0.494	0.013	42.1	6.25	43.5	7.62
	U1 Night	0.044	0.836	0.001	44.4	7.04	44.0	6.24
	U2 Day	0.653	0.424	0.017	39.4	7.51	41.3	8.02
	U2 Night	0.066	0.799	0.002	37.1	8.38	37.9	8.27
Rural Roads	R1 Dry	0.680	0.415	0.018	81.1	11.01	84.2	10.01
	R1 Wet	0.556	0.461	0.015	64.8	9.39	72.0	10.72
	R2 Dry	0.878	0.131	0.023	90.8	11.79	93.7	7.64
	R2 Wet	2.385	0.131	0.062	76.6	12.33	81.9	9.17

The inferential analyses comparing aware and unaware groups (Table 38) clearly show no difference in speed choices between road environment, types, or conditions. Additionally, among unaware participants, there was no significant difference in speed choice between driver age groups.

Similar means and confidence intervals were found in estimates speeds and speed choices made by Experienced drivers on several road conditions. Overall[35], Novice drivers estimated the vehicle to be travelling 33.7 km/h (*SD*= 5.74) on urban roads and 63.2 km/h (*SD*= 8.92) on rural roads, whereas Experienced drivers estimated the vehicle to be going at a greater speed on both urban 39.8 km/h (*SD*= 2.60) and rural roads 74.9 km/h (*SD*= 10.98). The actual average vehicle speed on urban roads was 30 km/h (the average of 10, 30, and 50), and on rural roads, the actual average vehicle speed was 66.6 km/h (the average of 30, 70, 100). In this respect, younger drivers were more accurate in their speed estimations.

Does knowing vs estimating the current speed of the vehicle influence the speed choice?

In this study, drivers' awareness of vehicle speed was compared to drivers who were unaware of vehicle speed. The awareness of vehicle speed was considered analogous to a drivers ability to check the speedometer before selecting an ideal speed to travel. The analysis clearly indicated that there was no significant difference in speed choice between drivers who were aware of the speed of the vehicle and drivers who were unaware and asked to estimate the vehicle's speed.

Furthermore, in this experiment, no perceptual effects were observed in relation to speed choice. This was unexpected, as Recarte and Nunes (1996) found that as vehicle speed increased, estimation error decreased. If drivers who were unaware were influenced by the lack of explicit knowledge of vehicle speed, some effect would likely be observed in error of estimation over the three filmed vehicle speeds for each road, however, no effect was observed in inferential testing.

Previous research conducted by Briziarelli and Allan (1989) found that drivers preferred speed was unaffected by participants being able to view a heads-up display of the vehicle speed compared to a traditional speedometer. Recarte and Nunes (2000) analysed the effect of driver distraction of speed choice and found that as mental load increased there was a reduction in speedometer inspection. However, if the drivers were not under high-speed control demands, their speed remained unaltered despite lack of speedometer inspection. This suggests that drivers utilize perceptual cues to regulate their speed, and are not dependant on explicit awareness of vehicle speed.

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[35] As the type and condition means and confidence intervals were sufficiently similar, estimates averaged into a single measure road each driver group.

Primate brains are devoted to perceiving motion to the extent that almost half of the cortex and subcortical structures are devoted to the processing of visual information (Luria, 2012)[36]. As driving is visually engaging, likely, the perception of speed is constantly being evaluated at a subconscious level. Hence, drivers are likely to be naturally estimating speeds when they are attending to the driving task, irrespective of frequent checking the speedometer. Therefore, it would appear that although drivers speed is influenced by cognitive load and various motivations (e.g., such as arriving on time), awareness of speed in the context of this experiment appears to have no effect.

On the whole, drivers tended to overestimate vehicle speed, whereas other research indicates that drivers are more likely to underestimate vehicle speed (Beardsley et al., 2011), albeit this is highly dependent on several aspects related to visual perception. For example, suppose drivers rely on fixed-point cues such as ‘cats-eyes’ (retro-reflectors mounted at the centre-line of the road). In that case, this may in part explain why drivers over-estimate the ‘time to passage’ and correspondingly imply a faster vehicle speed from this (Kim et al., 2017; Regan, 2002). What was curious is that novice drivers estimated speeds slightly slower than older experienced drivers, who are inclined to overestimate the vehicle's speed, and this is worthy of further study using a larger sample.

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[36] Luria published ‘The Higher Cortical Functions in Man’ in 1962. The 2012 republishing pays homage to the original masterpiece whilst including revisions by Luria (1980) and into the later part of his research career.

Appendix 8: Initial analysis of Experiment 1 Data

The repeated video scenarios showed that speed choice was highly consistent across trials ($r = 0.892$, $p < 0.01$), suggesting significant test-retest reliability as a measure of internal consistency. As there had been different vehicle speeds (e.g., 10, 30, and 50km/h for Urban roads, and 30, 70, 100km/h for Rural Roads), two ANOVA were performed 2(Type) X 2(Condition) X 3(Camera Speeds) were conducted to determine whether camera vehicle speed influenced participants speed choice. No significant main effects were found in relation to camera vehicle speed, with the results for rural roads $F_{(2,41)} = 0.880$, $p = 0.416$, $\eta_p^2 = 0.004$, and for urban roads $F_{(2,41)} = 0.794$, $p = 0.453$, $\eta_p^2 = 0.003$ and there were no significant interactions when gender, age group, and between drivers who were required to estimate versus drivers who were made aware of the vehicle speed. This indicated that there was no significant difference between the speed choices related to vehicle speed, which meant that an overall mean could be calculated from each of the three vehicle speeds.

The normality of all speed choice variables was assessed using Q-Q plots, histograms, and measures of skew and kurtosis. The distributions of participants speed choices for the Urban Day $D(23) = 0.210$, $p < 0.01$ and Rural Dry $D(23) = 0.227$, $p < 0.05$ conditions were significantly non-normal. A Box-Cox transformation was performed to reduce skew, and given the sample size was small, between-group effects were analysed using the Kolmogorov-Smirnov Z test, though the Mann-Whitney U test was also utilized, to reduce the likelihood of committing a Type-I error.

Outliers were defined as values that exceeded 1.5 times the interquartile range or are values outside two standard deviations from the mean. A single outlier that was evidence of unreasonable or erroneous behaviour (88 km/h) was excluded from the analysis of urban road data, where the speed limit is 50km/h. However, the outliers that range from 110 km/h to 60 km/h might represent normal behaviour on rural roads. An experienced driver chose the faster speed, and the four slower speeds belonged to novice drivers, who may be less confident and hence select slower speeds. After some consideration, these outliers were determined to be within the publicly accepted range of driving speeds for New Zealand motorists[37], as determined by the

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[37] This does not imply that these selected speeds are safe. An NZTA commissioned report found that motorists do travel these speeds on public roadways, and that the range of speeds observed in this experiment encompasses those observed in public driving. These findings are consistent with the Automobile Association of New Zealand (AANZ) commissioned report by Starkey, Charlton, and Malhotra (2017), and AANZ survey results from 2005-2007

New Zealand Transport Agency (NZTA) report by Turner, Bosher, Logan, Khoo, and Trumper (2014).

Appendix 9: Eye-tracking Overview and Techniques

Eye-tracking is a technique that measures changes in the relative position or movements of the eye(s) concerning stimuli presented in the visual field. Eye-trackers have been employed as research instruments across many disciplines for the last twenty years, and reduced costs and size have made eye-trackers a versatile and vital instrument for investigating human cognition and visual behaviour. In recent years, many researchers investigating the psychology of driving behaviour have employed eye-tracking techniques to identify how drivers interact with other road users and navigate roadside features.

