Assessment of Hazard Warning Signs used on New Zealand Roads

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Contents

Executive summary

The main purpose of this research, carried out in 2004 at the Traffic and Road Research Laboratory, University of Waikato, was to summarise the research findings associated with the effectiveness of hazard warning signs, and to demonstrate a method for evaluating new and existing hazard warning signs used on New Zealand roads. The review of the literature indicated no consensus on any single measure that best reflects the effectiveness of hazard warning signs. The testing protocol used in the present research included a range of measures in an attempt to assess the hazard warning signs as well as the consistency and sensitivity of the measures themselves.

Sixteen sign types and formats were selected, based on a survey of road safety practitioneers, for laboratory testing. A range of measures, including attentional and search conspicuity, implicit and explicit recognition, dynamic and static comprehension, and sign priming were collected.

Of the signs tested, road works and school warning signs were most often detected, remembered, and understood.

- Slippery surface warnings were associated with some of the lowest detection and comprehension rates.
- The effectiveness of the different formats depended on the type of hazard sign:
  - For road works warnings, a flashing variable message format was only slightly more conspicuous than the large dimension format, equal in comprehensibility, and perhaps somewhat worse in terms of memorability.
  - For school warnings, the flashing variable message format appeared to convey a greater sense of potential hazard, produced superior search conspicuity and priming, and was equal in terms of memorability and comprehensibility.

- The range of measures worked well as a whole in providing a methodology for assessing the relative effectiveness of warning signs. Were one to select a subset of the measures in constructing a testing protocol for signs, at this stage the two measures of conspicuity and the measure of static comprehension would appear to be of the greatest utility. The measurement of sign priming, dynamic comprehension, and recognition memorability (in that order) offer considerable potential benefits, but would require some additional work in refining the test methods associated with their collection.

Abstract

This study, carried out in 2004 at the Traffic and Road Safety Research Laboratory, University of Waikato, assessed driver reactions to 16 road hazard warning signs of various formats. A range of measures, including attentional and search conspicuity, implicit and explicit recognition, dynamic and static comprehension, and sign priming were collected for hazard warning signs for road works, schools, slippery surfaces and curves. Conclusions are presented about the effectiveness of hazard warning signs, and the method for evaluating new and existing hazard warning signs used on New Zealand roads.

1. Background and introduction

This research arose out of the practical question of how best to warn drivers of situations that may require reductions in speed or vehicle manoeuvres. The principal method of providing information regarding road and traffic hazards to drivers is by providing various types of roadside warning signs. Although relevant manuals specify the design, size, and placement of signs (to provide a minimum level of legibility and standardisation), these are not always sufficient to ensure that drivers notice, understand, and comply with the information presented. Road safety researchers have made a strong case that a significant contributor to road crashes is the failure of signage to provide adequate warning of an existing or potential roadway hazard (Dewar 1993).

When a hazard warning sign does not clearly convey its intended information, it may be ignored, or divert the driver's attention away from the roadway in an effort to understand the sign. For example, speed-related crashes are often noted to occur at curves and roundabouts where drivers underestimate their approach speeds and enter the curves or roundabouts at speeds far in excess of those which are safe. To assist drivers in negotiating curves safely, many curves are posted with warning signs to indicate the direction and approximate degree of the turn required. In addition, many of these curve warnings also have a supplementary plate showing a suggested speed for the curve. Research has shown, however, that relatively few drivers act in accordance with these suggested curve speeds (Donald 1998). One study reported that 90% of drivers exceeded the suggested speed and over half exceeded it by 10 to 30 km/h (Chowdury et al. 1998). This is perhaps not surprising in light of the finding that a majority of warning signs may not be noticed by drivers (Hughes & Cole 1984, Shinar & Drory 1983). In one study of drivers' attention to warning signs (e.g. cross roads, school crossings, sharp curves, etc.) only 6% of motorists could recall having seen the target warning signs and only 9% could recognise the correct sign (Drory & Shinar 1982).

Other studies have also noted generally low levels of attention and recall for warning signs and have questioned the effectiveness of the current system of traffic and warning signs (Fischer 1989, Johansson & Backlund 1970, Macdonald & Hoffmann 1991, Summala & Hietamäki 1984). It is interesting to note, however, that of drivers unable to recall a specific warning sign, 39% to 43% did make appropriate vehicle control adjustments before passing the sign (Fischer 1992). This finding can be interpreted as evidence that warning signs may serve as implicit cues for unconscious or automatic vehicle control responses (Crundall & Underwood 2001). Alternatively, the visual characteristics of the situation (e.g. a curve with limited clear sight distance, or increased congestion) may have prompted these drivers to slow down or alter their steering, consciously or unconsciously, without noticing a warning sign. It has been suggested that a sizeable proportion of warning signs are needed only under conditions of poor visibility. With good visibility, some warning signs are not noticed because they convey information that is redundant given other cues. (Drory & Shinar 1982, Hughes & Cole 1986).

