Improving Driver Awareness of Road Risk and Driver Behaviour Using KiwiRAP Ratings

Samuel G. Charlton

31 August 2011

Prepared for: The New Zealand Automobile Association Driver Education Foundation, Wellington, New Zealand.

This paper should be cited as: Charlton, S. G. (2011). *Improving Driver Awareness of Road Risk and Driver Behaviour Using KiwiRAP Ratings.* TERNZ Research Report. Auckland: Transport Engineering Research NZ.

Improving Driver Awareness of Road Risk and Driver Behaviour

Using KiwiRAP Ratings

Table of contents

1. Executive Summary

This report was prepared for the Trustees of the New Zealand Automobile Association Research Foundation in in order to assist them in identifying key research questions associated with understanding the relationship between actual road risks and drivers' perceptions of risk and their driving behaviour. The ultimate goal of this research is to improve road safety by better communicating the risk associated with specific roads to the drivers that use them. With that goal in mind, members of the New Zealand Automobile Association Research Foundation proposed two practical questions to be addressed:

> Can we make hazardous New Zealand roads appear to be more risky to drivers in order to improve the safety of their driving behaviour?
>
> Can we change the visual appearance of hazardous New Zealand roads to produce safer driving, regardless of drivers' perceptions of risk?

To address these questions, the present project was commissioned to review the available research findings on the subject of risk perception and driving, identify areas where more information was required, and develop research questions and indicative research projects to provide the needed information. To that end, over 130 research articles were located and reviewed for this report.

Since the earliest days of road safety research, it was a widely accepted belief that road users modify their behaviour according to the level of risk that they see ahead of them. Early theories maintained that drivers adjusted their driving to maintain a constant level of risk. Experimental evidence, however suggested that the relationship between driving and risk was more complex. Researchers pursued the questions of how well drivers detect road and traffic hazards, what factors lead them to perceive driving risk, and the relationship between hazard detection and drivers' feelings of risk.

Researchers found that drivers are more likely to detect hazards that are located towards the centre of their field of view and that experienced drivers have a broader functional field of view than less experienced drivers due to their different scanning behaviour. Of particular interest, however, was the unexpected finding that the type of events and situations that drivers consider hazardous appear to differ from driver to driver, with some of the largest differences found for drivers with different amounts of experience.

Research findings indicated that drivers do appear form subjective judgements about the risk of the road and traffic situations they encounter, but as with hazard detection, the accuracy of those judgements appears depends on their driving experience. This research also revealed that situations in which perceived risk is significantly lower than the objective risk (risk discordance) are more hazardous than situations where objective risk is correctly reflected in drivers' risk judgements. Further, some drivers adopt inadequate safety margins due to an incorrect assessment of their own driving skill or the driving difficulty associated with hazardous situations. This can lead to situations in which drivers adopt inadequate safety margins in spite of high levels of perceived risk (over-driving).

Although there is evidence that risk ratings are correlated with drivers' safety margins, some authors have argued that we cannot infer that perceptions of risk actually cause safe driving. Some of the findings suggest that subjective risk may only be a result of the driving experience rather than a controlling agent. Another line of research has found that some visual treatments, known as perceptual countermeasures, can reduce drivers' speeds, improve their lane position, and improve the quality of their decision-making. It has been suggested that many of the countermeasures, such as transverse lines, herringbones, and dragon's teeth, work by increasing drivers' unconscious experiences of speed or difficulty. When the perceptual features of roads are applied systematically to form visually distinct road categories there is evidence that drivers' will form conceptual categories that result in differentiated driving behaviour appropriate to each category, an approach called self-explaining roads. These findings suggest that there is potential for using perceptual features to create a road category for hazardous roads and improve drivers' safety margins. The effects of this approach on drivers' perceptions of risk are not known.

Following from the literature review, the answer to the practical questions posed at the outset of this research project appears to be a qualified "yes". There is, however, a need for additional research to address how to implement the goals implied by the questions. Eight research questions that should be addressed were identified. The most promising research methods available to address those questions have been reviewed and described in this report. The methods include: actuarial methods, surveys, focus groups, part-task photographic and videographic methods, simulation, naturalistic observation, and field trials. Finally, five candidate projects to address the research questions have been described, along with a discussion of which research methods would be most suitable for each project.

2. Background

This report was prepared for the Trustees of the New Zealand Automobile Association Research Foundation in in order to assist them in identifying key research questions associated with understanding the relationship between actual road risks and drivers' perceptions of risk and their driving behaviour. The ultimate goal of this research is to improve road safety by better communicating the risk associated with specific roads to the drivers that use them. With that goal in mind, members of the New Zealand Automobile Association Research Foundation proposed two practical questions to be addressed:

> Can we make hazardous New Zealand roads appear to be more risky to drivers in order to improve the safety of their driving behaviour?
>
> Can we change the visual appearance of hazardous New Zealand roads to produce safer driving, regardless of drivers' perceptions of risk?

To address these questions, it was proposed that a research project should review the available research findings on the subject of risk perception and driving, identify areas where more information was required, and develop research questions and indicative research projects to provide the needed information. As per the statement of work developed by the New Zealand Automobile Association Research Foundation and key stakeholders in February 2011, the research project was to be comprised of three interrelated activities:

1. Critically reviewing the available published literature related to drivers' perceptions of risk, hazard detection, and the effectiveness of hazard warnings and perceptual countermeasures in road design.
2. Development of key research questions to address what road characteristics New Zealand drivers use assess road risk and which characteristics are most effective in changing driver behaviour on hazardous roads.
3. Identification of a range of possible methods for addressing each of the research questions, including surveys, laboratory investigations, and field trials.

The NZAA National Council voted in favour of the research programme of which this project is an integral part on 17 March 2011 and on 28 April permission to was granted to begin work on this project with an effective start date of 1 May 2011.

Over 130 research articles were located and reviewed for this report. Based on the review of the published literature, eight principal research questions were developed that identify areas where further understanding of the relationships between road features, drivers' perceived risk, and driver behaviour is needed. Finally, a research prospectus was prepared describing the research methodologies applicable to these research questions (including actuarial methods, surveys, focus groups, part-task photographic and videographic methods, simulation, naturalistic observation, and field trials), and five candidate projects to address the research questions were described. The primary end users for this research are the New Zealand Automobile Association (NZAA) as well as the MOT, NZ Transport Agency, ACC, NZ Police, and other organisations that promote road safety. The ultimate end users and beneficiaries of the research include: the driving public, transport operators, insurance providers, driver trainers and the public in general.

3. Review of the Literature

Risk perceptions and driving

Since the earliest days of road safety research, it was a widely accepted belief that road users modify their behaviour according to the risk they perceive. Gibson and Crooks proposed that drivers adjust their speed and lane position according to a perceived "field of safe travel" (Gibson & Crooks, 1938). As shown in Figure 1, Gibson and Crooks hypothesised that drivers perceive a safety zone around their car and in their projected path ahead. Gibson and Crooks suggested that this safety zone consisted of "the field of possible paths which the car may take unimpeded" (p. 454) and that drivers' steering and speed were perceptually grounded to keep the car headed into the field of safe travel. Implicit in this account is that drivers avoid departures from the safety zone because of the perceived risk of collision and bodily injury with other cars and obstacles. This early risk perception model of driving was supported by Hall's (1966) idea of proxemics which described measurable comfort and safety zones that people attempt to maintain around their persons. Hall's idea was that people keep personal, social, and social zones that, when violated, may be perceived as a potential threat and trigger a fight or flight response. Thus, drivers maintain a critical distance threshold around them, with strong emotional characteristics associated with perceived risk.

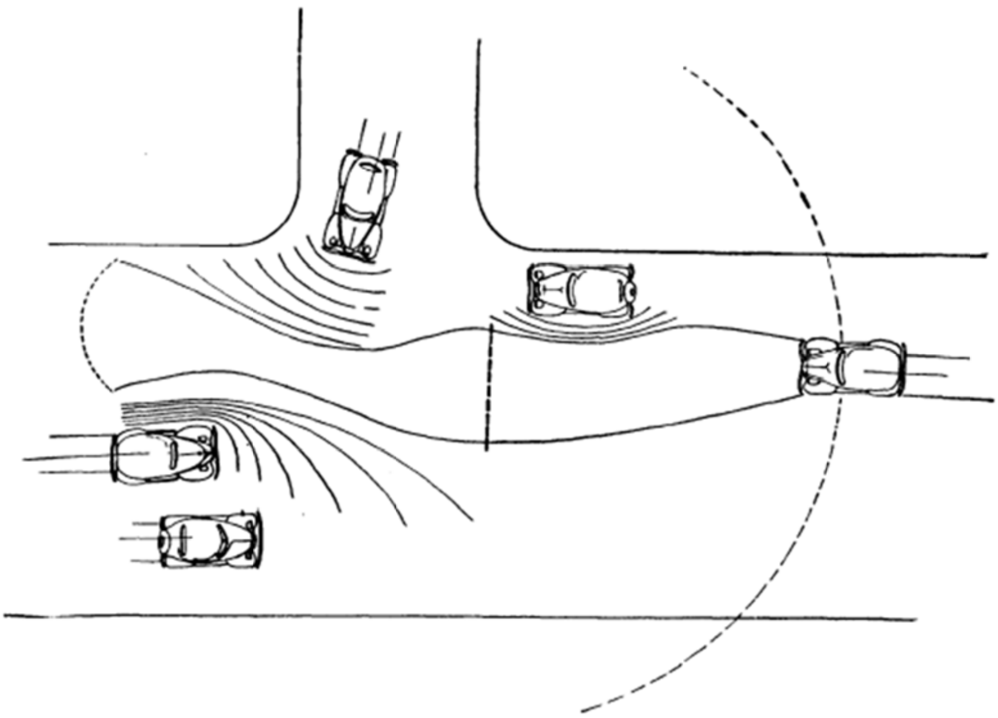

Figure 1. The "field of safe travel" as proposed by Gibson and Crooks (1938, p. 455).

Developing a similar line of thinking with regard to the task of driving, Taylor (1964) proposed that drivers' level of emotional tension or anxiety resulting from their distance to possible hazards served to govern their speed and lane position. Taylor based his proposal on the measurement of galvanic skin responses (GSR) in two on-road experiments in which 20 participants drove roads of varying levels of difficulty and accident risk. GSR, a measure of electro-dermal activity, is based on changes in skin conductance and has long been used as a psychophysiological indication of arousal, fear, and anxiety. These reactions, governed by the sympathetic nervous system have made it a central component of polygraph or lie detector equipment. Taylor reported that GSR levels for various road sections were correlated with accident probabilities and inversely related to driver speed during those road sections. Taylor also noted that mean GSR levels were significantly related to experience (GSR was reduced by years of driving experience). Taylor suggested that drivers regulated their own driving by adjusting their speed to maintain their level of anxiety, fear, and tension within acceptable levels.

In a widely-cited series of papers, Wilde (1982, 1988, 1998, 2002) elaborated these ideas into what he called the Theory of Risk Homeostasis. Wilde's theory proposed that drivers possess an internal, target level of risk and they will increase or decrease the safety of their driving in order to reduce the difference between their momentary perceived level of situational risk and their target level (Wilde, 1988). Wilde's interpretation of Taylor's findings was that increases in anxiety or arousal (as indicated by GSR) reflected drivers' perception of a level of risk beyond that which they personally considered acceptable or safe. The large individual differences in GSR activation noted by Taylor represented the different "set points" for allowable risk maintained by individual drivers. According to Risk Homeostasis Theory (shown in Figure 2), drivers perceive elements of risk in the driving environment and a risk comparator mechanism explicitly (consciously) compares that level to their internal set point for acceptable risk (target risk). The result of this comparison is that drivers adjust their speed, lane position, following distance, or other safety behaviour to make the perceived risk match the target risk as closely as possible. The implication of Wilde's theory was that if the perceived risk was higher than the target level drivers would increase their safety behaviours (e.g., slow down), but conversely, if the perceived level of risk was well below the target risk, drivers would increase their unsafe behaviours (e.g., increase speed) until the target risk more closely matched the perceived risk.

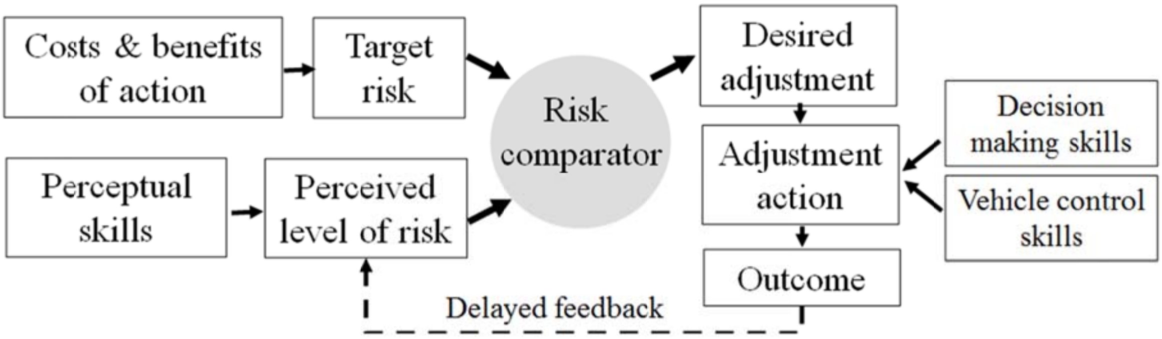

Figure 2. The Theory of Risk Homeostasis (adapted from Wilde, 1982, p. 212).

As evidence of his theory, Wilde cited the effects of Sweden's change from left- to right-hand drive in 1967. The change had been preceded by a considerable media campaign which had the effect of increasing the public's perception of risk associated with the impending switch to right-hand driving. Immediately following the change there was a 40% reduction in the traffic fatality rate, but the rate returned to its previous values after about 18 months (Näätänen & Summala, 1976). Wilde argued that drivers had responded to an increase in perceived risk by taking more care; as they became accustomed to the new regime, however, "people discovered - through the mass media as well as their own experiences - that the roads were not as dangerous as they had thought they were" (1998, p. 90). Wilde also used the example of mandatory seat belt laws, which, although they reduce the likelihood of death or serious injury, did not apparently result in a reduction of per capita death rates. Similarly, cars equipped with airbags, Wilde argued, "tend to be driven more aggressively and that aggressiveness appears to offset the effect of the airbag for the driver and increases the risk of death to others" (Ibid).

The notion of risk compensation even seemed to be presaged by the original work of Gibson and Crooks, who wrote "More efficient brakes on an automobile will not in themselves make driving the automobile any safer. Better brakes will reduce the absolute size of the minimum stopping zone, it is true, but the driver soon learns this new zone and, since it is his field zone ratio which remains constant, he allows only the same relative margin between field and zone as before" (1938, p. 458).