When studying the cognition of driving behaviour, eye tracking provides several useful insights into the hidden visual processes that are otherwise unobservable. In this thesis, eye-tracking technology will be utilised to explore how drivers view and use visual information related to the driving task, particularly the perception of hazards.

Driving as a process can be considered a hierarchical process involving strategic, tactical, and operational levels (Dario D. Salvucci & Taatgen, 2011), so the perceptual, cognitive, and behavioural elements must be duly considered when undertaking a study of driving behaviour. Furthermore, driving involves navigating a complex and dynamic situation where rapid changes often occur. These changes place the demand on a driver to adjust their behaviour' to control for factors leading to a potential collision, which might fit the looser definition of an immediate hazard.

Within this loose definition, there is almost an endless number of on-road and off-road features that might be or become hazards that drivers must navigate safely. Immediate hazards are those things that demand an immediate response from drivers, whereas latent or potential hazards are those things that, while not being immediately hazardous, might become hazards as a potential series of possible events unfolds. For instance, a car braking immediately ahead presents as an immediate hazard, and pressure must be applied to the brakes to prevent a collision. Likewise, a child playing with a ball on the side of the road is a potential hazard that could quickly become an immediate hazard if that child should run out into traffic.

The following section will discuss the measures of visual behaviour used throughout this thesis; they are:

1. Number of fixations
2. Fixation location
3. Fixation duration
4. Saccadic amplitude (distance)
5. Number of saccades
6. Blink events
7. Pupil dilation

Corneal Reflection (CR) and Pupillary (PR) Eye-tracking

The cornea is a transparent protective protrusion of the eye, through which light flows into the eye, separating the external environment from the vitreous fluid of the eye's interior. Eye-tracking takes advantage of the entoptic reflection of infrared (IR) light off the cornea to determine where the eye is fixated. This method is known as corneal-reflection (CR), and is the preferred method of measurement, as it remains remarkably consistent over time, allowing the position of the eye to be accurately measured to a high degree of spatial and temporal acuity. In this thesis, the CR method is the primary means of collecting eye-movement data.

Pupillary Reflection (PR) like the CR methods, pupillary methods rely on the distance between reflected IR light and the centre of the pupil to determine where the eye is looking. While this method is preferable in some situations (e.g., when corrective lenses are worn), it is less accurate a method. In this thesis, PR methods were used when the conditions for CR methods are not suitable.

EyeLink™ 1000 (desk mounted) and EyeLink II (head mounted)

Two eye-trackers were utilised in this thesis, measuring such factors as the spread and number of fixations and the amplitude and pattern of saccadic movements. These measures can be used to infer what drivers are using to create a mental representation of the road environment.

The primary eye-tracker used in this thesis is the EyeLink II, a head mounted binocular eye-tracker, which allows the participant freedom of head movement while still recording eye movements with a high degree of accuracy. As it is head-mounted, participants have a greater degree of freedom to move; however, they were instructed to remain as still as possible throughout the experiments after being comfortably seated and the validation and calibration procedure is complete. The EyeLink II experiments were conducted using a Samsung high-resolution 48” display, with a Dell Optiplex 780 to record the eye-movement data, and a Dell Minitower (Intel i5, 2.8GHz, 4Gb RAM, 4Gb Graphics Card) running Windows 8-10.

Fixed eye-tracking equipment requires a participant to keep their head in a stationary position, often using a chin and forehead rest that keeps the participants’ eyes in a single position relative to the eye-tracker; this kind of eye-tracker affords exceptionally high degrees of spatial accuracy. The EyeLink 1000 is a desk mounted monocular eye-tracker which records at a very high temporal resolution and is used in conjunction with a chin-rest and consistent screen and computer setup. Experiments using the EyeLink 1000 were developed using the Experimental Builder (V1.4) from SR Research Ltd. and run using two Dell OptiPlex 760 Minitower desktop computers (3GHz processor, 4GB RAM) running Microsoft Windows 7. One computer deploys the experiment, and the other computer processes the eye-tracker information. The computer deploying the videos is equipped with a 2GB graphics card, and videos were shown using a ViewPIXX 22 inch LCD monitor with a resolution of 1920 x 1200 pixels.

Eye movements were recorded using the participant's dominant eye at a sampling rate of 500Hz for the EyeLink-II and 1000Hz for the EyeLink 1000. As the eye-scanner was fixed, this required participants to use a chin and forehead rest to maintain a constant position and distance relative to the eye-tracker lens(es). In order to ensure that the eye movements recorded were accurate, the eye-tracker was calibrated before each experiment. Calibration removes any potential setup effects and standardizes the experiment by correcting for differences that occur between participants.

Eye-tracking Calibration and Validation

In order to ensure that data collected by eye-tracker equipment is accurate, it must be calibrated for each participant. This procedure applies and is identical for both the EyeLink II and the EyeLink 1000 used in this thesis. For calibration, a matrix of 12-dots appeared one at a time at points about the screen (to map the edges and centre of the screen. Participants were instructed to focus on each point as they appeared. This procedure was conducted twice to enable validation to be conducted before the start of each experiment. Using a 9 point calibration grid with an error threshold of +-2 degrees was the threshold for proceeding with the experiment. The initial calibration procedure took approximately 20 seconds and was followed by validation, which followed the same sequential target dot display.

Where possible during the experiment, drift correction was conducted between each trial. Drift correction involved the appearance of a single dot located in the centre of the screen, which participants focused. The eye-tracker was able to use any variation to recalibrate if any drift was perceived. If the participant's head position shifted during the experiment, or participants altered position noticeably between trials during an experiment, a calibration and validation procedure was conducted to correct for any potential error.

Real-time superimposition of Eye-movement over task

Initial pilot research was conducted to determine the best calibration settings for the head-mounted eye-tracker to ensure the fidelity of recorded visual information. During this process, the initial results showed there was the potential for miscalibration to occur at either that initial setup or 'drift' in eye movements to progress through the experiment, especially throughout all trials. While post-hoc drift correction is a useful means of correcting minor measurement errors, it is limited in compensating for larger measurement error, which was observed with a head-mounted eye-tracker.

We determined that it would be beneficial to the experimental process and future experiments for the experimenter to observe in real-time the eye-movement behaviour of participants during the experiment. This would allow for correction to be performed between trials (i.e., re-calibration or drift-correction) and give the experimenter a unique view into how participants viewed the road and traffic situation and what details attracted participants attention.

The software was developed, which would accomplish this role by superimposing participants' eye movements over the video clips as they played and allowed for this real-time data to be recorded for later inspection. The eye-movement overlay was shown ‘live’ on a separate display visible to the experimenter but not to the participants. This was rendered on a Dell Minitower (Intel Core i5, 2GHz, 4GB RAM) running Microsoft Windows 8.1.

Measuring Saccades and Fixations

An essential measure of eye movements is the saccade. Saccades can be defined simply as rapid eye movement with direction and acceleration, typically varying in duration from 10ms to 100ms (Duchowski, 2003). The perceptual system uses saccades to direct the eye from one point of interest to another. Eye movement is controlled by the planned output of the frontal eye field located adjacent to the dorsolateral prefrontal cortex (DLPFC); however, it can also be triggered by the posterior eye field located in the visual cortex. The saccadic movement of the eye is characterised as ballistic, in the sense that once it is initiated, it cannot be altered. This ballistic motion is probably due to the rapid movements not providing enough feedback to the visual system to alter the saccade after it has started (Duchowski, 2003). During a saccade, the perceptual input from the scene is also possibly decreased. This phenomenon, which is due to blurring that occurs during saccadic movement, is called saccadic suppression (Rayner, 1998). Whether the perceived stimuli remain in visual memory or is completely unprocessed is not clear. Interestingly, Duchowski (2003) proposed that during saccadic suppression, the perceptual system might become blind. The momentary state of blindness seems to have been supported by complementary studies in monkey and human subjects that have used neural imaging and interpretation of related processing regions within the visual system (Pierrot-Deseilligny, Milea, & Muri, 2004).