Drivers appear to obtain information from the driving environment in two distinct ways:

- information that is explicitly noticed by the driver and the meaning consciously considered (explicit or attentional cues),
- information that is processed implicitly or unconsciously and affects drivers' performance automatically (implicit or perceptual cues).

One example of these different processing methods comes from research into drivers' awareness of their speed which appears to be based on both explicit checking of the speedometer and implicit perceptual cues (Salvatore 1968, Recarte & Nunes 1996). Implicit cues as to current speed appear to result from 'edge rate' information presented to the driver's peripheral visual field (Gibson 1979, Lee 1974, Warren 1982). Thus, driving down a narrow road, a road lined with hedges, or through a tunnel is often accompanied by an exaggerated sense of speed whereas situations with reduced edge rate information, such as open highways with broad lanes and shoulder widths are frequently associated with lower perceived speeds (Fambro et al. 1981, Smiley 1997). These implicit cues have been the basis for a range of road treatments designed to reduce drivers' speeds by perceptually increasing their apparent speed (Fildes & Jarvis 1994, Godley et al. 1999, Jarvis & Jordan 1990). These treatments, known as perceptual countermeasures, appear to function at an implicit or 'automatic' level in the sense that drivers need not explicitly attend to them or consider their meaning in order for them to be effective.

In contrast, explicit visual cues in the form of signs or other traffic control devices require driver attention in order to be effective. The finding that so few traffic signs are noticed by drivers is somewhat understandable in light of the fact that unusual and unfamiliar objects will attract drivers' attention more than familiar objects, even when the familiar objects convey important information. For example, in the case of road signs, meaningless white disks placed along the side of the road will attract drivers' attention more than meaningful traffic signs of equal size (Hughes & Cole 1984). Signs containing symbols have been reported to be more conspicuous and memorable than those relying only on text information (Jacobs et al. 1975). However, events that distract drivers or demand increased attention (e.g. high traffic densities, radio tuning, or conversing on a cell phone) have been shown to draw drivers' attention away from warning signs, speedometer information, stop lights, and braking vehicles (Alm & Nilsson 1995, Charlton et al. 2002, Hancock et al. 2003, Macdonald & Hoffmann 1991, McKnight & McKnight 1993). Some researchers have argued that explicit cues such as hazard warning signs have the greatest consequences for driver performance and that perceptual countermeasures such as transverse bar treatments may actually serve as explicit warnings (rather than implicit cues) by increasing the attentional conspicuity of road features.

In the context of these disparate findings regarding the roles of explicit attentional and implicit perceptual factors of hazard warnings, it is of considerable interest to determine which types of hazard warnings work best and under what conditions. Designs that increase the conspicuity of hazard warnings (larger size, higher contrast or reflectivity) have been put into service, as have warnings with variable messages (designed to convey more complex information). Yet, relatively few studies have systematically evaluated the effectiveness of hazard warnings currently in use. The purpose of this research was to summarise the research findings associated with hazard warning signs' effectiveness and demonstrate a method for evaluating new and existing hazard warning signs in New Zealand. This report documents that research and is organised into the following sections:

- Chapter 2: a review of the research literature on the design and evaluation of the effectiveness of hazard warning signs,
- Chapter 3: a description of the selection, field observation, and laboratory testing of warning signs undertaken,
- Chapter 4: a discussion of the implications of the findings for the evaluation and use of hazard warning signs in New Zealand,
- Chapter 5: the conclusions.

2. Literature review

A roadway hazard can be defined as "any object, condition, or situation which, when a driver fails to respond successfully, tends to produce a highway system failure" (Lunenfeld & Alexander 1990: 1-9). In-depth analyses of crashes have estimated that as many as 26% to 56% of crashes are due to inattention or some form of 'recognition failure' regarding roadway hazards (Treat et al. 1979, Wang et al. 1996). While many of these crashes do not occur in the context of signed hazards, "the inability of drivers to identify hazardous situations on the roadway is a major determinant of accident likelihood" (Dewar 1993: 30).

One of the earliest attempts to establish standardised hazard warning signs was undertaken in 1909 by the Convention on the International Circulation of Motor Vehicles which recommended four signs: hump, curve, road crossing, and railroad crossing (Dewar et al. 1997). In 1926 the Convention Relative to Motor Traffic added two more hazard signs, uneven carriage way and curve, and adopted a triangular shape to depict danger (Dewar et al. 1997). In 1949 the United Nations Protocol on Road Signs, specifying more than 50 signs, was signed by 30 (predominantly Asian and European) countries. The protocol has been revised twice since that date, in 1953 and 1968, although there is still considerable non-uniformity in the implementation of the signs internationally (Dewar et al. 1997).