A number of studies documenting changes in the behaviour of large groups of drivers appeared to support the Theory of Risk Homeostasis. A classic example of the research illustrating drivers' responses to changed driving conditions is Summala and Merisalo's

(1980) study of driving on icy roads in which they demonstrated that drivers driving with studded tyres increased their speed such that their skid margin approached that of drivers driving with normal tyres. In a well-controlled on-road experiment Janssen (1994) measured the driving behaviour of two groups of drivers; those who did and did not habitually wear seat-belts. Janssen reported that when the habitual non-wearers were asked to wear a seat belt their driving became faster and less careful. Similarly, Sagberg, Fosser and Saetermo (1997) undertook on-road observations of 213 taxis in Oslo and found that taxi drivers in cars equipped with anti-lock brakes (ABS) maintained shorter headways (followed cars ahead more closely) than those without ABS, 2.2 seconds versus the 2.8 second headways of those without anti-lock brakes.

Similar findings have been reported for a range of safety improvements made in road designs. For example, Assum et al., (1999) hypothesised that introduction of road lighting would have little effect of drivers' behaviour, based on previous research. They found, however, that drivers' speeds increased significantly by 3.6 km/h after road lighting was introduced, and were 5% higher than a control section of highway. The researchers also reported that drivers' concentration was reduced by road lighting (as measured by lane position variability). In a large study of roads in the UK it was found that following road resurfacing, traffic speeds can increase by up to 2.6 km/h (Cooper, Jordan, & Young, 1980). A similar study of road surfaces in Finland reported that resurfacing increases the average traffic speeds, at least when the road is dry (Leden, Hämäläinen. & Manninen, 1998). In New Zealand it has been established that drivers' speeds increase following curve realignments (Wong & Nicholson, 1992) and they drive at higher speeds when road width increases (Burdett & Nicholson, 2010; Charlton & Baas, 2006).

The Theory of Risk Homeostasis was not without controversy however. Researchers have been critical of the theory for a variety of reasons, including: incorrect statistical interpretation of aggregated data used to support the theory (Lund & O'Neill, 1986); logical inconsistencies internal to the theory (McKenna, 1987); a lack of evidence that groups act to maintain a constant level of risk (Evans, 1995); and a level of ambiguity in the theory that made it very difficult to generate testable predictions (Elvik, 2004). Importantly for the present discussion, when used to predict individual drivers' behaviour, rather than aggregated group data, there was little evidence that individuals compensated for changes in the environment in the way that Risk Homeostasis Theory predicted. In a series of experiments in which participants rated the riskiness of driving situations at various speeds, Stetzer and

Hofmann (1996) found that when analysed at an aggregate level, groups of participants appeared to adjust their behavioural intentions according to the level of risk, but when analysed at the level of the individual very few participants (only 8%) changed their behavioural intentions enough to maintain a constant level of risk. In another important test of Wilde's theory, Hoyes et al., (1996) used a driving simulator to examine 14 specific driving behaviours and noted that while manipulations of both perceived risk and utility (costs and benefits of actions) did have significant effects on a number of behaviours, these did not combine at an individual level in the way that Risk Homeostasis Theory maintained they should.

Thus, although it is widely recognised that changes in driver behaviour occur in response to the presence of road hazards and changes in road design, there is now widespread agreement that these changes occur due to some process other than risk homeostasis. Alternative theories have been offered to replace risk homeostasis, including models that propose that drivers balance driving intensity and driving skill or workload (Fuller, 2005), balance comfort and the stress of sustained attention (Hancock & Warm, 1989), the effects of the sensation seeking personality type (Jonah, Thiessen, & Au-Yeung, 2001), or the driver's subjective pleasure experienced while driving (Rothengatter, 1988).

In addition to the alternative theoretical accounts, it has been proposed that these changes in driver behaviour are better thought of as "behavioural adaptation" so as to avoid the temptation to view them as necessarily an outcome of changes in the levels of risk or a conscious decision by drivers in response to their perceptions of risk (Lewis-Evans & Charlton, 2006). For example: "the consensus is now that although drivers tend to adapt their behaviour to improve road and vehicle engineering design, they do not in all circumstances adapt their behaviour such that risk remains constant" (Rothengatter, 2002, p. 251).

Lund and O'Neil (1986) were the first to suggest that offsetting behaviour (behavioural adaptation) would be more likely to occur for changes that affect crash probability (studded tyres) than changes that affect injury probability (seat belts). They proposed that because changes that reduce the likelihood of a crash also often provide direct and immediate feedback, drivers may be more likely to change their behaviour. In contrast, changes that increase occupant protection usually do not provide direct and immediate feedback to the driver and, therefore, should have no little or no effect on driving behaviour. Their analysis of the existing research was consistent with their prediction; behavioural adaptation is more likely to occur for accident-reducing rather than for injury-reducing measures (Lund and

O'Neil, 1986). Sagberg et al. (1997) reached a similar conclusion when their analyses also confirmed that accident-reducing measures like ABS are compensated for among road users' behaviour to a larger extent than injury-reducing measures such as an airbag. Similarly, Harless and Hoffer (2003) concluded that there is stronger support for behavioural adaptation when studded snow tires are adopted or when weather or lighting affect driving conditions (and hence the likelihood of an accident) whereas evidence of risk compensation is weaker or absent altogether for injury-reducing measures.

As mentioned previously, Elvik (2004) argued that Risk Homeostasis Theory was too vague in explaining the specific underlying behavioural mechanisms, which made empirical testing extremely difficult. Instead, Elvik proposed a set of six more specific factors that could be examined as regards their influence on drivers' behavioural adaptation:

(1) More easily noticed changes in road and traffic conditions are more likely to lead to behavioural adaptation;

(2) If there is antecedent behavioural adaptation to a certain risk factor, then behavioural adaptation to measures intended to reduce that risk factor, is more likely to occur (e.g., if road users have lowered their speed or increased their attention because the road is narrow, they will increase their speed or reduce their attention when the road is widened), the greater the behavioural adaptation effect;

(3) The greater the engineering effect (i.e., the size of the changes made in, for example, sight distance, separation between incompatible road users or complexity of the road and traffic environment), the more likely is behavioural adaptation to arise;

(4) Measures that primarily reduce the probability of an accident are more likely to lead to behavioural adaptation than measures that reduce injury severity (e.g., behavioural adaptation is more likely to occur in the presence of antilock brakes than of airbags);

(5) The smaller the likely size of material damage (closely related to vehicle size), the greater the behavioural adaptation effect; and

(6) If additional utility can be gained from changing behaviour, the more likely behavioural adaptation will occur.

Summary.

Although the proposition that drivers adjust their driving behaviour to maintain a constant level of risk has been set aside, an equally interesting question is how drivers perceive road hazards and driving risk. In other words, it is of considerable interest to examine the available findings about how well drivers detect road and traffic hazards, what factors lead them to perceive driving risk, and the relationship between hazard detection and drivers' feelings of risk.

It may be useful at this point for a brief clarification of definitions. A hazard is an aspect of the road environment, or any combination of circumstances on the road that poses a danger to drivers (i.e., increases the likelihood of a crash). Objective risk is the likelihood of a crash associated with the presence of a specific hazard as calculated by analysis of actuarial data from previous crashes. Objective risk is usually expressed in terms of statistics such as probability values or odds ratios. By contrast, subjective risk is the level of danger associated with a hazard, as perceived by an individual. Subjective risk is rarely quantified in absolute terms, but drivers appear capable of making comparisons between risk levels at different sites and detecting changes at individual sites over time. Subjective risk is thus in the eye of the beholder whereas a hazard is a property of the driving environment and as such there may be true hazards in an environment that individual drivers do not notice, or that they notice but do not consider to be a risk (Armsby, Boyle & Wright, 1989). This distinction is of significance to the present discussion since it is important that road hazards be noticeable to drivers and perceived as a driving risk. As Gibson and Crooks noted; "hidden obstacles are dangerous, when they are, because they tend to put the driver's field of safe travel out of correspondence with reality" (1938, p. 471).

Hazard detection by drivers

In one of the earliest studies of hazard detection by drivers, Laidlaw (1975, as reported in Brown, 1982) reported what has become one of the hallmark findings in hazard detection research; young drivers are not as good at detecting hazards as older, more experienced drivers. Laidlaw's research showed that young drivers (mean age of 23, median driving experience of 5 years) were relatively poor at identifying distant hazards, although they were just as good at detecting near hazards as very experienced older drivers (experienced police officers, mean age of 36, median of 16 years driving experience). The young drivers were also poorer at identifying hazard markings and hazard signs than the experienced drivers. Brown (1982) suggested that this difference in detection performance might be because of differences in visual scanning strategies gained with experience.

In a comprehensive set of investigations Chapman, Crundall, and Underwood and their colleagues have investigated the different visual scanning strategies used by novice drivers and experienced drivers (Chapman & Underwood 1998; Crundall & Underwood 1998; Crundall, Underwood, & Chapman, 1999, 2002; Chapman, Underwood, & Roberts, 2002; Underwood, Chapman, Bowden, & Crundall, 2002; Underwood, Crundall, & Chapman, 1997, 2002). Chapman, Crundall, and Underwood reported that a driving video shown to experienced drivers produced a search pattern different from that of novice drivers, just as novice and experienced drivers displayed different search strategies when actually on the road. Using a peripheral detection task in which targets were briefly presented (200msec duration) to various parts of the visual field while participants watched video clips, they found that targets with eccentricities of greater than 7 degrees from the participants' point of fixation took longer to detect and were more likely to go undetected. Most interestingly, however, experienced drivers were found adapt their visual search according to the particular demands of the roadway, while novice drivers maintained the same, inflexible strategy across all road types. For example, experienced drivers tended to monitor the focus of expansion closely during an undemanding rural drive with no other vehicles present. When the driving task became more demanding, such as when driving through a suburban area or monitoring other lanes of traffic on a dual carriageway, drivers' visual search spread wider (a wider Functional Field of View or FFoV), producing shorter fixation durations to deal with the increased amount of visual information. In contrast, novice drivers tended to have a narrower FFoV and longer fixation durations than more experienced drivers in most situations.

The presence of a hazard, however, such as the emergence of a bicycle from a side road, resulted in a quite different search pattern in experienced drivers, reducing their spread of search and increasing their fixation durations as attention focused on the hazard. In the presence of a hazard, novices' fixation durations increase by an even greater amount than experienced drivers but their spread of search does not. Apparently, experienced drivers were able to engage and disengage their attention to a wide range of traffic and road information, including hazards, in a more efficient manner. Highly practiced expert drivers, such as police officers, display an even greater visual sampling rate and spread of search during an emergency situation such as a vehicle pursuit (Crundall, Chapman, Phelps, & Underwood, 2003). Importantly for the present discussion, experienced drivers detect more hazardous situations than younger drivers and when they encounter a hazardous situation, experienced drivers apparently remember more peripheral details about the hazard than novice drivers (Underwood, Phelps, Wright, van Loon, & Galpin, 2005). This suggests that experienced drivers not only see a fuller picture regarding road hazards, they also have a better understanding and memory for the hazards they do see.

Figure 3. A scene from one of the film clips used in the hazard detection experiments with a fixation marker indicating the direction of gaze of a participant (Underwood, Phelps, Wright, van Loon, & Galpin, 2005, p. 350).

Chapman, Crundall, and Underwood suggested that the more flexible strategies of experienced drivers may explain why they perform better at hazard-perception tests. If experienced drivers know the optimum focal points for spotting potential hazards on a particular road, then they should be able to spot the hazard faster than novice drivers, and thus have longer to respond to the hazardous situation. They also suggested that the reason for these different search strategies could be the different level of cognitive demands for these two groups. Specifically, they proposed that novice drivers find the driving task, and all of the new visual elements of that task, to be extremely demanding of their mental resources. Although novice drivers will presumably have seen these elements before as passengers, “the extraction of visual data useful to the task requires more than passive observation of the world through the windscreen” (Crundall, Underwood, & Chapman, 1999, p. 1078). They argued that new drivers need to learn what visual information is important to the task and then develop the correct scanning strategies for detecting that information. Further, they argued that for experienced drivers most of the scanning strategies have been practiced so thoroughly that they have become automatic.

A range of other investigators have reported that experienced drivers respond faster to hazards as compared to new drivers. McKenna and Crick (1991) found that drivers with more than ten years of experience reacted significantly faster to hazards than those with less than three years of experience and that the experienced drivers were able to detect a greater number of hazards than the less-experienced drivers. Similarly, Sexton (2000) found that learner drivers were slower than novices with less than two years of experience, who in turn were slower than experienced drivers with more than ten years driving experience. Wallis and Horswill (2007) reported that experienced drivers (10 years or more of driving) responded significantly faster on a video-based hazard perception test than untrained novices (driving for 4 years or less on a provisional or open license. Using a video-based test that portrayed real-life hazards, Berfu Ünal (2010) found that novice drivers were significantly slower than experienced drivers in their ability detect hazards outside their own driving lane. Further, the self-assessments of the participants' hazard detection skill did not correlate with actual hazard detection latencies (reaction times). Quimby and his colleagues examined the relationship between hazard perception latency and crash frequency in accident-involved drivers and found that a long hazard perception latency was associated with higher crash rates after controlling for age, driving exposure, and simple reaction time (Quimby Maycock, Carter, Dixon, & Wall, 1984). They reported that the crash rate doubled between the 5th and 95th percentiles of drivers' hazard detection performance scores and concluded that long hazard detection latency is a significant risk factor for crash involvement.

Other investigators have reported that some of the largest hazard detection differences between new drivers and experienced drivers occur for potential, as compared to obvious hazards. In another study employing video-based presentation of road scenes, Borowsky, Oron-Gilad and Parmet (2009) asked experienced and inexperienced drivers press a button every time they detected a hazard in six videos, followed by a classification task in which the participants viewed the road scenes again and classified them according to the perceived similarities in the type of hazard. Significant differences between driver groups were found only in the way they classified hazards that were in "a potential state" (e.g., intersections and parked cars). Young-inexperienced drivers only rarely detected the potential events as being hazardous and tended to classify the movies at a "surface level" according to similarities among the instigators of any obvious hazards depicted. Experienced drivers on the other hand more often indicated that these potential hazards were hazardous and used more general traffic environment characteristics in their classification of road scenes. In a follow-on study using a somewhat different experimental procedure, Borowsky, Shinar, and Oron-Gilad (2010) once again found that experienced drivers were more sensitive to potential hazards than young drivers and were more likely to search for signs and traffic signals (from other motorists) to predict hazards. The experienced drivers also tended to fixate more often than young-inexperienced drivers on potentially hazardous locations such as the merging road to the right when approaching a T intersection, whereas inexperienced drivers looked straight ahead, paying less attention to the merging road (and any possible vehicles located there). Borowsky and his colleagues concluded that with experience, drivers search for and detect more potential hazards, and they use traffic and road environment characteristics to guide their search patterns.