Figure 88: Fixations are shown (top) as circles, the diameter of which represents their duration. Saccadic eye movements are shown (bottom) in orange, indicative of both the rapidly 'jumps' between fixations as well as the scan-path strategy used.

A fixation occurs when eye gaze is directed and is usually representative of processing. Fixation durations vary and are task-dependent. For example, the mean fixation duration on a reading task is 225ms while for scene perception, it is 330ms (Rayner, 1998). Duchowski (2003) has stated that during fixation, the eye is not entirely still but, as tremor drifts and micro-saccades occur. There is no an agreed minimum or maximum fixation duration throughout the literature, but Duchowski has claimed that fixation duration varies from 150ms to 600ms, although there are cases of fixations as short as 50ms appearing during reading (Rayner, 1998). During visual inspection, the eye's are fixated approximately 90% of the time. In this research, the default SR Research DataViewer settings were used to calculate fixations and filter out micro-saccadic and tremor noise. When alternative tools were used for analysis[38], the interval between saccades was determined to be a fixation. The distinguishing feature of a saccade from the background eye-movement noise was when the movement velocity exceeds the default threshold of 22 degrees per second (SR Research, 2014).

Fixation duration of 200ms is typical for perceiving hazard-related stimuli within a driving-related context (Velichkovsky et al., 2002; Pollatsek & Rayner, 1982). Fixation durations are highly task-related; their relative durations are influenced by the content and context of the information that a person is attempting to extract and process from the environment before a subsequent saccadic movement is triggered. As driving involves both salient components and knowledge (top-down) components, it is essential to consider that fixation duration may be strongly dependant on the type

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[38] The Python script that was used to generate fixation distributions using Kernal Density Estimation (KDE) relying on the fixation coordinates, with each coordinate corresponding to a fixed duration (250-500Hz), so the distributions are proportunate to both the length of the trial and the dwell time.

of information needed from the traffic environment. Longer durations approaching 600ms may be required to process complex traffic scenarios, whereas shorter fixations are more likely to relate to pre-attentive scanning for potential changes in the traffic situation that are controlled by a different schema. Kastner et al. (2009) provide a comprehensive overview of the cognitive neuroscience of selective visual attention, which I would recommend to the reader.

Fixations provide a means of determining where a driver has gained visual information about the road or internal vehicle instruments. The duration of these fixations is an essential measure of both the total time spent assessing the importance of features in the visual field to the driving task and the efficiency of a person's visual search strategies (Vlakveld, 2011). These measures can be used to differentiate between novice and experienced drivers effectively[39]as it is generally assumed that novice drivers require more sustained fixation time than experienced drivers to extract relevant driving-related information from the environment. Research also suggests that experienced drivers will make more saccadic movements across a broader area of the visual field and that the time between their saccades will be shorter, as they are more pre-attentive unless otherwise controlled by top-down knowledge governed schema.

While visually salient events cause most fixations, some cognitively salient processes such as knowledge governed processes are expected. These are likely to be closely related to hazard perception and situation awareness. Interpreting the difference between salience-driven eye movements and cognitively salient top-down eye movements is a complex task beyond this thesis's scope. It is anticipated that cognitively salient fixations of longer duration likely had a direct relationship with driving behaviour and that longer fixations on visually salient features were expected in novice drivers eye movements.

In this research, fixations that were shorter than an interval of 80ms were excluded, as these often preceded multiple short saccades and were considered corrective eye movements that were not related to the acquisition of visual information (Duchowski, 2004). Fixations with a greater duration than 140ms were considered to relate to sustained focal processing, potentially indicating where drivers' visual attention was orientated. This criterion was used to distinguish cognitive-process related fixations

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[39] Konstantopolis (2011) focused his thesis on the effeciancy of visual search and the importance of driver education and the development of training interventions.

from non-cognitive fixations (e.g., Crundall & Underwood, 1998). Additionally, to prevent blinks from interfering with data collection, fixations following blinks were removed to ensure reduced artefacts in the data.

Pupil Dilation as a Measure of Cognitive Workload

Another measure of visual attentiveness that researchers have used is pupil responsiveness. The pupillary response is an automatic process that regulates the amount of light entering the eye and reaching the retina (Beatty and Locero-Wagoner, 2000). Measuring the diameter of the pupil can indicate the amount of mental workload that is being undertaken (Beatty, 1982; Kramer, 1991). As a measure of underlying cognitive workload, it is expected that novice drivers will have a greater pupillary response to hazards than experienced drivers. The higher pupillary response was anticipated for novice drivers, as experienced drivers have a top-down cognitive process that activates schema associated with situation awareness and hazard responses. These schemas are underdeveloped or non-existent for novice drivers, and they do not have the same neural pathway and physiological response as the visually salient pathway that is more likely to be triggered in novice drivers who encounter complex and changing traffic situations.

Pupil dilation has also been used in commentary training, as it provides a useful insight into the extent of mental resources consumed by a secondary commentary task. Because commentary is a mentally demanding process that is secondary (albeit attendant) to the demands of driving, measuring pupil dilation has been used to provide a measure of 'first perception' of hazards, much like the traditional measures of physiological arousal, such as galvanic skin response (Marshall, 2007; Cai and Wang, 2006; Bailey and Iqbal, 2008). Pupil dilation is higher for participants conducting *online* commentary (i.e., commentary actively being conducted during a task) than for those participants who are not required to produce commentary or participants who have received commentary training but are performing offline post-commentary training testing.

Although pupil dilation may influence the calibration of some eye-trackers (Wang, 2009), it provides a useful indication of mental workload and physiological arousal (particularly when encountering demanding or unexpected hazardous traffic scenarios) and which has been used in several different studies related to task-demand and driver workload.

Blinks as a measure of Cognitive Workload

Blinks are also a useful measure of task-demand; however, several other eye-tracking measures can also be used to indicate mental workload (for instance, Ahlstrom and Friedman-Berg, 2005). As Wang (2009) suggests, blink rate and blink duration and saccadic duration may provide useful insight into the cognitive load during particular tasks.

Caution when using Eye-tracking to Provide Task Validity

Caution is always warranted in relying on visual information collected using video-based simulations compared to real-world behaviour, as there naturally are differences between the engagement of simulators compared to real-world driving (Mackenzie & Harris, 2015; Steinman, 2003). For example, Martens and Fox (2007) conducted a study to compare the fixation times of participants exposed to video footage against participants in real-world driving over the course of repeated trials. They found that initial fixation times did not significantly differ between driver groups, with fixation time and behaviour being similar on the first trial. However, as participants became more familiar with the route over time, the fixation times diverged, with fixation times decreasing for real-world drivers compared to the fixation duration of participants observing video. They suggested that the resolution of video footage may restrict participants ability to detect certain aspects, or that real-world driving is more dynamic and hence there is a greater need to focus on multiple visual elements.