On-road tests of hazard detection confirmed many of these experience-related differences in visual scanning and hazard detection. Lee and her colleagues (Lee et al., 2008) designed three hazard detection scenarios that could be presented on a test track; a hidden stop sign, hidden pedestrian, and hidden pedestrian with a lane closure (this last also included a text-messaging task). They then compared the reactions of newly licensed teen drivers (within 2 weeks of licensure) with experienced adult drivers. They reported that significantly more of the adult drivers looked at hidden hazards including the obscured stop sign and pedestrian and that the majority of the adults displayed signs of recognition that a potential hazard was present. Nearly half of the novice teen drivers failed to disengage from the text-messaging task in the presence of hazards and 95% of the teens did not scan for the pedestrian.

In an investigation of the hazard detection performance of drivers near the end of their driving careers, Horswill et al., (2008) presented a video-based hazard perception test to a sample of older drivers (65 years and older) along with an battery of measures of cognitive ability, vision, and simple reaction time to see which of these abilities might be linked to hazard perception ability. These researchers reported that hazard perception response times increased significantly with age but that the age-related increase appeared to be linked to changes in contrast sensitivity, useful field of view and simple reaction times. In a second study, Horswill et al., (2011) gave a video-based hazard perception test to 307 drivers aged 65-96. In this experiment they found that older drivers' self-monitoring judgements on hazard perception performance appeared to have little or no correspondence to objective measures of their actual hazard detection performance. In other words, these drivers' confidence in their test performance did not match their actual performance on the hazard perception test. The participants' confidence ratings and their self-ratings of driving ability did, however, predict self-reported regulation or preferences for self-regulation of driving such as avoiding driving after dusk or in adverse weather conditions (albeit the authors did note that there was no way of verifying whether the participants actually engaged in these self-regulation behaviours). Similarly, in one of the studies mentioned earlier (Borowsky, Shinar, & Oron-Gilad, 2010), it was found that older drivers were only partially aware of their own limitations although they were significantly slower to respond to hazards (1.5 - 2.15 sec slower) than experienced drivers, and although they still detected more potential hazards than young inexperienced drivers, they relied on road signs and the behaviour of other road users to detect them. Interestingly, the researchers also noted that the older drivers "tended to claim that other road users were responsible for putting them at risk and rarely considered themselves as those responsible for the hazardous events" (p. 1248).

Summary.

Research into the detection of hazards while driving has shown that drivers are more likely to detect hazards that are located towards the centre of their field of view and that experienced drivers have a broader FFoV than less experienced drivers due to their different scanning behaviour. Of particular interest, however, was the unexpected finding arising from this body of research that the type of events and situations that drivers consider hazardous appear to differ from driver to driver, with some of the largest differences found for drivers with different amounts of experience. In other words, the question of how a driver's detection of a hazard is translated into a feeling of hazardousness or subjective risk is of crucial importance to our understanding of the degree to which drivers' perception of, and attention to the road environment are causal contributors to crashes.

Perceptions of subjective risk

In an early study of drivers' perceptions of risk, Pelz and Krupat (1974) showed 60 undergraduate men a 5 minute wide-angle film of highway driving as seen from the driver's seat and recorded moment-to-moment judgments of danger by means of an "Apprehension Meter". While watching the film, the participants moved a lever with a scale marked SAFE at one end and UNSAFE at the other, with about 10 unmarked calibrations in between. The participants were asked to move the lever according to how safe or unsafe they felt as a driver throughout the film. The participants were divided into three groups based on their driving records: Safe Record, Accidents only, and Violations-or-both groups. The groups were found to differ significantly on five scores comprising a "caution profile". The Safe Record group had the highest baseline level of caution between hazards and the longest duration of elevated caution for each hazard (measured between onset and offset of decreased safety ratings). In other words, the participants in this group recognized driving risk sooner and longer. Pelz and Krupat also measured the basal resistance levels (BRLs) and galvanic skin responses (GSRs) of the participants as they watched the film and found positive correlations between the ratings of danger obtained with the Apprehension Meter and the physiological skin-resistance measures (0.35 with BRL (inverted) and 0.24 with GSR) indicating that perceptions of risk were positively related to psychophysiological arousal.

A quite different method of determining drivers' subjective risk judgements was employed by Colbourn (1978) who used a computer simulation of gap-closure situations commonly experienced at road junctions. The participants' task was to avoid a collision between their car (indicated by a moving square) and traffic approaching from the left and right (represented by moving lines) by selecting the appropriate "GO" or 'STOP" response. Feedback was presented to the participants at the end of each trial, to confirm the outcome of the STOP decisions and maintain the participants' motivation to continue the experiment. In a separate series of trials, the participants provided subjective estimates of their certainty in their GO or STOP decisions on the task. The results of the study indicated significant differences in the performance of the task depending on the participants' age and gender. Younger males and older females made faster decisions than the older male drivers. The accuracy of the participants' performance as measured by their ability to avoid traffic, however, did not differ with regard their age and gender. The number of false alarms (incorrect STOP responses) did, however, differ among these participant groups. The older drivers who responded with the same speed as the young drivers did so by changing their speed-accuracy trade-off strategy. That is, the older females maintained decision latencies equivalent to those of the younger subjects at the expense of more false alarm responses whereas the older males maintained the accuracy of their responses at the expense of decision speed.

In a second study Colbourn (1978) used colour photographs of actual road scenes to obtain direct measures of the perceived driving risk under differing motivational conditions. The participants, all older women (average age of 46 years), were asked to "indicate what you consider to be the probability of some road or traffic situation developing in which you will need to make a driving manoeuvre" (Colbourn, 1978, p. 137). The participants were also divided into groups and given quite different instructions about the context of their drive.

One group was told to imagine they were taking a leisurely drive in the country with members of their family as passengers. Another group was told to imagine they were driving alone on a regular commuter or shopping trip. Other groups were told to imagine they were alone and late for an appointment, teaching a younger person to drive, or driving a sick relative to hospital in an emergency. Colbourn reported that the more stressful instructions were associated with significantly greater perceived risk than the more normal driving situations.

To try and convey a more dynamic sense of the driving task, Benda and Hoyos (1983) presented two photos of each driving situation, representing the same scene separated by brief intervals in time (as shown in Figure 4). The participants were divided into two groups and asked to sort 39 different traffic situations (that showed various road and weather conditions) according to their "hazardousness". Their results showed that experienced drivers were able to construct a ranked order of the hazardousness of driving scenes "thus dealing with hazardousness as a quantity" (p. 5). The less experienced drivers (roughly half the years' of experience) grouped the photos according to the type of hazard and did not differentiate the different level of hazardousness shown (e.g., ''The situations in this group are similarly hazardous because of the intersections in each", ''all wet road situations", etc., p. 6).

The researchers concluded that ''the greater the driving experience the more able the driver to regard hazardousness as being a holistic attribute of the traffic situation and to integrate many different aspects of the situation" (p. 6). The authors also reported that when similar scenes were shown in motion via film clips an equivalent pattern of results was produced. The researchers noted that the participants in each of the experimental conditions tended to separate "comfortable driving" from all other situations. According to Benda and Hoyos, comfortable driving "means driving under good conditions in which drivers do not need to process too much information… relatively few control activities are required. This kind of driving is obviously regarded as fairly nonhazardous" p. 8). Based on this finding they suggested that drivers' perceptions of hazardousness, or subjective risk, depends on both their amount of experience with various sorts of driving hazards and the information load in the situation, higher information loads leading to higher levels of subjective risk.

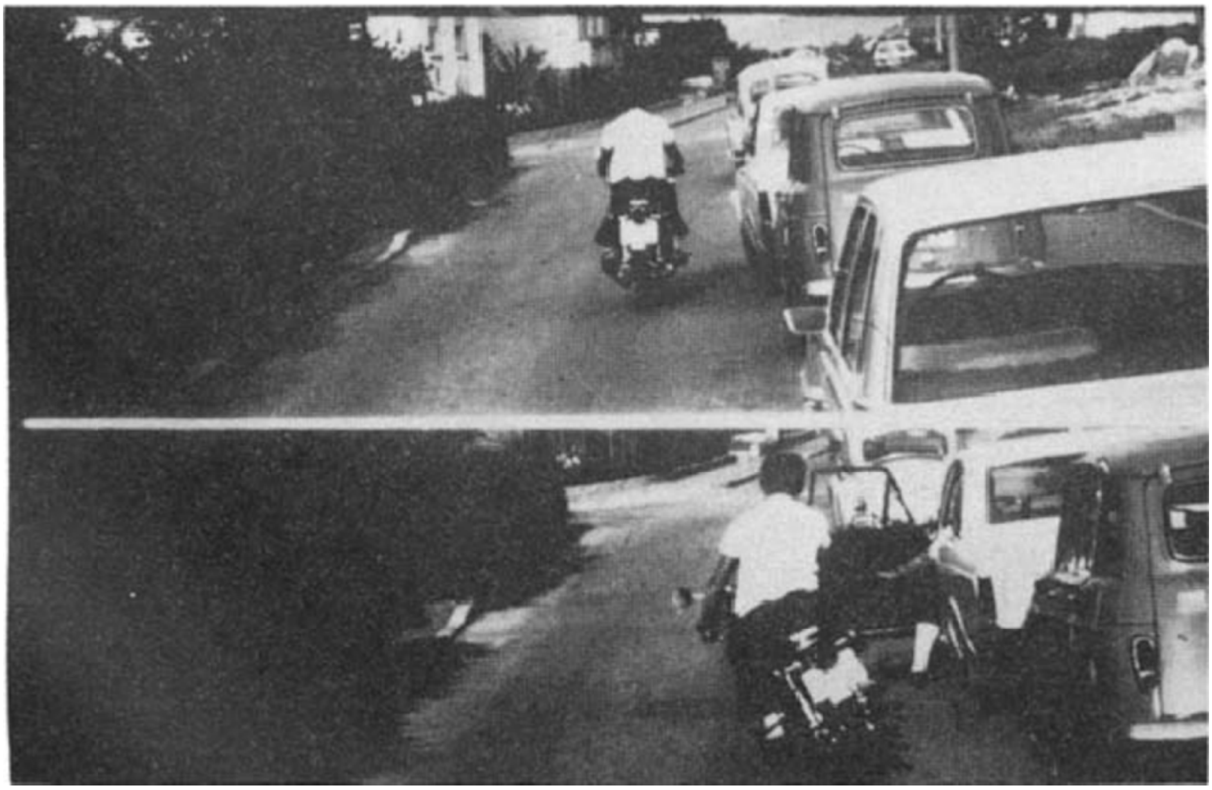

Figure 4. An example of the two-phase hazard scenes used by Benda and Hoyos (1983, p. 4)

Armsby, Boyle and Wright (1989) used several methods to assess drivers' perceptions of risk, including interviews and the repertory grid method. The researchers noted that the interviews often gravitated towards the inconvenience and frustrations of driving, with occasional comments about the hazards generated by other road users. In general, however, they found only very a low level of responses concerned with specific "road environment" hazards. Armsby, Boyle and Wright suggested that this may be because "drivers are generally unaware of the large variations in risk from one location to another, and view the road environment not as a place at which accident risk varies systematically from place to place, but as a neutral setting in which other road users suddenly and indiscriminately threaten their safety" (1989, p. 56).

Similar to the hazard detection experiments described earlier, Armsby, Boyle, and Wright (1989) also identified large differences in the perceptions of risk of experienced and inexperienced drivers. Young, inexperienced drivers tended to rate driving in fog as less hazardous than a pedestrian crossing the road whereas experienced drivers ranked the risk of these traffic situations in the opposite order. The researchers suggested that experienced drivers are more familiar with pedestrian crossing situations and therefore less threatened by pedestrians than less experienced drivers. They also reported that the inexperienced drivers perceived parked vehicles as part of the road environment, whereas older, experienced drivers saw them as separate entities and therefore a greater potential source of risk. Armsby, Boyle and Wright concluded that drivers may only be aware of those hazards that experience has taught them may lead to near-misses or accidents, and that those experiences form the basis for drivers' perceptions of risk.

Joshi, Senior, and Smith (2001) asked 291 pedestrians, cyclists, motorcyclists, car drivers and bus drivers to keep a diary (over seven days) of their near-misses and conflicts between themselves and other road users, and then compared them to actual crash data. The results showed that pedestrians and cyclists reported many more incidents per mile travelled than the motorcyclists, car drivers and bus drivers. Comparing the incident figures to traffic flow and crash data from the local council it was found that three types of road users were over-represented in the incident reports; cyclists, buses, and lorries. Cars, on the other hand, were under-represented in the incident reports. A closer examination of the pattern of the reports revealed a reporting bias such that car drivers paid more attention to near-misses with less vulnerable road users (i.e. those who could harm them) than they did to near-misses with more vulnerable road users (i.e. those whom they could harm). In other words, car drivers over-reported their rate of near-misses and conflicts with large vehicles relative to the accident data and under-reported their incidents involving pedestrians and cyclists. Cyclists and bus drivers, however, displayed very accurate judgements; in their incident diaries they correctly ranked the other as the second highest contributor, which is precisely where they were ranked in each other's accident statistics. Joshi and her colleagues suggested that these results revealed some interesting insights into how drivers perceptions of risk are formed; the risk perceptions of car drivers in particular appeared to be biased in terms of the degree to which other road users in the immediate vicinity could harm them but tended to underestimate the risks when the other road users were smaller and more vulnerable than their own vehicle.

Charlton, Newman, and Baas (2003) reported similar asymmetries in the risk perceptions of 327 New Zealand drivers. Using a series of photographs of driving scenes that had been edited to contain different types of road users in each scene, they collected ratings of the degree of driving risk in each situation, the participants' willingness to accept the risk in that situation, and their degree of control over their own vehicle in that situation. They found that, overall, participants rated urban scenes as least risky, followed by rural scenes, with motorway scenes receiving the highest risk ratings; levels of perceived risk that were much different than the objective risk in these situations as determined by actual crash data. Risk ratings for the scenes representing turning vehicles at urban intersections were particularly under-rated as compared to their actual risk. For these scenes the ratings of risk were found to increase linearly with the age of the participants. The female participants generally rated all of the scenes as being riskier than did the men, but rated scenes containing motorcycles as much riskier. Male participants, on the other hand, were more willing than women to accept the risk in the situations with the highest risk ratings (urban and rural overtaking scenes), and rated their skill as being better able to cope with the situations.