In this experiment, repeated exposure to the same roads did not result in variation in fixation duration, although fixation behaviour did differ as anticipated between novice and experienced driver groups as expected. We, therefore, conclude that any video-based influence on visual search, while a constraint of laboratory tasks, is an ecologically valid representation with good ‘physical correspondence’ (Blaauw, 1982) to real-world behaviour, even though there may be small variations between the laboratory task and real-world driving (Santos et al., 2005).

Appendix 10: Laboratory-Based Measures

While traffic statistics and crash reports provide useful information about drivers' speed choice, it is not possible to control for the many variables that often lead to a crash. One method which has been used is naturalistic studies, where instruments are installed in participants vehicles, and their behaviour is monitored over some time. The most well-known example of this is the 100 car naturalistic study (Dingus et al., 2006), where drivers behaviour was examined for a year using in-vehicle telemetry and dashboard cameras.

The Frontal Lobe Study as an Example of Observational Methods

Another method of naturalistic study is having participants drive in a vehicle that has been fitted with instrumentation, often requesting participants to navigate either a pre-arranged route on public roadways or a race-track (Eby, 2011). For example, Isler, Starkey, Sheppard, et al. (2008) studied 38 young novice drivers who participated in a two-week 'Driver Training Research' camp based in Taupo, New Zealand. In order to examine drivers behaviour, their project utilised psychometric measurements of attitudes and beliefs, measures of cognitive function, and observation of driving behaviour on a nearby racing-track. The results of the study found that before training, attitudes towards speed were directed toward greater risk, and self-rated confidence was also high. Observational assessment on track involved coding drivers behaviour, as well as drivers self-generated verbal report related to the driving task, such as the identification of hazards.

Drivers were randomly allocated to three training groups, which involved differing techniques of training, ranging from a 'higher-order' coached commentary training to basic training of vehicle handling skills. Isler, Starkey, Sheppard, et al. (2008) found that drivers who received the higher-order training performed the best out of the three training groups, with drivers who received the simple training performing worst. They also found that driving competency was related to more advanced executive functions.

While this form of observational study and a naturalistic method are possible, they are often both resource-intensive and often expensive. There is no guarantee that participants will complete an entire series of longitudinal assessments, limiting the generalisability of the results. Because of these constraints, researchers often rely on a combination of self-report measures and laboratory-based simulators that attempt to replicate the natural driving behaviour of participants.

Laboratory-Based Simulators: Advantages and Disadvantages

Carsten and Jamson (2011) provide an excellent overview of traffic simulators, acknowledging that they are now a primary method of driving research. According to their review, there is no clear definition of a simulator, as a laboratory-based methods range from a (low-fidelity) single computer monitor attached to a simple controller (e.g., joystick or steering wheel) to an immersive (high-fidelity) vehicle interior with 360° field of view and functioning mirrors. However, they do generalise the characteristic features of a simulator having screens or an image-projected surface, vehicle controls such as steering wheel and pedals, a sound system that replicates the sound of the road and vehicle, and a dashboard with displays such as vehicle speed (Carsten & Jamson, 2011). While the first available simulators utilised either filmed or pre-rendered traffic scenarios, with advances in computer graphics technology in recent years, many simulators function using real-time image generation.

There are a broad array of reasons that researchers utilise traffic simulators over naturalistic or observational techniques. Firstly, naturalistic studies are limited in their scope, as generating experiments involving elevated risk is accompanied by the possibility that participants could be harmed. Because harm is minimised in a simulator, studies can involve aspects that would be unsafe or unethical in naturalistic or observation-based research (e.g., the effects of alcohol on drivers performance).

Another advantage to simulators is that the range of extraneous variables that cannot be controlled for in naturalistic studies can easily be removed in a simulator. For instance, participants in a naturalistic study may be required to drive a fixed route; however, as traffic and weather conditions can be highly variable, no two drives are the same. In a simulator, all participants can be exposed to the same environment and stimuli, which adds a dimension of control not available to real-world methodologies. This degree of control affords the researcher the ability to manipulate variables in a precise way for all participants while being able to make close observations of driving behaviour such as speed, following distance, and/or lane-position (Carsten & Jamson, 2011), including tests such as physiological measures of heart rate variability, galvanic skin response (Kinnear, 2009), and eye movements.

However, with laboratory-based measures, there is always the question as to how reliable the measures of drivers performance is, and how well drivers behaviour in a laboratory setting corresponds to real-world behaviour. For example, in measuring drivers risk-taking behaviour in a lab where there is no risk, do drivers behave in a similar way to how they would in the real world where risk is a reality? This question then is at the forefront of researchers thinking when conducting laboratory experiments, especially when related to risk-taking.

While simulators obviously of great value to researchers, they are not without their limitations. The question of ecological validity often hangs over simulator-based experiments, as there is the potential that participants behave differently in a simulated environment than they would in the real world.

Advantages to Video-Based Methods in the Laboratory

As hi-fidelity simulators are expensive and involve much development for experimental roads and conditions, some researchers have turned to use video footage as a research tool, which does not require the same degree of resources or development. Video footage of real-world driving filmed from the drivers perspective can be easily obtained by researchers, and can cover a range of naturally occurring driving conditions without the need to develop computerized scenarios and renderings, and can be quickly deployed as a laboratory tool over a range of laboratory or online settings (Isler & Cockerton, 2003; Isler & Isler, 2011).

Appendix 11: More information on the Hazard Perception Task

This section will discuss the measures of hazard perception used in this thesis:

1. Number of immediate hazards correctly identified
2. Time to detect hazard from the appearance
3. The number of clicks that were not associated with immediate hazards (errors, covert hazard)

Moreover, where appropriate, secondary task measures will include:

4. The number of tracking errors
5. The duration of tracking errors

Hazard perception has two components: the ability to anticipate road and traffic events, and the ability to assess risks; perception is just one stage of this process, as it involves not only the ability to recognize a possible hazard but also the preparatory actions that allow for timely intervention in order to prevent a potential incident (Vlakveld, 2011). Vlakveld (2011) condenses the definitions of hazard to two components a) the ability to anticipate road and traffic events, and b) the ability to assess risks. Furthermore, Vlakveld (2011) notes that perception is just one stage of the process. It is not only the recognition of a possible hazard but also the preparatory actions that allow for timely intervention to avoid a crash should the hazard materialise.

In this thesis, the primary measure of hazard perception was the perception of immediate overt hazards, rather than covert hazards, which include situations in which an overt hazard may or may not materialise. Hazard perception time for immediate hazards can be measured from the moment the hazard becomes visible until the point where the driver (participant) attends to it through either sustained visual attention (visual time on target) or by indicating perception through some signal (hazard window). The distinction between hazard anticipation and hazard perception is of importance, as anticipating a hazardous road environment despite the absence of immediately visible hazards may influence a driver's eye-movement behaviour, as well as other behaviours such as speed choice.

However, the hazard perception task used in this thesis only provided a measure of drivers' perception of immediate hazards, that is, hazards that required them to respond with a vehicle manoeuvre potentially. Across the driver research literature, there are several definitions covering hazard perception. Deery and Love (1996) define hazard perception as the process of identifying hazardous objects and events in the traffic system and quantifying their dangerous potential, whereas Groeger and Brown (1988) provided an expanded definition: the ability to detect hazards, assess the risk involved, and compare the outcomes of each assessment to determine whether or not one can cope with the hazard. Helman (2008) defines hazard perception as “the ability to identify potentially dangerous traffic situations as early as possible” (p. 8). Here a distinction needs to be made between the *perception* and the *anticipation* of hazards (McKenna, Horswill and Alexander, 2006). A driver may anticipate hazards, but until the hazard manifests itself, it is not detectable. Various methods have been developed over the past several decades ranging from verbally identifying hazards, to the more commonly employed video and simulator-based tasks which involve participants either using a mouse click or pressing a touch-screen when they identify a visually apparent hazard (Horswill and McKenna, 2004; Isler, Starkey, and Williamson, 2009).