Based on an analysis of accident data, crash investigations, and driving performance measures Howarth (1988) suggested that there is a large discrepancy between objective risk and drivers' subjective estimates of risk. On the basis of his analysis, Howarth argued that driver behaviour was actually determined more by objective risk than drivers' perceptions of subjective risk. Using the example of driving in the presence of child pedestrians, Howarth demonstrated that the behaviour of drivers is more closely related to the objective risk, which is very low, than to the subjective risk, which drivers tend to think is rather high.

In an excellent comparison of the correspondence between drivers' perceptions of risk and the objective risk of various driving situations, Watts and Quimby (1980) asked 60 drivers to make assessments of risks along a 16 mile route on a rural road. The participants' speeds and forward visibility were also measured along the route, and combined with crash data from the road allowed a calculation of their objective risk at 45 points during the drive. The correlation between the objective risk and the participants' subjective risk was only moderate (Spearman's rho = 0.37) and there were many locations where the risks were underestimated, or overestimated. Among the locations where the risk was significantly underrated was a rural T-junction where drivers were required to turn left of the major road. Three daytime crashes had occurred at the location in four years and the researchers conjectured that the low levels of traffic and rural nature of the intersection may have contributed to the under-estimates of driving risk. The second-most dangerous location on the route (in terms of objective risk) was also significantly under-rated by the participants. This location was a rural crossroads controlled by traffic lights, with five injury accidents at the site in the preceding four years. The researchers noted that the long, straight approach and uninterrupted tree lines may have formed a perceptual trap and combined with the low traffic volumes led to the deficient perceptions of risk.

Watts and Quimby suggested that the low levels of perceived risk at these sites may have contributed to the high levels of objective risk, and conversely, there was no crash history at the five locations receiving the highest risk ratings, perhaps as a result of the high levels of perceived risk. In order for this presumed relationship between perceived risk and crash history to be true, however there must be some correspondence between subjective risk and the safety margins adopted by drivers. Watts and Quimby noted that in general the safety margins maintained by drivers correlated well with their subjective risk ratings for those sites, but there was one noteworthy location on the route where this relationship was not maintained. At this location, a left hand curve edged with a 1.5 m hedge that limited the forward visibility, the drivers displayed both high speeds and high risk ratings. Although the drivers did note an increase in subjective risk, they were apparently willing to accept the increase in risk rather than slow down to maintain an adequate safety margin.

Kanellaidis and Dimitropoulos (1994) compared drivers' ratings of subjective risk and the objective risk for five curves on a four-lane divided arterial road in Athens. Thirty-four volunteer drivers drove the 3 km section of road in each direction and subjective risk ratings were given verbally at the midpoint of each curve. Measurement of objective risk at the curves was calculated by filming the curves from both directions and rating the road elements according to the German Guide for Traffic Evaluation of Highways. A very good correspondence between the objective and subjective risk values was observed for the curves (Spearman's rho = 0.78). Two of the curves on the route were generally regarded as accident "black spots" (although no crash history data were provided in the report) and the greatest discrepancy between objective risk and subjective risk ratings occurred at one of these curves.

In a follow-on study, Kanellaidis, Zervas, and Karagioules (2000) followed a similar procedure for three different road sections and compared a group of 96 drivers aged 18 to 64 to a group of 40 drivers aged 65 to 75 years. The analysis revealed, once again, that differences between actual risk and perceived risk were associated with increased accident frequency, and that in these cases (where subjective risk is viewed lower than the objective risk) the presence of warning signs becomes most important in maintaining adequate safety margins. The researchers also reported that subjective risk ratings increased with drivers' age, the drivers' familiarity with the roads, and self-assessment of driving skill (the higher the rating of driving skill, the lower the rating of subjective risk).

Several studies have reported that drivers' experience of subjective risk in various driving situations is affected by their estimates of their driving skill, particularly for young male drivers (Deery, 1999). For example, Finn and Bragg (1986) reported that although the crash risk for young drivers is higher than the general driving population, young drivers rate their probability of being involved in a crash as much less than other young drivers, and lower than other drivers in general. Similarly, Matthews and Moran (1986) found that young drivers rated themselves as being more skilled than other drivers (regardless of age) whereas older drivers rated themselves as equally skilled to other drivers their own age but superior to younger drivers. Gregersen (1996) reviewed these studies and concluded that young drivers are poor at estimating their own ability and thus at estimating risks adequately. Gregersen suggested that this pattern, young drivers underestimating the risks and overestimating their driving skill, demonstrates an obvious relationship between estimated risk and estimated ability. "If a driver believes that he is a skilled driver able to handle a dangerous situation, the situation is not interpreted to be as dangerous as it would be by a driver who underestimates his skill" (p. 244). Of interest is a related finding that, on roads with an 80 km/h speed limit, drivers generally prefer to drive 8 km/h faster than the limit and 4 km/h to 5 km/h faster than the speed they consider to be safe (Goldenbeld & van Schagen, 2007). The explanation for this finding was presumed to be drivers' tendency to rate their own driving skills more favourably than other drivers and thus the opinion that they can safely drive faster than other drivers.

In an experiment designed to investigate age and gender-related differences in drivers' assessments of their own and others' driving skill, Groeger and Brown (1989) administered questionnaires to participants of various ages. The questionnaires asked the participants to rate their own driving skills, or the skills of "the average driver", as well as various characteristics of their driving style. Fewer differences than expected were found in the participants' assessments of driving skill, but the researchers did report that young drivers viewed other drivers as indecisive and that young males described their own driving as less smooth and more reckless than most other road users. Instead of the gross overestimates of driving skill found in previous studies (Matthews & Moran, 1986; McCormick, Walkey & Green, 1986), Groeger and Brown found that their participants provided more modest estimates of their driving skill and rated themselves as better than "an average driver" but not as good as a "very good driver." Based on an analysis of the participants' answers to other questionnaire items, the researchers inferred that drivers often overstate their own driving abilities in order to present themselves in a favourable light to the experimenter, but that this does not mean they necessarily have an inaccurate perception of their driving skill. Groeger and Brown did conclude, however, that the interaction between drivers' perceptions of subjective risk and driving skill needed to be carefully considered; "…in any future research on perceived/subjective risk among drivers, to distinguish individuals' perception of hazard/ danger from self-ratings of their coping ability on the road. Studies that confound these two determinants of perceived/subjective risk will do little to advance our understanding of accident-provoking behaviour and hence not contribute to the development of reliable accident countermeasures" (Groeger and Brown, 1989, p. 165).

In a related study, Groeger and Chapman (1996) showed films of 24 road situations to 64 participants with differing levels of driving experience. Participants were seated at the steering wheel of a partial car and watched the filmed traffic scenes through the windscreen. At the conclusion of each scene the participants answered several questions about the level of risk depicted in the scene, how much driving skill was required by a driver in that situation, the amount of control over the danger they would have as a driver in that situation, and other related questions. Detailed analysis of the participants' ratings indicated that drivers responded to three main characteristics of the situation when considering the road scenes: danger, difficulty, and controllability/abnormality (their level of control and what they would normally expect in that situation). Examining how these factors affected drivers of different ages and experience levels, Groeger and Chapman reported that young drivers tended to respond to the danger of the situation more than the difficulty involved in manoeuvring (and appear to treat danger and difficulty as opposite characteristics), but they considered the situations less dangerous compared to older drivers. Novice drivers rated the scenes as busier than other drivers but did not differentiate the situations according to the controllability/ abnormality of the situation, whereas young experienced drivers placed more importance on this aspect of the scene than any other group. Based on this, and other research, Groeger and Chapman pointed out that although drivers attend to these three factors in their judgements of driving situations, it does not necessarily mean that their judgements of subjective risk were accurate. They argued that, in fact, there is compelling evidence that ratings of subjective risk are highly unreliable and prone to distortions associated with the context in which the judgements are made (Groeger & Chapman, 1990, 1991, 1996).

Summary.

Research into drivers' perceptions of risk has shown that drivers do form judgements about the risk of the road and traffic situations they encounter. When compared to the objective risk of the situation, the accuracy of those judgements appears to be highly variable depending on the amount of driving experience. Although there is some question about the degree to which drivers adjust their safety margins (e.g., speeds and headway distances) to match their risk perceptions, it appears that situations in which perceived risk is significantly lower than the objective risk are more hazardous than situations where objective risk is more accurately reflected in drivers' risk judgements. Further, it is apparent that some drivers adopt inadequate safety margins due to an incorrect assessment of their own driving skill or the driving difficulty associated with hazardous situations.

It is also reasonable to ask, however, whether there are some situations that are more likely to produce "over-driving", in which drivers adopt inadequate safety margins in spite of high levels of perceived risk. A related question is the degree to which drivers' safety margins are a consequence of their experience of subjective risk as opposed to some other factor. Although there is evidence that risk ratings are correlated with drivers' safety margins, we cannot infer that the perceptions of risk actually produced safe driving. Howarth (1988) has argued that driver behaviour more closely corresponds to objective risk rather than subjective risk in any case, and Groeger and Chapman's (1990, 1991) findings suggest that subjective risk may only be a result of the driving experience rather than a controlling agent. In Howarth's words, "When behaviour is well practised and automatic it does not require conscious control. Under these circumstances, conscious verbal 'knowledge' may be a reflection of social stereotypes rather than having any close relationship with the tacit knowledge which is controlling behaviour… It follows from this argument that the most effective safety measures are likely to be those which operate directly on behaviour, rather than indirectly through manipulation of conscious estimates of risk" (Howarth, 1988, p. 527).

Perceptual countermeasures

Some authors have argued that driving has a strong automatic or unconscious component in many situations (Charlton and Starkey, 2011; Summala, 1988; Summala & Räsänen; 2000). For example, Summala's Zero-risk Theory of driver behaviour maintains that with experience, driving becomes a habitual, largely automatic activity in which the subjective risk of driving is typically zero in most circumstances (Näätänen & Summala, 1974; Summala, 1988, 1996). Specific events or situations may, however, trigger a sense of increased risk or difficulty (either concurrently or retrospectively) when they exceed an attentional threshold (Charlton & Starkey, 2011; Lewis-Evans, de Waard, & Brookhuis, 2010). Importantly, changes in traffic and road conditions may result in changes to drivers' safety margins without any corresponding change in their subjective experience of risk. In other words, behavioural adaptation to changes in road conditions may not be the result of drivers' conscious deliberation or reflection on the subjective risk or driving difficulty associated with the situation.

Lewis-Evans and Charlton (2006) used a simulated driving task to examine the effect of road width on drivers' performance, perceptions of risk, ratings of driving difficulty, and driving confidence. As expected, reductions in road width did produce decreases in drivers' speeds, as well as higher ratings of risk and driving difficulty. Analysis of the rating responses that best predicted their driving speeds indicated that the participants' ratings of driving confidence was the largest determinant, followed by ratings of relative risk and accident likelihood. Importantly for the present discussion, however, when asked how the roads differed and why they rated the roads in the way they did, most participants mentioned the amount of traffic, the number and severity of curves, amount of signage, and road delineation as being the differences between the three roads (none of which differed for the three simulated roads). Lewis-Evans and Charlton concluded that "…these results strongly suggest that behavioural adaptation does not rely on explicit consideration of objective risk" and "…risk appeared to be a subjective reaction that arose from their implicit experience of the road environment, rather than an explicit factor motivating conscious decisions about appropriate speeds" (p. 615).

When a road is widened (for safety or other reasons) behavioural adaptation can occur such that drivers' speeds typically increase. If, as has been suggested above, drivers' experience of risk is not the cause of these changes, what is the reason for the speed reductions? Researchers have long noted that when roads are widened, there is often a corresponding reduction in a driver's sense of speed because of a change in visual cues; a wider road produces a decrease in the amount of stimulation in the driver's peripheral vision (Denton, 1980). The perceptual cues affecting our sense of speed appear to involve implicit, or unconscious, processing of edge rate information in the peripheral visual field and are the reason that driving down a narrow road or through a tunnel is often accompanied by an exaggerated sense of speed (Lee, 1974; Salvatore, 1968). Recarte and Nunes (1996, 2002) demonstrated that drivers' awareness of their speeds is a function of implicit visual cues as well as explicit checking of the speedometer. Drivers' use of their speedometer appears to predominate during acceleration, whereas deceleration and speed maintenance are more often left to perceptual cues. The reliance on perceptual cues is not without its drawbacks however. In a study where participants were asked to estimate speeds from the passenger seat of a real car (where they could not read the speedometer), they tended to underestimate the speeds, with largest errors at the lowest speeds. At 80 km/h, the participants underestimated the car's speed by approximately 17 km/h, at 100 km/h the participants underestimate was approximately 13 km/h.

These sorts of perceptual effects on drivers' speeds have been the basis for a range of road treatments designed to reduce drivers' speeds, treatments that have come to be known as perceptual countermeasures (Charlton, 2004; Fildes and Jarvis, 1994; Godley, Triggs, & Fildes, 2004). For example, transverse lines painted on the road and intended to influence drivers' perception of speed have been shown to reduce speeds in several laboratory and field studies (Godley, Triggs, & Fildes, 2000). In one of the earliest applications of these treatments, Denton (1980) applied visual patterns developed in earlier laboratory work to the area preceding the Newbridge Roundabout on the M8 in Scotland and found that drivers' average roundabout entrance speeds were significantly reduced by 12.8 km/h.

When transverse line patterns have been placed on approaches to dual carriageway roundabouts or at the beginning of villages they have resulted in speed reductions ranging from 4 km/h to 13 km/h and in crash reductions of up to 50% (Carsten, Tight, Pyne, & Dougherty, 1995; Elliott McColl, & Kennedy, 2003). Herringbones, dragon's teeth, and a range of other pavement markings have also been shown to have similar speed reducing effects. The results of the laboratory tests and field trials of these techniques, however, have shown that their effectiveness is can be limited when applied over longer distances (Macaulay, et. al., 2004; Martens, Comte, & Kaptein, 1997). A herringbone lines pattern (peripheral transverse lines extending 1.0 m into the lane from each edge-line) developed using a driving simulator (Charlton, 2003a) was recently the subject of before and after field tests at two locations on New Zealand state highways (Martindale & Urlich, 2010). The markings were applied at the approach to a hazardous intersection and a river bridge beginning 410 m from the hazard sites. Speeds were reduced significantly (a maximum of 12.2 km/h reduction in average speed), but the effect was greatest over the first 150 m of the treatment, with lesser (although still significant) speed reductions 50m from the hazards.

Similar markings were also found to improve drivers' path through hazardous curves (Charlton, 2007). Other perceptual changes on the approach to dangerous rural intersections, such as reducing clear sight distances by adding a roadside shade cloth, can reduce drivers' speeds and improve safety (Charlton 2003b; Uchida, de Waard, & Brookhuis, 2011).

Figure 5. A herringbone lines perceptual countermeasure as applied in simulation (left) and on SH57 in Levin, NZ (right).

Godley, Fildes, Triggs, and Brown, (1999) tested several types of perceptual countermeasures in a driving simulator; transverse lines that extended across the entire lane, several variations of a herringbone pattern (peripheral transverse lines), and edge-line markings such as chequered and textured edge-lines. Speeds at the transverse lines and herringbone patterns decreased between 8 km/h (normal driving) and 11 km/h (speed adapted). The only speed difference found between the transverse line and herringbone patterns was in the first 100 meters of treatment (with slightly slower speeds found for the transverse lines) but had equivalent effects over the remainder of the 400m length of the perceptual treatments tested. The textured edge-line treatment (which also narrowed the lane) was found to reduce speeds by 1.88 km/h (compared to a wide control road) and resulted in drivers' lane that were closer to the centre line (compared to a control road).

Godley and his colleagues concluded that the speed differences observed at the start of the transverse line treatments were the result of an alerting property of the full transverse lines, but the comparability of the speed reductions produced by the full transverse lines and herringbone patterns over the remainder of the treatment indicated that they both produced an increase in drivers' perceptions of speed (Godley, Fildes, Triggs, & Brown, 1999, Godley, Triggs, & Fildes, 2000). Participants' ratings of mental workload and risk suggested that speed reductions obtained with the textured (lane narrowing) edge-line were associated with perceptions of increased driving difficulty, whereas the chequered edge-line was associated with increased ratings of subjective risk but no significant reductions in drivers' speeds.

Retting, McGee, and Farmer (2000) applied pavement markings consisting of a gradual taper of existing edge-lines to freeway off-ramps with horizontal curves. When compared to pre-treatment speeds, the markings produced significantly lower drivers' speeds at three out of the four test locations. Passenger vehicles exceeding the posted speed by more than 16.1 km/h (10 mph) decreased from 83% to 66% at one exit ramp in New York, and from 40% to 27% and 27% to 21% at two freeway exits in Virginia. In a somewhat different application of perceptual speed markings, Manser and Hancock (2007) conducted a study in which 42 participants experienced three different visual patterns (vertical segments that decreased, increased, or remained a constant width) while driving through a simulated tunnel. When compared to a baseline condition, the participants gradually decreased their speeds in the presence of the decreasing width visual pattern and increased their speeds with the increasing width visual pattern. All of the patterns reduced drivers' speeds below their baseline speeds.

Recently, Montella and his colleagues, (Montella et al., 2011) tested a range of perceptual countermeasures intended for use on the approaches to rural intersections. Using a driving simulator, they compared transverse lines and dragon's teeth markings (based on the principles of alerting and speed perception), a coloured intersection area (based on a principle of intersection highlighting), and painted and raised median islands (based on the principle of lane narrowing). The dragon's teeth markings performed slightly better than the transverse lines, producing a significant speed reduction of 6 km/h 75 m before the intersection. The intersection highlighting also produced a significant speed reduction of 11 km/h, measured at the centre of the intersection, with significant deceleration starting 150 m before the intersection. The painted median did not produce speed reductions but the raised median island resulted in significant speed reductions of 8 km/h 150 m before the intersection centre.

As mentioned earlier, manipulations of road width and number of lanes have been shown to have significant, long-lasting effects on drivers' speeds. Van der Horst and Hoekstra (1994) tested several strategies proposed for reducing drivers' speeds on 80km/h rural roads, including changes in lane width, edge markings, and centre markings. Using a driving simulator, two lane widths and three experimental edge-lines were compared. The largest effects were obtained for a 2.25 lane width and the speed reductions produced appeared to be long-lasting (immune to adaptation), even when participants were given instructions intended to put them under time pressure.

An even more extreme reduction in lane width was the subject of a field test in England where the overall carriageway width was reduced 33% to 3m (by creating a 1.5m non-motorised lane). The treatment was highly effective, achieving significant 21% reductions in both mean and C85 speeds (mean speed of 25 mph & C85 of 30 mph) (Traffic Advisory Unit, 2004). Vey and Ferreri (1968, cited in Martens, Comte, and Kaptein, 1997) compared two nearly identical bridges and found that 3m lanes produced significantly lower speeds than 3.4m lanes. An analysis of rural two-lane roads found a significant positive correlation between pavement width and speed even though the speed limit was the same on all roads (Martens, Comte, & Kaptein, 1997). Similarly, a significant relationship between lane width and speed on urban arterials has been reported in a wide variety of locations and situations (Heimbach, Cribbins, & Chang, 1983; Lum, 1984). In one study of four-lane arterials, every 0.3m of lane width over 3m was shown to produce an increase of 4.64 km/h in 85th percentile speeds (Fitzpatrick Carlson, Wooldridge, & Brewer, 2000). In an extensive review of lane narrowing trials, road narrowing by itself, without any supplementary design measures, was found to produce speed reductions of 5.7 km/h for every meter of lane width reduction beyond 4 meters (Martens, Comte, & Kaptein, 1997).

As with other perceptual countermeasures, the effectiveness of lane narrowing is presumed to result from increasing drivers' implicit perceptions of speed. Lane narrowing has been found to reduce drivers' estimates of their driving speeds by as much as 11 km/h (Chinn & Elliott, 2002; Elliott, McColl, & Kennedy, 2003). Highways with wide 3.5m lanes are generally rated as safer by drivers than narrow 2.7m lanes, and associated with higher chosen speeds, but interestingly they are rated lower in their aesthetic qualities (Zakowska, 1997). The opposite pattern is found for narrow lanes of 2.7m (higher aesthetics but lower safety and speed choice) and even a small increase in width (to 3m) produces much higher speeds with only slightly higher perceived safety ratings (Zakowska, 1997). The lateral clearance between the edge of roadway and roadside objects appears to have similar effects on drivers' speeds. A reduction of lateral clearance from 30m to 15m decreases drivers' speed by only 3%, but decreasing lateral clearance to 7.5m reduces speeds by 16% and can reduce the proportion of drivers exceeding the speed limit from 81% to 58% (Martens, Comte, & Kaptein, 1997). Buildings, trees, and parked cars immediately adjacent to the road have all been found to reduce speed by 12% to 14%, and the distance of housing from the road has been found to be positively correlated with urban car speeds (Martens, Comte, & Kaptein, 1997). Urban buildings affect estimates of drivers' own travel speed by 1.6 km/h to 4.8 km/h and the amount of architectural detail has also been found to be strongly correlated with drivers' assessed speeds (Elliott, McColl, & Kennedy, 2003).

Even more subtle manipulations of the roadway have also been shown to have significant effects on drivers' speeds. As mentioned earlier in this review, Cooper Jordan, and Young (1980) reported the results of an experiment on three major roads in the United Kingdom. The researchers found that resurfacing after typical surface deterioration resulted in increases in traffic speeds by up to 2.6 km/h. The largest increase occurred for a section of road that had deteriorated to the worst state of irregularity. Similar findings were reported for recently resurfaced roads in Finland; resurfacing increased speeds by 0.6 km/h and increased still more (by 0.5 km/h) after the first winter period for a total increase of 1.1 km/h (Leden, Hämäläinen, & Manninen, 1998). In a study of different kinds of road surfaces, smooth road surfaces followed by rough surfaces were associated with an immediate reduction in mean speeds of 5%, although when a rough surface was followed by a smooth surface no immediate change in speed was noted (Te Velde 1985, cited in Martens, Comte, & Kaptein, 1997). Even larger reductions in speed due to road surface roughness have been reported in some cases, up to 14% to 23% reductions in average speeds in some locations (Slangen, 1987, cited in Elliott, McColl, & Kennedy, 2003).

The systematic application of these perceptual effects to change driver behaviour (e.g., speed and lane position) and improve road safety has been called the Self-Explaining Roads (SER) approach (Charlton et al., 2010; Theeuwes, 1998; Theeuwes & Godthelp, 1995; Weller, Schlag, Friedel, & Rammin, 2008). The SER approach has its roots in cognitive psychology and attempts to improve road safety via two complementary avenues. The first is to identify road designs that promote desirable driver behaviour. Perceptual properties such as road markings, delineated lane width, and roadside objects can function as built-in instructions and guide driver behaviour, either implicitly or explicitly (Charlton, 2004, 2007; Riemersma, 1988; Weller, Schlag, Friedel, & Rammin, 2008). A second aspect of the SER approach is to help establish mental schemata, memory representations that will allow road users to easily categorise the type of road on which they are travelling and behave accordingly (Theeuwes & Godthelp, 1995). When the visual features of roads are applied consistently within a hierarchy of road types, drivers will be more likely to form schemata that automatically evoke the desired expectations and driving behaviours.

Weller, Schlag, Friedel, and Rammin (2008) conducted a laboratory study in which participants were asked to rate a variety of rural road pictures. The study revealed that drivers could reliably distinguish between three different rural road categories based on only their lane width and road markings and that these categories successfully predicted participants' ratings of the appropriate speed for each road. Interestingly, participants' subjective ratings of risk and danger did not reliably predict preferred speeds for the three road categories, whereas subjective comfort and monotony did (the higher the comfort and monotony, the higher the speeds). Using a similar experimental procedure, Stelling-Konczak, Aarts, Duivenvoorden and Goldenbeld (2011) found that participants could reliably discriminate between rural roads with different speed limits using only edge-lines, coloured median treatments, and physical separation between lanes.

In New Zealand, a recent field trial of SER designs demonstrated a significant effect of changes in road delineation and forward visibility, resulting in improved speed management in an urban area (Charlton et al., 2010). Drivers' speeds became differentiated to the two road categories, and speed variability within each category was dramatically reduced. Ratings of pre-treatment and post-treatment photographs of the roads revealed another interesting finding; residents' ratings of their normal driving speeds and safe driving speeds were more highly correlated for the photos of the SER treatments than for the pre-treatment photos. In other words, the ratings of preferred speeds and perceived safe speeds mirrored the speeds measured on the roads. Further, post-treatment photographs of the two road categories produced significantly different road ratings and treated roads were associated with lower speed ratings than photographs of untreated roads. This effect, speed reductions and differentiations obtained for photo representations of the roads, independent of any physical effect of the treatments' on drivers' speeds, suggested that conceptual road categories had been established.

Although none of the studies of SER have used objective risk to define road categories, some authors have suggested it as a possibility (Steyvers & Johnson, 2005). One particularly interesting idea came from Campagne (2005) who proposed colouring the markings used on roads to indicate the level of risk to the driver when exceeding the speed limit (e.g., red lines for high speed motorways, green lines for moderate speed distributors and blue lines for low speed access roads). Alternatively, the colour of the delineation could be used to indicate the level of danger to other road users (e.g., red lines for urban roads with high numbers of pedestrian and green lines for high speed motorways, shown in Figure 5). Campagne argued that colour coding would be superior to signs alone because it would always be present, and would not require as much cognitive interpretation (e.g., red has pre-existing association with danger). Other researchers, however, have argued that drivers' speed-choice behaviour (but not the attitude towards that behaviour) can be changed without changing the perceived level of risk (Rothengatter, 1988). It has further been argued that in fact there is a need to identify perceptual features that do not affect the subjective safety of roads so that the perceptual benefits can be achieved without the danger of them being overcome or diluted by drivers' risk compensation mechanisms (Riemersma, 1988).

Figure 6. A proposed colour coding of roads to indicate the level of risk to other road users when drivers exceed speed limits (from Campagne, 2005, p. 295).

Summary.

A wide range of perceptual countermeasures have been found to reduce drivers' speeds, improve their lane positions, and increase the quality of their decision-making at high-speed intersections. Answering the question of how perceptual countermeasures achieve these changes in drivers' behaviour is somewhat less clear-cut. It has been suggested that many of the countermeasures, such as transverse lines, herringbones, and dragon's teeth, work by increasing drivers' unconscious experience of speed (Denton, 1980; Manser & Hancock, 2007). Other authors have argued that perceptual countermeasures work because they also have a conscious alerting function, and may also increase perceived driving difficulty enough to cause drivers to slow down (Godley, Triggs, & Fildes, 2000). There is mounting evidence that a driver's speed and lane position are usually maintained through habit patterns and momentary changes produced by perceptual countermeasures are the result both perceptual influences on speed and well-learned reactions to road and traffic stimuli that can maintain or modify driving behaviour without the driver's conscious awareness (Charlton & Starkey, 2011).

When the perceptual features of roads are applied systematically to form visually distinct road categories there is evidence that drivers will form conceptual categories that result in differentiated driving behaviour appropriate to each category. Unlike many applications of perceptual countermeasures where a single hazard or crash blackspot is treated, SER treatments are applied to large areas in order to establish a default, automatic driving speed that is elicited when a driver encounters a road with a particular look and feel. The potential for using perceptual features to create a road category for particularly hazardous roads has not been attempted thus far to our knowledge, although some authors have speculated on the properties that such a road category ought to possess (Campagne, 2005; Rothengatter, 1988; Riemersma, 1988). As with other SER trials, however, some combination of edge-line markings, lane narrowing, and coloured medians could be used to create a high-risk road category as shown in Figure 7. Further work needs to be done to determine whether perceptual countermeasures introduced to improve drivers' safety margins on objectively risky roads would be successful in creating a clear road category and how it would interact with drivers' perceptions of subjective risk.

Figure 7. Possible road treatments for hazardous rural roads;
a rural median trial in New Zealand (left) and The Netherlands (right).

4. Research Questions

The goal of this project was to identify the state of knowledge regarding two practical questions identified by the Automobile Association Research Foundation. First, can hazardous New Zealand roads be made to appear to be more risky to drivers in order to improve the safety of their driving behaviour? Second, can the visual appearance of hazardous New Zealand roads be changed to produce safer driving regardless of drivers' perceptions of risk?

In the light of the literature review related to risk in driving, hazard detection, perceptions of risk, perceptual countermeasures, and their relationship to driver behaviour the answers to both of these practical questions would appear to be a qualified "yes". As regards the first question, although it has been established that there are large individual differences in drivers' perceptions of risk, and that drivers' risk judgements are not always accurate, there is sufficient evidence that subjective risk is affected by the road environment and that in many circumstances relative levels of subjective risk do retain a general correspondence to the levels of objective risk in the driving environment. It is also clear from the literature that sections of road where drivers' perceived risk is significantly lower than the objective risk (risk discordance) present a significant hazard to drivers. What is unknown, however, is what levels of subjective risk are currently experienced by drivers on hazardous roads. These issues point to the first three research questions:

What levels of subjective risk are experienced on hazardous New Zealand roads?