There are an almost endless series of on-road and off-road features that might be or might become hazards and must be navigated safely by drivers. A distinction can be made between immediate hazards which demand an immediate response from drivers, and covert or potential hazards, which are not immediately hazardous but might become hazards as a potential series of events unfolds. For instance, a car braking immediately ahead presents as an immediate hazard, and pressure must be applied to the brakes to prevent a collision. Whereas, a child playing with a ball on the side of the road might not be an immediate hazard, although this situation could quickly become an immediate hazard if that child should mistakenly run out into traffic.

The essential difference between immediate (overt) and covert hazards is that immediate hazards readily present themselves as apparent, whereas covert hazards are anticipatory and are based on the context in which driving is occurring. For instance, covert hazards may always be present in the mind of the driver and eye movements may indicate the active scanning for such hazards, but this may only influence behaviour once probability of emergence becomes sufficiently high (i.e., a driver may slow down in anticipation of covert hazards when driving past parked vehicles during school recess).

Immediate hazards have been loosely defined as 'Changes in the road situation, which place a demand on a driver to adjust their behaviour'. The perception of an immediate hazard requires drivers to change their behaviour either to avoid or control for factors that may lead to a potential collision. In contrast, covert hazards are not readily apparent, and both novice and experienced drivers have greater difficulty in predicting whether a potentially hazardous event is imminent.

Research conducted by Pradhan et al., (2005) noted that young novice drivers have a harder time anticipating hazards which are not visible than older and more experienced drivers. This finding was subsequently supported by Sagberg and Bjornskau (2006). It is thought that hazard anticipation is related to contextual factors which trigger top-down knowledge-based schema experienced drivers possess, leading to modifications to driving behaviour, whereas novice drivers have not yet had sufficient time to develop these schemata. This assumption bears some consideration in light of findings made by Kelly et al., (2010) who concluded that novice and experienced drivers sorted videos of different traffic scenarios containing overt and covert hazards differently based on contextual factors that rely on higher-level cognitive processing rather than visual salience.

Measures Employed for Perception of Hazard-related Events

Based on Isler et al (2009) research, primary measures of hazard perception will be a) the number of hazards identified, and b) the time from onset of hazard to the time the hazard is identified. If a hazard is not identified, the time the hazard was visible was used. Secondary measures of hazard perception based on Vlakvald used are c) the time between the nearest fixation on the hazard and the time to which the participant identified the hazard, and d) The number of non-hazardous environmental features identified (e.g., traffic signs) which nevertheless may inform the driver of future hazardous situations which could emerge.

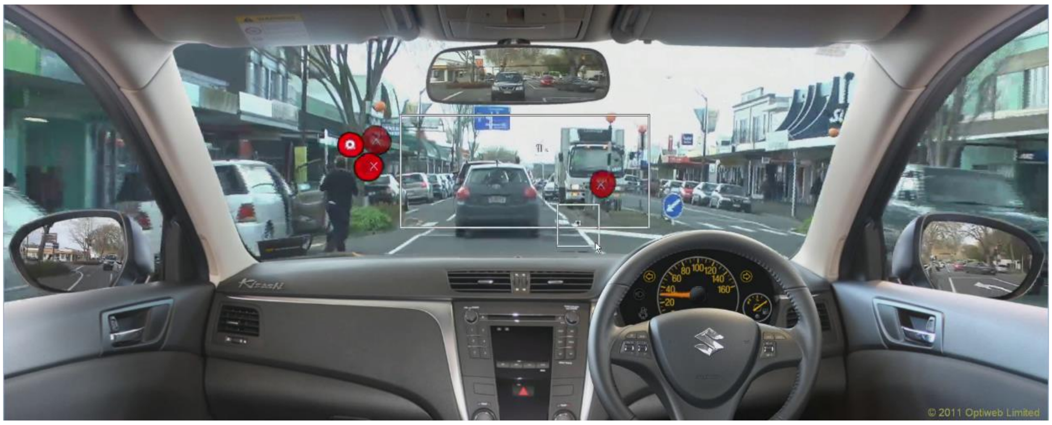
The Roads Used in the Hazard Perception Task

In this experiment, eight distinct road situations were used to explore the relationship between hazard perception and eye movements between novice and experienced drivers as pre and post-training measures, as well as determining the relationship between hazard perception measures and speed choice. The videos for all hazard perception tasks have been consistent across the two experiments for the sake of consistency, save for two videos that were bisected into two additional shorter videos in the commentary training task due to software and hardware limitations in smooth playback.

In this section, each of the eight videos will be described, and a list of the immediate hazards provided. The images are also displayed with the secondary task overlaid, as well as the eye-movement fixations indicated by red dots.

Grey Street (High Density)

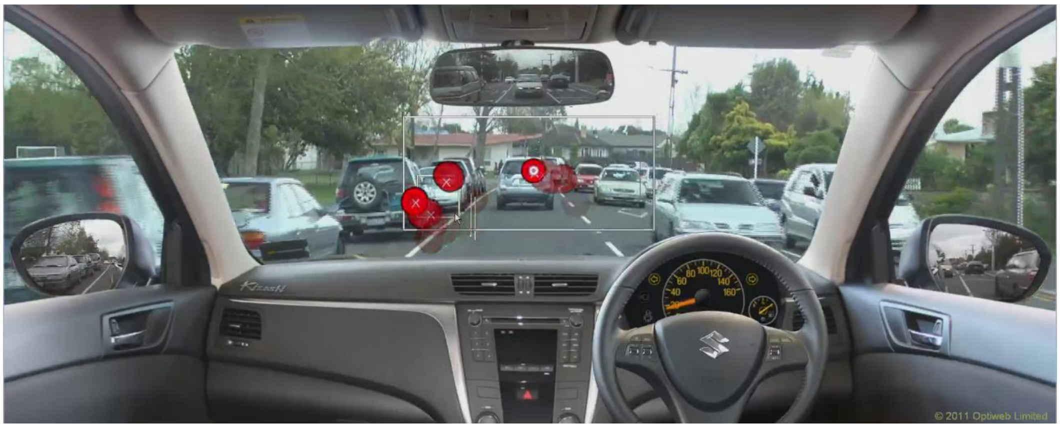
Grey Street is a section of medium to high-density commercial buildings with several side roads and intersections with a single lane in either direction with clear markings and traffic islands. There are a large number of immediate hazards, and in order to safely traverse this section of road then there needs to be adequate visual attention both to pedestrian activity on edges of the roads, as well as the possibility for vehicles to cross the path of traffic or stop in the lane ahead.

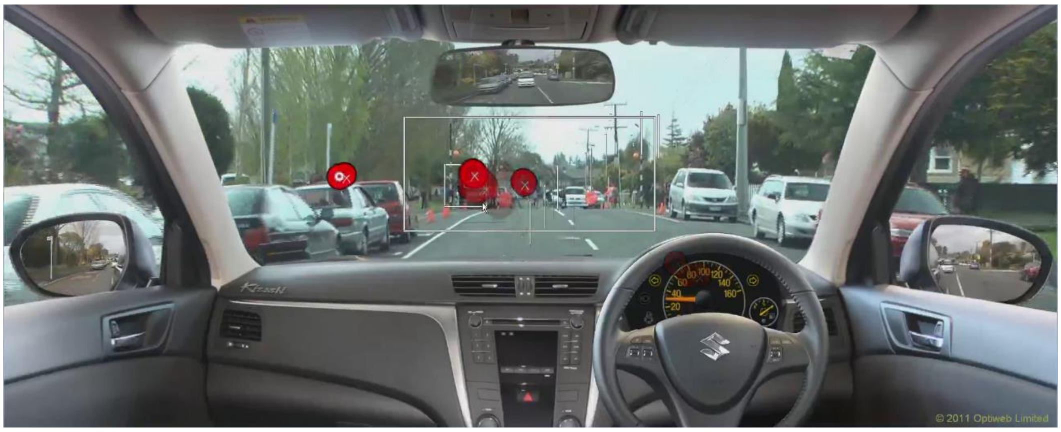


The first Grey Street scenario had multiple cars braking immediately ahead, pedestrians on the left-hand side of the vehicle preparing to cross the road, and drivers on the left-hand side exiting their vehicles. The second Grey Street scenario involved drivers exiting their vehicle on the left-hand side, a truck parked on the centre medium displaying hazard lights, cars turning across the oncoming path of traffic and vehicles entering the traffic stream from the left-hand side. Additionally, there were vehicles parked on the left-hand side with passengered preparing to exit the vehicle.

Knighton Road (High Density Primary School Zone)

Knighton Road scenario is a section of road that acts as a moderately dense arterial road, with a primary school and pedestrian crossing, as well as multiple vehicles parked along the side of the road. The traffic flow is prone to substantial changes in density throughout the day, with the maximum amount of traffic and pedestrian activity occurring during the beginning and end of the school day. This was the time where the video scenarios were generated for this road.

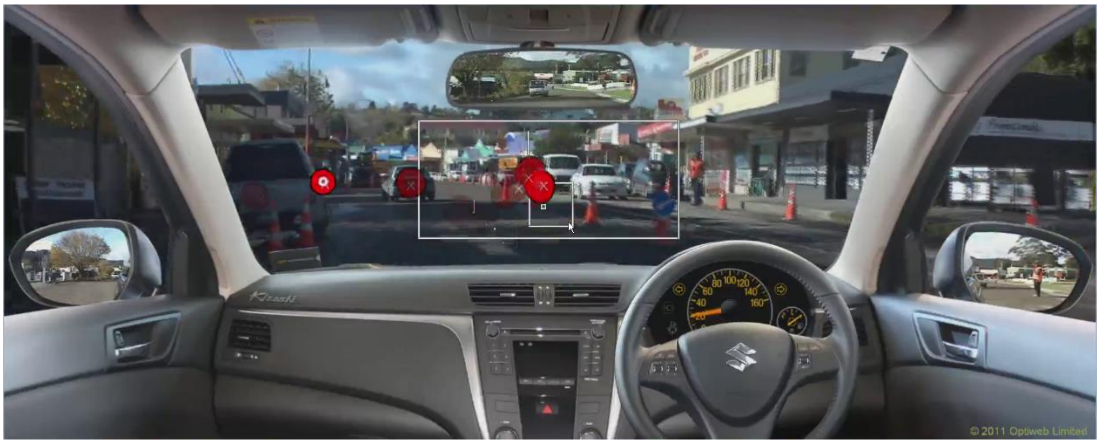




The first of the Knighton Road scenarios involved vehicles turning immediately across the path of oncoming traffic, multiple drivers exiting/entering vehicles parked on the left-hand side, a pedestrian crossing on approach with vehicles slowing. The second scenario involved cars stopping ahead, people exiting the vehicle on the left-hand side, and the presence of multiple pedestrians, and persons getting into a vehicle on the left-hand side. These two scenarios were the most demanding as far as requiring participants to be mindful of both the left-hand sides of the road for pedestrian activity and vigilant for vehicles ahead to be braking frequently.

Kawakawa (Low density, road maintenance)

The Kawakawa Road involved travelling through the main street of a small rural town while road construction was underway. This involved vigilance not only for pedestrians and road workers but also intersecting traffic and road working machinery. This scenario presented initially with road workers on the right and left-hand sides and a number of pedestrians crossing from the left-hand side, and an obscured intersection where a vehicle was exiting crossing the path of traffic and entering the opposing carriageway.



Christchurch (high-density arterial road)

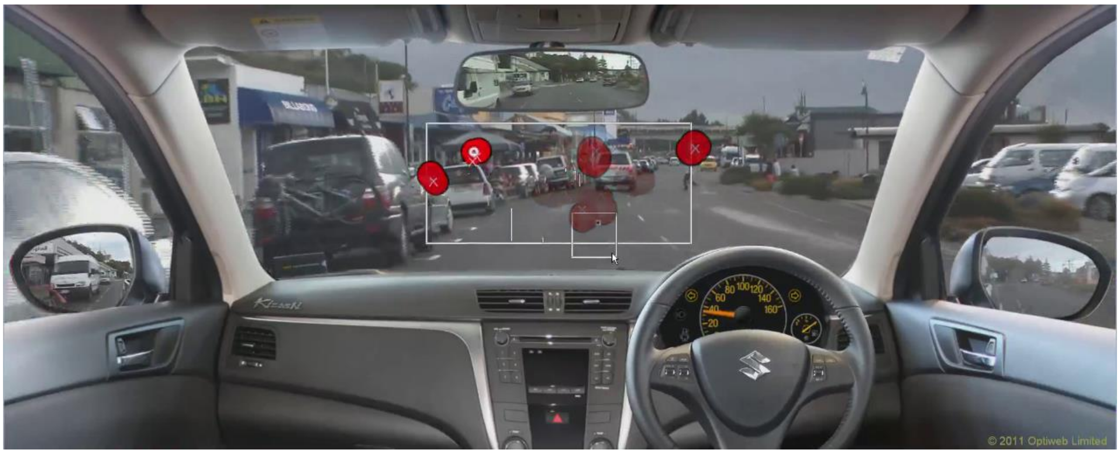
The Christchurch traffic scenario involved a moderately active arterial road in a commercial region. In this scenario there are multiple vehicles braking, pedestrians crossing from the right-hand side, pedestrians exiting a vehicle from the left-hand side, and vehicles crossing the path of traffic and coming to a stop in an entranceway partially blocking the road ahead.

Victoria Street (medium density)

Victoria Street is a central city street in the Hamilton CBD, which is speed limited due to the high number of pedestrian activity. A partition and pedestrian walkway separate the opposing carriageway. In this scenario, there is a pedestrian crossing ahead with one pedestrian crossing from the right-hand side using the crossing, and several pedestrian-crossings further down from both the right and left-hand sides of the road. There are also vehicles ahead and parked along the side of the road.

Kaikoura (multiple pedestrians and braking vehicles)

Another scenario involving the main road of a rural town, this road scenario involves multiple vehicles parked along the sides of the road, with vehicles oncoming and pedestrians crossings down the road from the right-hand side. There is also an obscured pedestrian who emerges from behind a vehicle on the left-hand side with short notice, and a vehicle being followed that crosses a traffic bump, then proceeds on several occasions to brake suddenly.



The hazard scenarios provide both a cross-section of commonly encountered on-road hazards such as braking vehicles, whilst also requiring the participant to be vigilant of the sides of the road in locations where pedestrians and other hazards might spontaneously emerge.