What hazardous road sections or situations are under-recognised by New Zealand drivers (i.e., show the greatest dissociation between objective and subjective risk)?

What roads are generally over-driven (i.e., roads where drivers display poor safety margins in spite of high levels of subjective risk) by New Zealand drivers?

Although the research findings suggest that driver characteristics such as age and self-assessments of driving skill have a large influence on hazard detection and risk perception, it is worthwhile considering what can be done to increase the conspicuity of road hazards. Drawing drivers' attention to static (i.e., fixed location) road hazards, particularly hazards that are apparently undetected or under-appreciated may have positive safety consequences for all drivers, regardless of their age or self-perceptions of their driving skill. These considerations lead us to propose two additional research questions:

Will the introduction of site-specific hazard warnings for under-recognised hazard locations increase drivers' perceptions of risk and result in better safety margins?

What traffic control devices or other interventions (e.g., perceptual countermeasures) will increase drivers' safety margins at sites where drivers' perceptions of risk are already high?

As regards the second practical question posed at the outset of the research, the research literature is clear in suggesting that perceptual countermeasures could be effective in modifying drivers' behaviour on hazardous New Zealand roads. The effect of these countermeasures on drivers' perceptions of risk, however, is not known. It is of considerable interest to ask how the application of site-specific perceptual countermeasures will affect drivers' perceptions of risk (particularly at locations where there is a mismatch between subjective risk and objective risk). A related question is raised in this context when we consider the research into the SER approach; will perceptual "corridor treatments" (applied to routes rather than discrete sections of road) be successful in increasing drivers' safety margins and what effects will they have on drivers' perceptions of risk? These considerations lead us the next three research questions:

Will the introduction of perceptual countermeasures at hazardous locations (site-specific treatments) increase drivers' safety margins and what effect will they have on perceptions of risk?

Which perceptual countermeasures are most effective in reducing speeds and increasing safety at site-specific locations on hazardous New Zealand roads?

What perceptual features can be used to delineate a high risk road category (i.e., corridor treatments) and will they produce appropriate driver expectations and safety margins (i.e., correct understanding of their meaning as well as improved behaviour)?

The range of research methods available to address these questions, as well as five indicative research projects that could be used to answer the questions will be described in the next section.

5. Research Prospectus

In the previous section we identified eight research questions based on gaps in the research literature and the practical questions about how to use risk perceptions and perceptual countermeasures on high-risk roads. There is, of course, a range of possible methods of answering each of the questions including: surveys, questionnaires, focus groups, laboratory experiments, observations, and field tests. In this final section we will consider each of these methods, as well as describe some candidate research projects that might be undertaken to answer the research questions.

Candidate methods

Archival methods.

To address most, if not all, the research questions, there needs to be some way of determining the objective risk of roads. The objective risk of specific roads and locations is typically determined through analysis of crash records by means of archival tools such as the Crash Analysis System (CAS) or its precursor, the Accident Investigation System (AIS). CAS is a computer-based system maintained by the NZ Transport agency and can provide the crash history for specific locations or road sections, as well as a wealth of information regarding the crash types, contributing factors, and consequences for the people involved. For many locations, however, a crash history may significantly underestimate the objective risk as it will not include near-miss events and the potential for future crashes.

Because of these limitations, KiwiRAP star ratings should also be used to identify roads of particular interest and Road Protection Scores (RPS) produced by KiwiRAP used as a measure of prospective risk. KiwiRAP, The New Zealand Road Assessment Programme, is a road safety partnership between the New Zealand Automobile Association, the NZ Transport Agency, Ministry of Transport, Accident Compensation Corporation, and New Zealand Police. KiwiRAP Road Protection Scores (RPS), which are calculated for every 100-metre section of the state highway network, can be thought of as a way of assessing the future potential for crashes at a given location, in other words, prospective risk. KiwiRAP RPS are based on the road elements known to be associated with three primary crash types: run-off road crashes, head-on crashes and intersection crashes. The road elements used to calculate risk scores include the number of lanes and type of lane separation, lane widths and shoulder widths, geometric features such as horizontal alignment, road delineation, provisions for overtaking traffic, speed environment, presence of roadside hazards, and traffic volumes. For many of the research projects to be described, the KiwiRAP RPS can be used as a measure of prospective risk, a potentially valuable surrogate for objective road risk.

Survey methods.

Survey methods include a wide range of techniques including structured interviews, questionnaires, and focus groups. These techniques can provide a wealth of subjective data, some of it quantitative (e.g., speed preferences, risk judgements, etc.) and some of it qualitative (descriptions of reasons for speeds chosen, types of risks identified, etc.). These methods are relatively inexpensive and easy to use, albeit they are more difficult to use well. The most common pitfall associated with survey techniques is to use them in situations where they are not needed. Because they are frequently perceived as an easy way to collect data, they are often casually prepared, and poorly-prepared surveys or questionnaires, used in situations where other data sources are available, can be worse than collecting no data at all; they can convey false information. There are numerous examples in the literature of how survey methods can be used effectively to collect risk perception data relevant to driving risk research (e.g., Armsby, Boyle, & Wright, 1989; Siren, & Kjær, 2011; Sjöberg, 2000).

In addition to interviews and questionnaires, participatory design workshops (a type of focus group) can play an important role in identifying and assessing candidate road designs. Participatory design is a process that involves eliciting the knowledge, ideas, and opinions of users throughout the stages of design. One of the main goals of participatory design is to elicit the tacit or implicit knowledge of users, knowledge that designers may lack due to their different perspectives on the system or artefact being designed. As regards the current research, participatory has been used sucessfully in transport planning and urban design (Charlton, In press; Maarttola & Saariluoma, 2002; Tang & Waters, 2005).

Part-task methods.

Part-task methods are data collection techniques in which some component of the behaviour or task of interest (in this case, driving) is created and used under controlled conditions, often a laboratory or similar setting. For example, the use of photographs to collect drivers' ratings of perceived risk or judgement of safe speeds has been successfully used by many of the risk perception studies described in the review of the literature. Photographs can also be digitally altered to present road scenes that vary in controlled, systematic ways or to present situations that are too hazardous to recreate or road treatments that do not yet exist (as described in detail by Uzzell & Muckle, 2005).

Also included in part-task methods is the use of films or videos presented on television screens or to participants seated in a full or partial automobile such as that used by Groeger and Chapman (1996) to investigate the perceptions of danger and difficulty. Video and films can be used to elicit a wide range of quantitative data from participants with the advantage that the stimuli are presented dynamically (with or without a secondary task such as steering), a higher fidelity method than still photographs for examining speed choice and perceptions of driving risk. Videographic methods can be used to digitally edit or change filmed scenes to provide greater control over the stimuli, introduce particular hazards, or test candidate road treatments as described by Charlton (2006a) in an assessment of New Zealand road hazard warning signs. Videographic methods do require considerable time in developing the stimuli, but the equipment required has become much more affordable and readily available

Driving simulation.

Another laboratory method, driving simulation can allow the examination of a wide range of driving situations with a very high degree of control over the road and task components. Advanced driving simulators offer levels of efficiency, safety, ease of data collection, as well as experimental control, that are not otherwise possible. A large amount of research activity has demonstrated that they can be an effective tool for research on driving speeds, lane position, and road designs (Bella, 2008; Jamson, Lai, & Jamson, 2010). The artificiality of laboratory procedures generally, and simulations specifically, must be taken into account when generalising the results from experimental studies to real-life situations. In the case of research into driving risk, the fidelity of driving simulators may be an issue (depending on the conditions under test) due to the fact that the perceived risk of simulator driving is usually lower than actual driving (given that the outcome of a simulator crash will not result in injury). It can also be time-consuming and expensive to prepare simulation scenarios, and difficult to recruit desired sample of drivers as experimental participants, but for some research questions simulations may be the only ethical and practical way to collect the information required.

Observation.

Observational methods include the use of speed counters and accompanying video cameras to collect data on drivers' speeds, headway distances, and lane positions (as described by Burdett, 2011, and Charlton, 2006b). For these methods to work well, they need to be as unobtrusive as possible (i.e., the presence of the data collection apparatus should not affect drivers' behaviour). For some methods of collecting speed data, such as hand-held speed guns and cameras, this can be a significant issue as drivers often assume that the activity is associated with speed enforcement. Tube counters can provide accurate speed data over long periods, and when used in conjunction with unobtrusively placed cameras, provide data that suffer from none of the loss of fidelity associated with driving simulation and part-task methods. The main disadvantage of observation is that it provides little or no control over, or information about, the type of participants and the conditions under which they are driving. Drivers' speeds, lane positions, and headway distances may vary for reasons other than the variables of interest (upstream or downstream road works, time pressures, weather, listening to music or radio broadcasts).

Another promising observation technique should be mentioned as regards its applicability for research into road risk. The "Hands-on" naturalistic observation method (de Waard, Van den Bold, & Lewis-Evans, 2010; Thomas & Walton, 2007; Walton & Thomas, 2005) is based on the finding that drivers' hand positions may reflect the momentary level of subjective risk or driving difficulty they are experiencing. Observation of drivers' hand positions can be accomplished reliably, unobtrusively and can be used in both daytime and night time conditions (Thomas, 2011). The hands-on method has the additional advantage over other risk judgement methods of being concurrent with the driving task (as opposed to retrospective). It shares the disadvantages of other observational methods in its lack of control over the participants and their driving situations.

Field trials.

Field trials of new or proposed changes to the roadway such has road markings or signs, may provide a more realistic portrayal of the issues involved in driving and drivers' perceptions of risk than some of the other methods described above. As with observation, however, there are a multitude of factors outside of the evaluator's control (e.g., bad weather, delays, data loss, etc.) and the expense of field testing may restrict the types of interventions that are tested. Although not often acknowledged, issues regarding the degree of control mean that the results produced from field trials can lack precision and preclude any causal inferences from being drawn from the data. A carefully constructed field trial (e.g., adequate length, use of control sites, etc.) will, however, produce a compelling circumstantial case, enough data to evaluate competing designs, or enable an informed decision to proceed with a wider introduction of a road safety intervention.

Candidate projects

Although a fairly large number of possible projects could be designed to address the eight research questions proposed in the previous section, either individually or in combination, the following five candidate experiments have been identified:

Project 1. Subjective risk and safety margins on rural New Zealand Roads.

The goal of this possible project is to provide initial answers to the first three of the research questions. A representative set of rural roads with various levels of objective risk (as determined by KiwiRAP ratings or crash histories) would be selected for study in conjunction with a steering group or NZTA representatives. The prospective risk would then be calculated (using KiwiRAP RPS scores) for 10-20 road sections drawn from the roads of interest. Drivers' judgements of subjective risk would then be collected for each of these road sections to quantify the correspondence between the prospective risk and subjective risk for these road sections. The subjective risk data could be collected in several ways including presentation of photographs and videos to participants in a part-task study, or by using the hands-on observation technique (simulation could also be used, but may not offer any advantage over film in this application). Finally, drivers' performance data would be collected to determine the safety margins associated with each study section. Ideally, the risk judgements and driving performance data would be collated for each driver, a requirement that could favour use of naturalistic observation techniques at some stage. Analysis of the data would be directed at identification of road sections where risk is under-recognised (subjective risk is much lower than prospective risk) and sections that are over-driven (subjective risk is high and safety margins are low). The results could be used to identify areas where site-specific road safety interventions would be most useful or locations for additional testing and field trials.

This project could be divided into stages or de-scoped to provide more general findings should they be of interest. For example, a combination of a drivers' survey and speed data could provide a comparison of large sections of road with different levels of prospective risk, but would lack much of the precision available by examining risk and performance at individual sections of road. Conceptually, this project is a replication and extension of earlier studies conducted in England and Europe (Watts & Quimby, 1980; Kanellaidis & Dimitropoulos, 1994; Kanellaidis, Zervas, & Karagioules, 2000) and applied to the New Zealand driving environment.

Project 2. The effect of perceptual countermeasures on drivers' safety margins and judgements of subjective risk.

The goal of this project is to answer the fourth and sixth research questions; can perceptual countermeasures be effective in improving driver behaviour at risk discordance locations (where subjective risk is low and prospective risk is high), and what are their effects on drivers' subjective risk judgements? In many ways, these are the most important theoretical issues underlying the practical questions proposed at the outset of this programme of research. Although the research literature contains many relevant findings on the effectiveness of a variety of perceptual countermeasures, their relationship to subjective risk, and their suitability for application to risk discordance locations is unknown. The results of this study could have considerable practical importance and could inform future versions of NZTA's *High-Risk Rural Roads Guide*.

As with the previous project, this project would begin by selecting a small number of road sections of interest, including risk discordance locations by comparing KiwiRAP RPS scores and measures of subjective risk. (Note that this project could make use of the results from Project 1 if the timing of the two projects were to permit it.) For each road section candidate perceptual countermeasures would be selected for investigation (individually or in combination). The perceptual countermeasures could either be selected with assistance from the available research literature, advice from a steering committee, or through the use of participatory design workshops. The selected designs would then be tested by means of a laboratory experiment using driving simulation or a before-after field trial. Data to be collected would include drivers' safety margins (speeds, lane positions, and headway distances) as well as perceptions of risk. The analysis would identify whether the perceptual countermeasures resulted in improvements in drivers' safety margins, any change in drivers' subjective risk judgements, and any differential effects associated with pre-treatment levels of prospective and subjective risk.

Once again, this project could be divided into stages or de-scoped to provide more general findings should they be of interest. In this case, however, it is doubtful whether survey methods could provide the site-specific data required for the analysis. Conceptually, this project is an extension of recent studies of perceptual countermeasures (Martindale & Urlich, (2010; Montella, D'Ambrosio, Galantea, Maurielloa, & Pernetti, 2011) but the results regarding improvements in drivers' safety margins and suitability for risk discordance locations would be new information of both theoretical and practical interest.

Project 3. Identification of road safety interventions for high-risk roads.

The goal of this project would be to address research questions five and seven: understanding which traffic control devices could be used to improve driver behaviour at locations of high prospective risk, particularly where subjective risk may also be high (i.e., sections of road that are over-driven). These locations pose a particular problem for road safety in that drivers apparently engage in unsafe driver behaviours, even when they are experiencing high levels of subjective risk. As identified in the literature, there may be several reasons for this behaviour; external pressures such as time on long inter-urban routes, a shortage of overtaking opportunities, or an overestimation of driving skill/underestimation of driving difficulty.