Tables of Identified Immediate Hazards in the Video Clips

Throughout this experiment, eight individual video clips covering a range of Urban road situations and hazards are used. As these remain consistent throughout the entirety of the thesis and are used in both variation of the hazard perception task, as well as for pre- and post-training for the commentary experiment. The two sequences, A and B, are alternated for each sequential participant (i.e., for participant one, the sequence is A->B, for the following participant, B->A). This was done to reduce the likelihood of bias should one sequence be easier than the other.

Table 0.1.

Film Sequence 1 with Immediate Hazards Identified for use in Hazard Perception Tasks

Road Scenario	Immediate Hazard	Time of onset of hazard
TRIAL1:	1. Car on the left	0:00 - 0:05
	2. Car in front braking	0:03 - 0:06
HAMILTON EAST	3. Schoolboy on the left	0:00 - 0:13
	4. Car braking again	0:24 - 0:29
	5. Drivers leaving their cars (one click)	0:24 - 0:29
TRIAL 2:	1. Road worker on the right	0:00 -0.02
	2. Pedestrian on the left	0:09 - 0:13
KAWAKAWA	3. Road worker	0:13 - 0:19
	4. Pedestrian far	0:34 - 0:47
	5. Pedestrian near	0:36 - 0:42
	6. Car turning	0:46 - 0:53
TRIAL 3:	1. Car in front is braking	0:00 - 0:11
	2. Pedestrian from the right	0:19 - 0:23
CHRISTCHURCH	3. A driver leaving the car on the left	0:23 - 0:31 0:23 - 0:31
	4. Car turning right is getting stuck	0:31 - 0:36
	5. Pedestrian from the left	
TRIAL 4:	1. Oncoming white van turning	0:00 - 0:09
HAMILTON	2. The driver and car on the left	0:13 - 0:20
KNIGHTON ROAD	3. School patrol	0:15 - 0:38
SCHOOL	4. Mother gets into car left	0:53 - 0:58

Table 0.2.

Film Sequence 2 with Immediate Hazards Identified for use in Hazard Perception Tasks

Road Scenario	Immediate Hazard	Time of onset of hazard
TRIAL 5 Knighton Road	1. Car in front stopping 2. Family leaving car left 0:06 – 0:22 3. Car in front stopping again 4. Car stopping once more 5. Car stopping again (School patrol) 6. People getting into a car	0:00 - 0:01 0:06 – 0:22 0:15 - 0:17 0:19 - 00:25 0:35 - 0:45 1:11 – 1:15
TRIAL 6 VICTORIA STREET	1. Lady in a red coat on the left 2. Two pedestrians crossing (one click) 3. Pedestrian from the left	0:00 - 0:03 0:01- 0:04 0:03 -0:04
TRIAL 7 KAIKOURA	1. Car in front stopping speed bump 2. First pedestrian from the right? 3. Car front braking again 4. Second pedestrian from the right 5. Pedestrian from the left 6. Pedestrian from the left	0:00 - 0:07 0:23 - 031 0:25 - 0:30 0:27- 0:34 0:27- 0:29 0:34 - 0:41
TRIAL 8 Hamilton East	1. Drivers left leave car 2. Truck with hazard lights on 3. A car turning right behind a truck 4. Car in front braking 5. Car parked left	0:00 - 0:02 0:00 - 0:06 0:00 - 0:06 0:05 - 0.08 0:05 - 0:08

Appendix 12: Scripts, Schema, and Hazard Perception

When drivers encounter similar situations repeatedly over time, they develop cognitively economic ways of dealing with them, allowing them to negotiate traffic in ways that maximise cognitive resources to the driving task. Human cognition appears to be based on categorical thinking, and being able to sort things into categories quickly allows for rapid judgements to be made. The cognitive structure is referred to as scripts and schema. Schema is the most basic routine, a simple rule when encountering an event or object. These are bundled together to form scripts.

Hazard Perception and the consumption of Cognitive Resources

As we have noted, hazard perception requires considerable cognitive resources and attention, and although much of the visual search saccade and salience network processes are subconscious (e.g., Supervisory Attentional System), this skill may still be regarded as deliberate – requiring conscious effort – and unlikely to become automatized, requiring working memory and devoted cognitive resources, in contraposition to lower-level vehicle handling skills (Bellet et al., 2009; Isler et al., 2009; Konstantopoulos et al., 2010). It follows that experienced drivers have more available cognitive resources free to be allocated to hazard perception and visual search, as the primary vehicle control skills are sufficiently automatized as not to compete for available resources (Horswill & McKenna, 2004; Underwood, 2007).

However, in one study, Kass et al. (2007) investigated the situation awareness (SA) of novice and experienced drivers, and found that experienced drivers had more comprehensive recall of aspects of the traffic environment when queried. However, both groups showed similar degradation of SA under cognitive distraction caused by mobile phones; indicating that both novice and experienced drivers are susceptible to the effects of distraction on attentional resources, and that drivers are not passive recipients of visual information, but must be actively engaged in the driving task (Kanwisher & Wojciulik, 2000; Lemercier et al., 2014).

Furthermore, it has been proposed that hazard perception is a skill that competes with other driving tasks for attentional resources before it becomes an automatic and sub-conscious process. Hence, young and inexperienced drivers may experience an inability to simultaneously dedicate cognitive resources to the task demands of hazard search and vehicle control (McKenna & Crick, 1991; Underwood, 2007;

Geoffrey Underwood et al., 2002). Driving is a complex task and needs prioritisation over other processes/activities. Wickens (2005) suggests that incidences (such as crashes) occur as a result of ‘cognitive or attentional tunnelling’ which occurs when the management of tasks (e.g., speed choice) breaks down or are incorrectly prioritized.

The regulation of conscious processes and attention has been strongly connected with the brain's prefrontal and anterior cingulate circuitry, which has previously been noted to continue maturing into the mid-twenties (Eshel et al., 2007; Isler & Starkey, 2008). This has numerous implications for adequate hazard perception, as these neurological systems are responsible for a wide range of executive processes (Keating, 2007). In particular, control of eye movements and awareness of visual information and assessment and response are dependent upon the prefrontal circuit, which may not be fully developed in younger persons (Passingham & Wise, 2012).

Appendix 13: Driver Education and Training: Road Commentary

As discussed earlier, training of higher-level skills and executive functions seems to play an essential role in driving behaviour and in reducing crash risk of young drivers. The crucial question is if the development of these life-saving 'executive functions' can be fast-tracked in young novice drivers? Some promising research shows that training of executive functions, such as hazard perception using video-based traffic scenarios, improves the risk-taking behaviour of young drivers within a short period of time (Isler & Starkey, 2008; Isler et al., 2009; McKenna et al., 2006). There is also evidence that visual search and attention in young drivers can be improved using an innovative training intervention of eye-tracking technology (Underwood, 2007).

Training to Repair Defective Schema

Another approach used by Prabhakharan and Molesworth (2011), looks to modify faulty cognitive processes related to speeding using episodic-based training based on the work of Molesworth et al. (2006), which engages the trainee as if integrating them into a story or narrative. By utilising narrative and feedback in the form of traffic rules, this engages the cognitive structures that are deeply grounded in knowledge-based semantic memory and story-based episodic memory, which, when simultaneously activated, assists the consolidation of memory (Schank & Abelson, 2013). We will later explore this approach in the context of generative learning and commentary as a training technique.

Video-based Road Commentary Training

Results from the "Frontal Lobe Project" support these findings, it showed some evidence that frontal lobe executive functions were indeed associated with driving-related performance (Isler, Starkey, Drew, et al., 2008). In the same study, a clear association between training in higher-level skills on driving-related assessments was identified and improved attitudes towards driver risk-taking, suggesting that young drivers behaviour can be significantly improved using higher-order commentary-based training, Higher-level training skills significantly improved search behaviour regarding on-road assessment. Furthermore, it has been shown, that by using the specific road commentary training method which involves verbally pointing out all immediate hazards and how to manage them, the number of hazards perceived and the number of actions in response to hazards was increased in a brief period (Isler et al., 2009).