As with the previous two candidate projects, this project would use KiwiRAP RPS scores as a measure of objective risk. Drivers' estimates of subjective risk could be derived from some combination of survey, part-task, or observational methodologies. Exploring the reasons for drivers' unsafe behaviour at these sites would be an important stage of this project and focus groups or participatory design workshops may provide the only way of determining this information. Once the reasons for unsafe driver behaviour have been identified, the likely effectiveness of possible interventions could be examined using focus groups and surveys. More robust evaluations of effectiveness could be obtained in a second stage of the research (or in a follow-on study), using part-task methods, a driving simulation, or a before-after field trial. This project represents an innovative investigation into a vexing road safety problem; why do drivers persist in unsafe behaviour and what interventions can improve their safety?

Project 4. The creation of self-explaining road markings for high-risk rural roads.

The goal of this project is to address the last of the eight research questions from the preceding section. In some ways, it is the most ambitious of the projects identified, but also one with the largest potential returns. As described earlier, the essence of the self-explaining roads approach is the consistent application of road designs whose unique appearance serves to establish and activate drivers' mental schemas about the appropriate driver behaviour for that type of road. The look and feel of the road design should itself encourage appropriate safety margins (speeds, lane positions, headway distances), but the real power of the approach is the ability to create a default driving mode that is elicited when drivers are in the presence of the visible cues associated with the road category – a mode that produces homogeneity of driver behaviour, even when drivers are not paying particular attention to the driving task.

A variety of methods will be required for successful completion of this project, and as with some of the previous candidate projects, could be executed in a series of research stages. Focus groups and participatory design workshops will be useful in reviewing and exploring design concepts. Part-task methods employing digitally edited photographs or videographs can be used to test whether the designs are visibly distinct, promote desirable safety margins, and evoke correct expectations regarding risk and safety. Once candidate road markings have been identified they could receive additional testing in a driving simulator (to assess subjective driver reactions and objective driver performance) prior to introduction into the roading environment. Ultimately, however, the testing of their effectiveness will need to occur through application of the designs to a few selected sites. The data collected at this final stage should include both driver performance data (collected via naturalistic observation) as well as subjective data regarding road user perceptions of the markings via intercept surveys or postal surveys. This study would extend on-going work in the area of establishing a safe systems road hierarchy in New Zealand and of self-explaining roads efforts internationally.

Project 5. Development of a method for identifying successful road safety interventions based on perceived risk and emotion.

This final project comes from ideas implicit in several of the research questions, and from some of the earliest studies of risk perceptions in driving. The essential ideas in this project are twofold: will effective road safety treatments produce a change in drivers' perceptions of safety (as measured by risk judgements and psychophysiological measures such as GSR); and whether these measures can then be used to predict the success of new road safety treatments. As described in the literature, psychophysiological arousal as measured by GSR has long been associated with feelings of risk and other emotions. Further, psychophysiological measures may provide an even better predictor of drivers' responses to objective risk in some situations. Previous research has shown that humans use implicit (unconscious) physiological cues to guide our decision-making, and that these physiological responses (somatic markers) respond to objective risk long before we become consciously aware of it (Damasio, 1996). Using primarily part-task videographic methods, this project would explore whether changes in safety margins and introduction of perceptual countermeasures are accompanied by changes in subjective risk estimates and psychophysiological responses (GSR).

Establishing the concordance between these two measures in the context of driving would be interesting in itself from an academic perspective, but if GSR is found to be a reliable indicator and predictor of the likely success of perceptual countermeasures (and other interventions) then it will provide a practical tool of considerable value. Although this approach may sound somewhat unusual to those unfamiliar with the procedures, advertising companies have been using psychophysiological methods to effectively guide their sales campaigns for many years (Poels & Dewitte, 2006). Identifying images and phrases that produce arousal in prospective consumers help advertisers predict the effectiveness of both commercials and in-store product displays. The available research literature suggests that this approach could be very promising, and if demonstrated to be useful in the context of road safety and road design it would represent a valuable addition to our transport engineering toolkit.

6. References

Armsby, P., Boyle, A. J., & Wright, C. C. (1989). Methods for assessing drivers' perception of specific hazards on the road. *Accident Analysis and Prevention, 21*, 45-60.

Assum, T., Bjornskau, T., Fosser, S., & Sagberg, F. (1999). Risk compensation – the case of road lighting. *Accident Analysis and Prevention, 31*, 545-553.

Auberlet J-M., Pacaux M-P.¸ Anceaux,F., Plainchault, P., & Rosey, F. (2010). The impact of perceptual treatments on lateral control: A study using fixed-base and motion-base driving simulators. *Accident Analysis and Prevention*, *42,* 166-173.

Bella, F., (2008). Driving simulator for speed research on two-lane rural roads. *Accident Analysis & Prevention*, *40,* 1078–1087.

Benda, H. v., & Hoyos, C. G. (1983). Estimating hazards in traffic situations. *Accident Analysis and Prevention*, *15*, 1-9.

Berfu Ünal, A. (2010). *Discriminating Novice and Experienced Drivers Using Actual Driving Hazard Videos in Specific Risk Domains*. Paper presented at the 27th International Congress of Applied Psychology, Melbourne: International Association of Applied Psychology.

Borowsky, A., Oron-Gilad, T., & Parmet, Y. (2009). Age and skill differences in classifying hazardous traffic scenes. *Transportation Research, Part F: Traffic Psychology and Behaviour*, *12*, 277–287.

Borowsky, A., Shinar, D., & Oron-Gilad, T. (2010). Age, skill, and hazard perception in driving. *Accident Analysis and Prevention, 42*, 1240–1249.

Brown, I. D. (1982). Exposure and experience are a confounded nuisance in research on driver behaviour. *Accident Analysis and Prevention*, *14,* 345-352.

Burdett, B. R. D., & Nicholson, A. J. (2010). Speed Management on Rural Roads. In Proceedings of IPENZ Transportation Group Conference. Christchurch: Institution of Professional Engineers New Zealand.

Burdett, B. R. D. (2011). *NZTA Rural Medians Trial*. Paper presented at the The New Zealand Roadmarkers Federation Conference 2011. Rotorua: Zealand Roadmarkers Federation.

Campagne, D. M. (2005). Road speed colour coding and traffic speed control: An applied psychology approach. *Traffic Engineering & Control*, *46*, 292-295.

Carsten, O. M. J., Tight, M. R., Pyne, H. C., & Dougherty, M. S. (1995). *Speed on Rural Arterial Roads*. Report number GR/J48870. Leeds, UK: Institute for Transport Studies, The University of Leeds.

Chapman, P., & Groeger, J. A., (2004). Risk and the recognition of driving situations. *Applied Cognitive Psychology*, *18*, 1231-1249.

Chapman, P., & Underwood, G. (1998). Visual search of driving situations: Danger and experience. *Perception*, *27*, 951–964.

Chapman, P. R., Underwood, G., & Roberts, K. (2002). Visual search patterns in trained and untrained novice drivers. *Transportation ResearchPart F*, *5*, 157-167.

Charlton, S. G. (2003a). *Development of a Road Safety Engineering Modelling Tool*. Technical Report. Auckland, NZ: Transport Engineering Research NZ Ltd.

Charlton, S. G. (2003b). Restricting intersection visibility to reduce approach speeds. *Accident Analysis and Prevention*, *35*, 817-823.

Charlton, S. G. (2004). Perceptual and attentional effects on drivers' speed selection at curves. *Accident Analysis and Prevention*, *36*, 877-884.

Charlton, S. G. (2006a). Conspicuity, memorability, comprehension, and priming in road hazard warning signs. *Accident Analysis and Prevention*, *38*, 496-506.

Charlton, S. G. (2006b). *South Waikato and Taupo Target 2010 Remediation Treatments Monitoring*. (Technical Report). Report contracted by Transit New Zealand. Hamilton, NZ: Transport Engineering Research NZ Ltd. & Waikato University Traffic and Road Safety Research Group

Charlton, S. G. (2007). The role of attention in horizontal curves: A comparison of advance warning, delineation, and road marking treatments. *Accident Analysis and Prevention*, *39*, 873-885.

Charlton, S. G., & Baas, P. H. (2006). *Speed Change Management for New Zealand Roads*. Land Transport New Zealand Research Report No 300. Wellington, NZ: Land Transport New Zealand.

Charlton, S.G. (In press). Using local road features and participatory design for self-explaining roads. In M. Sullman and L. Dorn (Eds) *Proceedings of the International Congress of Applied Psychology* 2010, Aldershot: Ashgate Ltd.

Charlton, S. G. Mackie, H. W., Baas, P. H., Hay, K., Menezes, M., & Dixon, C. (2010). Using endemic road features to create self-explaining roads and reduce vehicle speeds. *Accident Analysis and Prevention*, *42*, 1989-1998.

Charlton, S. G., Newman, J. E., & Baas, P. H. (2003). Patterns of road use and perceptions of driving risk by New Zealand drivers. *Road and Transport Research*, *12*, 28-39.

Charlton, S.G., & Starkey, N.J. (2011). Driving without awareness: The effects of practice and automaticity on attention and driving. *Transportation Research Part F: Traffic Psychology and Behaviour,* doi:10.1016/j.trf.2011.04.010.

Chinn, L., & Elliott, M. (2002). *The Effect of Road Appearance on Perceived Safe Travel Speed: Final Report*. Report PA3827/80. Crowthorne, Berkshire, UK: Transport Research Laboratory.

Colbourn, C. J. (1978). Perceived risk as a determinant of driver behavior. *Accident Analysis and Prevention*, *10*, 131–141.

Cooper, D. R. C., Jordan, P. G., & Young, J. C. (1980). The Effect on Traffic Speeds of Resurfacing a Road. TRL Report 571. Crowthorne, Berkshire, UK: Transport and Road Research Laboratory.

Crundall, D. E., & Underwood G. (1998). The effects of experience and processing demands on visual information acquisition in drivers. *Ergonomics*, *41*, 448-458.

Crundall, D., Underwood, G., & Chapman, P. (1999). Driving experience and the functional field of view. *Perception, 28*, 1075-1087.

Crundall, D., Underwood, G., & Chapman, P. (2002). Attending to the peripheral world while driving. *Applied Cognitive Psychology, 16*, 459-475.

Crundall, D., Chapman, P., Phelps, N., & Underwood, G. (2003). Eye movements and hazard perception in police pursuit and emergency response driving. *Journal of Experimental Psychology: Applied*, *9*, 163–174.

Damasio, A. R. (1996). The somatic marker hypothesis and the possible functions of the prefrontal cortex. *Philosophical Transactions of the Royal Society of London, Series B, 351*, 1413–1420.

Daniels, S. Vanrie, J., Dreesen, A., & Brijs, T. (2010). Additional road markings as an indication of speed limits: Results of a field experiment and a driving simulator study. *Analysis and Prevention*, *42*, 953–960.

Davidse, R., van Driele, C., Goldenbeld, C. (2004). *The Effect of Altered Road Markings on Speed and Lateral Position. A Meta-Analysis*. Report number R-2003-31. Leidschendam, The Netherlands: SWOV Institute for Road Safety Research.

de Waard, D., Van den Bold, T. G. M. P. R., & Lewis-Evans, B. (2010). Driver hand position on the steering wheel while merging into motorway traffic. *Transportation Research Part F: Traffic Psychology and Behaviour*, *13*, 129-140.

Deery, H. A. (1999). Hazard and risk perception among young novice drivers. *Journal of Safety Research, 30*, 225-236.

Denton, G. G. (1980). The influence of visual pattern of perceived speed. *Perception, 9*, 393-402.

Elliot, M. A., McColl, V. A., & Kennedy, J. V. (2003). *Road Design Measures to Reduce Drivers' Speed via 'Psychological' Processes: A Literature Review*. Report number TRL564. Crowthorne, Berkshire, UK: Transport Research Laboratory.

Elvik, R. (2004). To what extent can theory account for the findings of road safety evaluation studies? *Accident Analysis and Prevention*, *36*, 841-849.

Evans, L. (1985). Human behaviour feedback and traffic safety. *Human Factors*, *27*, 555-576.

Fildes, B. N., & Jarvis, J. (1994). *Perceptual Countermeasures: Literature Review*. Report CR4/94. Canberra, Australia: Federal Office of Road Safety.

Finn, P., & Bragg, B. W. E. (1986). Perception of the risk of an accident by young and older drivers. *Accident Analysis and Prevention*, *18*, 289-298.

Fitzpatrick, K., Carlson, P. J., Wooldridge, M. D., & Brewer, M. A. (2000). *Design Factors That Affect Driver Speed on Suburban Arterials*. Project Report 1769-3. Austin, Texas: Texas Transportation Institute.

Fuller, R. (2005). Towards a general theory of driver behaviour. *Accident Analysis & Prevention*, *37*, 461-472.

Fuller, R., & Santos, J. A., (2002). Psychology and the highway engineer. In: Fuller, R., Santos, J.A. (Eds.), *Human Factors for Highway Engineers* (pp. 1–10). Oxford: Pergamon.

Gibson, J. J, & Crooks, L. E. (1938). A theoretical field-analysis of automobile-driving. *The American Journal of Psychology*, *11*, 453-471.

Godley, S., Fildes, B., Triggs, T., & Brown, L. (1999). *Perceptual Countermeasures: Experimental Research.* Road Safety Research Report CR 182. Canberra, Australia: Australian Transport Safety Bureau.

Godley, S. T., Triggs, T. J., & Fildes, B. N. (2000). Speed reduction mechanisms of transverse lines. *Transportation Human Factors*, *2*, 297-3122.

Godley, S. T., Triggs, T. J., & Fildes, B. N. (2004). Perceptual lane width, wide perceptual road centre markings and driving speeds. *Ergonomics*, *47*, 237-256.

Goldenbeld, C., & van Schagen, I. (2007). The credibility of speed limits on 80 km/h rural roads: The effects of road and person(ality) characteristics. *Accident Analysis and Prevention*, *39*, 1121–1130.

Gregersen, N. P. (1996). Young drivers' overestimation of their own skill–An experiment on the relation between training strategy and skill. *Accident Analysis and Prevention*, *28,* 243–250.

Groeger, J. A., & Brown, I. D. (1989). Assessing one's own and others' driving ability: influences of sex, age, and experience. *Accident Analysis and Prevention*, *21*, 155–168.

Groeger, J. A., & Chapman, P. (1990). Errors and bias in assessments of danger and frequency of traffic situations. *Ergonomics*, *33*, 1349-1363.

Groeger, J. A., & Chapman, P. (1991). The unknown risks we run: Feelings of danger and estimates of accident frequency when driving. In G. B. Grayson and J. F. Lester (Eds.), *Behavioural Research in Road Safety,* (pp. 131-138). Crowthorne, U. K.: Transport and Road Research Laboratory.

Groeger, J. A., & Chapman, P. R. (1996). Judgment of traffic scenes: The role of danger and difficulty. *Applied Cognitive Psychology*, *10*, 349–364.

Hancock P. A., & Warm, J. S. (1989). A dynamic model of stress and sustained attention. *Human Factors*, *31*, 519-537.

Harless, D. W., & Hoffer, G. E. (2003). Testing for offsetting behaviour and adverse recruitment among drivers of airbag-equipped vehicles. *The Journal of Risk and Insurance*, *70*, 629-650.

Heimbach, C. L., Cribbins, P. A., & Chang, M. S. (1983). Some partial consequences of reduced traffic lane widths on urban arterials. *Transportation Research Record*, *923*, 69-72.

Horswill, M. S., Marrington, A. A., McCullough, C. M. Wood, J., Pachana, N. A., McWilliam, J., & Raikos, M. K. (2008). The hazard perception ability of older drivers. *The Journals of Gerontology, Series B*, *63*, 212-218.

Horswill, M. S., Anstey K. J., Hatherly, C., Wood, J. M., & Pachana, N. A. (2011). Older drivers' insight into their hazard perception ability. *Accident Analysis and Prevention*, *43*, 2121–2127.

Howarth, C. I. (1988) The relationship between objective risk, subjective risk and behaviour. *Ergonomics*, *31*, 527-535.

Hoyes, T. W., Dorn, L., Desmond, P., & Taylor, R. (1996). Risk homeostasis theory, utility and accident loss in a simulated driving task. *Safety Science*, 22, 49-62.

Jamson, S., Lai, F., & Jamson, H. (2010). Driving simulators for robust comparisons: A case study evaluating road safety engineering treatments. *Accident Analysis and Prevention*, *42*, 961-971.

Janssen, W. (1994). Seat belt wearing and driving behaviour: An instrumented-vehicle study. *Accident Analysis & Prevention*, *26*, 249-261.

Jonah, B.A., Thiessen, R., & Au-Yeung, E. (2001). Sensation seeking, risky driving and behavioral adaptation. *Accident Analysis & Prevention*. *33*, 679–684.

Joshi, M. S., Senior, V., & Smith, G. P. (2001). A diary study of the risk perceptions of road users. *Health, Risk & Society*, *3*, 261-279.

Kanellaidis, G., & Dimitropoulos, I. (1994). Subjective and objective evaluation of risk on roadway curves. *Traffic Engineering and Control*, *55*, 451–454.

Kanellaidis, G., Zervas, A., & Karagioules, V. (2000). Drivers' risk perception of road design elements. *Transportation Human Factors*, *2*, 39-48.

Leden, L., Hämäläinen. O., & Manninen, E. (1998). The effect of resurfacing on friction, speeds and safety on main roads in Finland. *Accident Analysis and Prevention*, *30*, 75-85.

Lee, D. N. (1974). Visual information during locomotion. In R. MacLeod and H. Pick (Eds.), *Perception: Essays in Honor of James J. Gibson* (pp. 250-267). Ithaca, NY: Cornell University Press.

Lee, S. E., Klauer, S. G., Olsen, E.C. B., Simons-Morton, B. G., Dingus, T. A. Ramsey, D. J., & Ouimet, M. C. (2008). Detection of road hazards by novice teen and experienced adult drivers. *Transportation Research Record*; *2078*: 26–32.

Lewis-Evans, B., & Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis and Prevention, 38,* 610-617.

Lewis-Evans, B., de Waard, D., & Brookhuis, K. A. (2010). That's close enough – a threshold effect of time headway on the experience of risk, task difficulty, effort, and comfort. *Accident Analysis and Prevention, 42,* 1926–1933.

Lum, H. S. (1984). The use of road markings to narrow lanes for controlling speed in residential areas. *Institute of Transportation Engineers Journal*, *54*, 50-53.

Lund, A. K., & O'Neill, B. (1986). Perceived risks and driving behaviour. *Accident Analysis & Prevention, 18*, 367–370.

Maarttola, I., & Saariluoma, P. (2002). Error risks and contradictory decision desires in urban planning. *Design Studies*, *23*, 455–472.

Macaulay, J., Gunatillake, T., Tziotis, M., Fildes, B., Corben, B., & Newstead, S. (2004). *On-Road Evaluation of Perceptual Countermeasures*. Report CR219. Canberra, Australia: Australian Transport Safety Bureau.

Manser M. P., & Hancock, P. A. (2007). The influence of perceptual speed regulation on speed perception, choice, and control: Tunnel wall characteristics and influences. *Accident Analysis and Prevention*, *39*, 69–78.

Martens, M., Comte, S., & Kaptein, N. (1997). *The Effects of Road Design on Speed Behaviour: A Literature Review*. Working Paper R 2.3.1, Managing Speed on European Roads (MASTER) project. Finland: VTT.

Martindale, A., & Urlich, C. (2010). *Effectiveness of Transverse Road Markings on Reducing Vehicle Speeds*. NZ Transport Agency research report 423. Wellington, New Zealand: NZ Transport Agency.

Matthews, M. L., & Moran, A. R. (1986). Age differences in male drivers' perception of accident risk: The role of perceived driving ability. *Accident Analysis and Prevention, 18*, 299-314.

McCormick, I. A. Walkey, F. H., & Green, D. E. (1986). Comparative perceptions of driver ability-a confirmation and expansion. *Accident Analysis and Prevention, 18,* 205-208.

McKenna, F. P. (1987). Behavioural compensation and safety. *Journal of Occupational Accidents, 9,* 107–121.

Mckenna, F. P., & Crick, J. L. (1991). Hazard perception in drivers: a methodology for testing and training. Final Report, Behavioural Studies Unit, Transport and Road Research Laboratory, Crowthorne, UK.

Montella, A., Aria, M., D'Ambrosio, A., Galantea, F., Maurielloa, F., & Pernetti, M. (2011). Simulator evaluation of drivers' speed, deceleration and lateral position at rural intersections in relation to different perceptual cues. *Accident Analysis and Prevention, 43*, 2072-2084.

Näätänen, R., & Summala, H. (1974). A model for the role of motivational factors in drivers' decision-making. *Accident Analysis & Prevention, 6,* 243-261.

Näätänen, R., & Summala, H. (1976). *Road User Behaviour and Traffic Accidents*. Amsterdam: North-Holland.

Peltzman, S. (1975). The effects of automobile safety regulation. *Journal of Political Economy, 83,* 677–725.

Pelz, D. C. and Krupat, E. (1974). Caution profile and driving record of undergraduate males. *Accident Analysis and Prevention, 6,* 45–58.

Poels, K., & Dewitte, S. (2006). How to capture the heart? Reviewing 20 years of emotion measurement in advertising. *Journal of Advertising Research, 46*, 18-37.

Pollatsek, A., Narayanaan, V., Pradhan, A., & Fisher, D. L. (2006). Using eye movements to evaluate a PC-based risk awareness and perception training program on a driving simulator. *Human Factors, 48,* 447–464.

Quimby, A. R., Maycock, G., Carter, I. D., Dixon, R., & Wall, J. G. (1984). *Perceptual Abilities of Accident Involved Drivers*. TRRL Report 27. Crowthorne, Berkshire, England: Transport and Road Research Laboratory.

Recarte, M. A., & Nunes, L. M. (1996). Perception of speed in an automobile: Estimation and perception. *Journal of Experimental Psychology: Applied, 2*(4), 291-304.

Recarte, M. A., & Nunes, L. M. (2002). Mental load and loss of control over speed in real driving. Towards a theory of attentional speed control. *Transportation Research, Part F: Traffic Psychology and Behaviour, 5*, 111-122.

Retting, R. A., McGee, H. W., & Farmer, C. M. (2000). Influence of experimental pavement markings on urban freeway exit-ramp traffic speeds. *Transportation Research Record, 1705*, 116-121.

Riemersma, J. B. J. (1988). An empirical study of subjective road categorization. *Ergonomics, 31*, 621-630.

Rothengatter, T. (1988). Risk and the absence of pleasure: a motivational approach to modelling road user behaviour, *Ergonomics*, 31, 599-607.

Rothengatter, T. (2002). Drivers' illusions - no more risk. *Transportation Research, Part F: Traffic Psychology and Behaviour, 5*, 249-259.

Sagberg, F., & Bjørnskau, T. (2006). Hazard perception and driving experience among novice drivers. *Accident Analysis and Prevention, 38*, 407–414.

Sagberg, F., Fosser, S., & Saetermo, I., F. (1997). Investigation of behavioural adaptation to airbags and antilock brakes among taxi drivers. *Accident Analysis and Prevention*, *29*, 293-302.

Salvatore, S. (1968). The estimation of vehicular velocity as a function of visual stimulation. *Human Factors*, *10*, 27-32.

Sexton, B. (2000). Development of hazard perception testing. In Proceedings of the Novice Driver Conference (1st–2nd June), Bristol: available at http://www.dft.gov.uk.

Siren, A., & Kjær, M. R. (2011). How is the older road users' perception of risk constructed? *Transportation Research Part F: Traffic Psychology and Behaviour*, *14*, 222-228.

Sjöberg, L. (2000). The methodology of risk perception research. *Quality and Quantity*, *34*, 407-418.

Stelling-Konczak, A., Aarts, L., Duivenvoorden, K, & Goldenbeld, C. (2011). Supporting drivers in forming correct expectations about transitions between rural road categories. *Accident Analysis and Prevention*, *43*, 101-111.

Stetzer, A., & Hofmann, D. A. (1996). Risk compensation: Implications for safety interventions. *Organizational Behavior and Human Decision Processes*, *66*, 73-88.

Steyvers, F. J. J. M., & Johnson, A. (2005). Making road safety (and danger) visible. *Ergonomics in Design*, *13*, 20-24.

Summala, H. (1988). Risk control is not risk adjustment: The zero-risk theory of driver behaviour and its implications. *Ergonomics, 31*, 491-506.

Summala, H. (1996). Accident risk and driver behaviour. *Safety Science*, *22*, 103-117.

Summala, H., & Merisalo, A. (1980). A method for determining the effect of studded tires on safety. *Scandinavian. Journal of Psychology*. *21*, 193-199.

Summala, H., & Räsänen, M. (2000). Top-down and bottom-up processes in driver behavior at roundabouts and crossroads. *Transportation Human Factors*, *2*, 29–37.

Tang, K. X., & Waters, N. M. (2005). The internet, GIS and public participation in transportation planning. *Progress in Planning*, *64*, 7–62.

Taylor, D. H. (1964). Drivers' galvanic skin response and the risk of accident. *Ergonomics*, *7*, 439-451.

Theeuwes, J. (1998). Self-Explaining Roads: subjective categorization of road environments. In A. Gale (Ed) *Vision in Vehicles VI*, (pp. 279-288). Amsterdam: North Holland.

Theeuwes, J., & Godthelp, H. (1995). Self-explaining roads. *Safety Science*, *19*, 217-225.

Thomas, J. A. (2011). *"Hands On" Assessment for the Effect of Better Road Delineation on Driving*. Paper presented at the The New Zealand Roadmarkers Federation Conference 2011. Rotorua: Zealand Roadmarkers Federation.

Thomas, J. A., & Walton, D. (2007). Measuring perceived risk: Self-reported and actual hand positions of SUV and car drivers. *Transportation Research Part F. Traffic Psychology and Behaviour*, *10,* 201–207.

Traffic Advisory Unit (2004). *Rural Traffic Calming: Bird Lane, Essex*. Traffic Advisory Leaflet 2/04. London: Department for Transport.

Uchida, N., de Waard, D., & Brookhuis, K. A. (2011). Countermeasures to prevent detection failure of a vehicle approaching on collision course. *Applied Ergonomics*, *42*, 540-547.

Uzzell, D, & Muckle, R. (2005). Simulating traffic engineering solutions to predict changes in driving behaviour. *Transportation Research Part F. Traffic Psychology and Behaviour*, *8,* 311–329.

Underwood, G., Chapman, P., Bowden, K., & Crundall, D. (2002). Visual search while driving: Skill and awareness during inspection of the scene. *Transportation Research Part F: Traffic Psychology and Behaviour*, *5,* 87–97.

Underwood G., Crundall, D. E., & Chapman P. (1997). Visual attention while performing driving and driving-related tasks'. In Behavioural Research in Road Safety, Volume 7, (Ed. B. Grayson), pp 60-74. Crowthorne, UK: Transport Research Laboratory.

Underwood, G., Crundall, D., & Chapman, P. (2002). Selective searching while driving: The role of experience in hazard detection and general surveillance. *Ergonomics*, *45,* 1–12.

Underwood, G., Phelps, N., Wright, C., Van Loon, E., & Galpin, A. (2005). Eye fixation scanpaths of younger and older drivers in a hazard perception task. *Ophthalmic and Physiological Optics*, *25,* 346-356

van der Horst, R., & Hoekstra, W. (1994). Testing speed reduction designs for 80 kilometre per hour road with simulator. *Transportation Research Record, 1464,* 63-68.

Wallis, T. S. A., & Horswill, M. S. (2007). Using fuzzy signal detection theory to determine why experienced and trained drivers respond faster than novices in a hazard perception test. *Accident Analysis and Prevention*, *39*, 1177–1185.

Walton, D., & Thomas, J. A. (2005). Naturalistic observations of driver hand positions. *Transportation Research Part F. Traffic Psychology and Behaviour*, *8*, 229–238.

Watts, G. R., & Quimby, A. R. (1980). *Aspects of Road Layout That Affect Drivers' Perception and Risk Taking*. TRRL Report 920. Crowthorne, Berkshire, England: Transport and Road Research Laboratory.

Weller, G., Schlag, B., Friedel, T., & Rammin, C. (2008). Behaviourally relevant road categorisation: A step towards self-explaining rural roads. *Accident Analysis and Prevention*, *40*, 1581-1588.

Wilde, G. J. S. (1982). The theory of RHT: Implications for safety and health. *Risk Analysis*, *2*, 209-226.

Wilde, G. J. S. (1988). Risk homeostasis theory and traffic accidents: Propositions, deductions and discussion of dissension in recent reactions. *Ergonomics*, *3*, 441-468.

Wilde, G. J. S. (1998). Risk homeostasis theory: An overview. *Injury Prevention*, *4*, 89–91.

Wilde, G. J. S. (2002). Does risk homeostasis theory have implications for road safety? *British Medical Journal*, *324*, 1149–1152.

Wong, Y. D., & Nicholson, A. (1992). Driver behaviour at horizontal curves: Risk compensation and the margin of safety. *Accident Analysis and Prevention*, *24*, 425-436.

Zakowska, L. (1997). Dynamic road view research for road safety and aesthetics evaluation. *Journal for Geometry and Graphics*, *1*, 51-57.