Overall, it seems that by targeting high-order metacognitive skills and reflective thinking (i.e., self-awareness, self-monitoring, self-evaluation, and risk management) there is promise in counteracting the high crash risk of young novice drivers. Improving road safety is internationally regarded as a vital issue of 'Best Practice in Road Safety' (e.g., Bartl, 2010; European Commission, 2007), and are recommended by the National Road Safety Committee in New Zealand (The National Road Safety Committee, 2008).

Despite the promising results on short-term effects of those studies, it is still unclear whether this higher-level driving skills training will have any long-term safety benefits in young driver's every-day driving. To address this matter research literature has identified a need for more sensitive and objective post-training outcome measures than using self-reported driving diaries, which could be biased, and quite general or data from police reports. Using new technology, it is also possible to gain more understanding and influence young drivers' behaviour, which is essential to improve road safety.

In driver education, much of the work in developing good driving behaviour involves developing or replacing absent or faulty scripts and schema with safe and well-constructed scripts and schema. This could be likened to the process of training used by Parker et al. (1996), which focused on identifying and modifying beliefs related to speeding, using the Theory of Planned Behaviour (TPB), in which social, moral norms, and actively acknowledging control over conduct are used to reduce deliberate violation of the speed limit. This technique attempts to persuade that the driver has control over his or her behaviour, and that speeding or traffic violations are both socially and morally unacceptable – such that speed would be disapproved by peers, and can lead to serious negative consequences. This method has become a primary means of televised traffic campaigns to reduce drivers' risky behaviours (Phillips et al., 2011).

As visual behaviour varies during stages of human development, notably when the human brain is progressing through adolescence, this needs to be understood in the context of both driver research and the development of future training programs. Konstantopoulos makes a suggestion that is particularly relevant to training methods in this thesis:

> Some additional practical implications of the present findings might include the development of training interventions for more efficient visual search strategies. In the past training interventions about eye movements of learner drivers have been successful but time-limited (Chapman et al., 2002). One of the reasons that such training might be short lived could be the general nature of any instruction. Future training should consider the fragmentation and adoption of different visual allocation under different conditions such as rain and night driving. (p. 833)

Konstantopoulos (2010) adds a word of caution while providing this promising approach, in that driver's process visual information in very different ways under different driving circumstances, and this needs to be considered in future research.

Appendix 14: Visual Attention and Perception

Renowned neuroscientist Daniel Kahneman (1973) has proposed that there is far too much information[40] to be reasonably attended to by the brain, so behaviourally irrelevant information is filtered out to allow for more relevant information to be attended to at a higher level of processing. There are thought to be two systems that process the flow of visual information; one is bottom-up, which draws attention to objects moving that might be of a threatening nature. The other system involves top-down cognition: information needed by the brain to complete some task or operation based on existing knowledge or schema (Beck & Kastner, 2009; Cowan, 1988; Groeger, 2013). The brain contains many representations of knowledge, structured in multiple levels, and directed by both voluntary and involuntary influences (Monsell & Driver, 2000).

As a fundamental survival mechanism, it is the case that humans focus attention quickly on unfamiliar or potentially threatening objects. This bottom-up, saliency driven system draws unexpected elements from the raw visual stream and immediately thrusts these into the forefront of attention, often initiating a response before entering conscious awareness (Purves et al., 2004). A heightened sensitivity drives the bottom-up system to novelty, and this is not surprising given its neural afferents run deep into the recesses of the limbic system (Sarter et al., 2001).

The top-down approach is the alternate system competing for visual resources. It is driven almost entirely by knowledge and established schema and controls the eyes in a way that is conducive to extracting the essential visual elements to complement a particular planned mental process (Castro, 2008; Desimone & Duncan, 1995). The evolution of this system is a much more recent and complex development than its bottom-up counterpart, with only the mammalian family present with this remarkable feature. The top-down system engages existing knowledge to drive the recognition, application, and manipulation of the environments and is in part responsible for the creation of new knowledge, for knowledge of any sort the kind humans employ, such as reading this sentence would not be possible without it (Hopfinger et al., 2000). For example, it is the knowledge-driven top-down control of the eyes that carefully scans each word of this sentence and comprehend its meaning

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[40] High resolution foveal vision is neurophysiologically expensive, in that, for each of the foveal cells, many thousands of neurons in the visual cortex are required to process the visual information at even the most primary level. Higher levels of visual processing increase exponentially in order of magnitude. The remainder of the retina is low resolution, and hence, the brain directs attention of the high-resolution visual system at features which are important, and the vast remainder of visual information is unoticed or diregarded (Azzopardi & Cowey, 1993; Ptak, 2012).

before scanning the next line. However, should something suddenly intrude into the environment, the bottom-up system would immediately engage and seize visual attention immediately (Beck & Kastner, 2009; Itti & Koch, 2000).

A common analogy regarding visual attention is that it operates much like a 'spotlight' scanning over areas of interest and disregarding irrelevant details from the visual scene (Erikson & Erikson, 1974), and is associated directly with eye movements overtly (Itti & Koch, 2000). However, it is noteworthy that attention can occur without eye movements, known as covert attention (Itti & Koch, 2000). Visual attention is either space-based or object-based, such that the 'spotlight' moves in relation to objects or areas of interest before reintegrating (Driver, 2001; Lavie & Driver, 1996; Logan, 1996).

Neglect of information outside of this theoretical visual 'spotlight' about the locus of attention has led researchers to consider the importance of visual neglect, namely the phenomenon of change and inattentional blindness. Change blindness occurs when some aspect of the scene changes and the brain is unaware that an element in the scene has been removed. Inattentional blindness, by contrast, occurs when visual attention is focused onto one location while neglecting changes occurring in another area of the visual field which falls outside of the 'spotlight'. This effect has been most famously demonstrated by Daniel Simons (2003) in the classic 'dancing gorilla' task, where participants are asked to count how many passes of a basket-ball are made by players wearing white shirts. During the game, a gorilla walks through the centre of the players. Most people are oblivious to the gorilla if they are attentively engaged with the ball counting task[41].

For example, results of the '100 car naturalistic study' showed that 78% of crashes and 65% near-crashes were attributed to driver inattention, with young drivers disproportionately involved in distraction-related crashes (Klauer et al., 2006). These results are in line with the findings of Whelan et al. (2004) who showed that novice drivers concentrate more on cars in other lanes and focus too little on cars in their own lane, which could also support the cause for the involvement in rear-end collisions. Studies done by Crundall and Underwood (1998) gave evidence that young drivers have difficulties in gathering relevant visual information while driving, especially when driving conditions become more complex, which is supported by the

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[41] For more information, I would refer the reader to Kahneman, D. (2011). *Thinking, fast and slow*. Macmillan.

findings of Whelan et al. (2004); there, novice drivers show to be more disrupted by distraction in their situation awareness.

Both change and inattentional blindness has been studied in relation to driving behaviour (Crundall et al., 2004; Galpin et al., 2009). For instance, in a study of following a simulated car through a city scenario, participants who were attentive of the car failed to notice pedestrians, resulting in more traffic violations (such as driving through red lights) and crashes, and also limited horizontal visual scanning and produced longer fixations on the car being followed (Crundall et al., 2004).