Historically, hazard warning signs have been designed and evaluated by traffic engineers, police, and planners. Alternatively, traffic engineers and regulators in some countries have decided to adopt and adapt designs from existing systems such as the United States' Manual on Uniform Traffic Control Devices or the International Organisation for Standardisation (ISO) Committee on Public Information Symbols. Unfortunately, the design of the signs in these systems was based on little or no systematic research (Dewar et al. 1997). Only in the past 30 years have there been concerted efforts to design and evaluate warning signs in the light of research-based behavioural and cognitive principles.

In a survey of traffic sign experts in Australia, Canada, New Zealand, and the United States, Dewar (1988, 1993) identified four criteria for hazard warning signs: understandability and conspicuity of the signs were rated as most important, followed by reaction time and legibility distance. Other researchers and organisations have developed similar criteria for effective traffic warning signs, including the following characteristics:

- conspicuity (the ability to command attention),
- legibility (distance and glance),
- comprehension and reaction time (the need to be easily and rapidly understood),
- obviousness of required action,
- distinguishability from other signs and consistency from location to location (AASHTO 1990, Dewar et al. 1997, Donald 1995, FHWA 2002, Pline 1992, Standards Australia 1992, State of California 1990, Wogalter et al. 2002).

The specific criteria for some of these characteristics (e.g. legibility distance) vary from standard to standard, and other characteristics (distinguishability and consistency) are qualitative rather than quantitative. For example, the criterion for the most commonly employed evaluation standard, comprehension, ranges from 65% to 80% accuracy across the various standards, although the rationale for the specific levels of performance are not clear (Dewar et al. 1997).

Translating these top-level design principles into effective warning signs is not always straightforward, however. In a nationwide study of traffic signs in the United States, Knoblauch & Pietrucha (1987) assessed 30 signs for the Federal Highway Administration (FHWA) and recommended specific improvements. Tests of the re-designed signs, however, indicated only limited success; fewer than half of the re-designed signs showed any improvement in driver comprehension and several were substantially worse. Purduski & Rys (1999) devised an improved advance flagger warning sign and compared its effectiveness to the existing sign. Results of both laboratory and field testing showed improved glance legibility (recognition of signs presented for brief periods) but no improvements in reaction time or comprehension. Similarly, Ward & Wilde (1995) evaluated improved warning signage for railroad grade crossings with restricted lateral visibility and found reduced approach speeds and longer visual search visual times but no reliable increase in the numbers of drivers coming to a complete stop and engaging in search behaviours.

2.1 Effectiveness of warning signs

One aspect that most of the warning signs standards fail to address, however, is the method of testing and evaluating existing and proposed hazard warning signs. Although some testing of warning signs has occurred on public roads (e.g. Fischer 1992, Hughes & Cole 1984, Johansson & Backlund 1970, Summala & Hietamäki 1984, Ward & Wilde 1995), most tests have occurred in the laboratory or in surveys and focus groups (e.g. Al-Madani 2000, Crundall & Underwood 2001, Dewar et al. 1976, King 1975, Mackie 1966, 1967, Shoptaugh & Whitaker 1984). Only rarely have evaluations of warning signs employed a combination of field and laboratory techniques (Macdonald & Hoffmann 1991, Purduski & Rys 1999).

The reason for the overwhelming preference for laboratory evaluations has been alluded to earlier: when observing drivers on public highways there is no way of ascertaining whether drivers have seen the sign, comprehended its intended meaning, chosen to disregard the sign, or have reacted to some other cue. Laboratory testing affords substantially greater control and interpretability of the results but may lack operational realism or fidelity. For example, a substantial number of testing regimes (particularly for sign comprehension) have used static images of signs in isolation (e.g. Al-Madani 2000, Dewar et al. 1976, King 1975, Mackie 1966, 1967). Other researchers have employed static images of signs embedded in road scenes in order to assess their comprehensibility, conspicuity, or legibility in a naturalistic context (e.g. Dewar et al. 1997, Knoblauch & Pietrucha 1987, Shoptaugh & Whitaker 1984). Still other studies have used video and film (Macdonald & Hoffmann 1991) or high-fidelity driving simulations (Charlton 2003b, de

Waard & Brookhuis 1997, Godley et al. 2002) to present moving images of warning signs in context that afford perhaps the greatest combination of realism and experimental control.

2.1.1 Sign registration and memory

Early research into the information value of hazard warning signs focused on the ability of drivers to recognise or recall road signs they had recently passed (Johansson & Rumar 1966, Johansson & Backlund 1970). The focus of this approach was to identify the conscious awareness or *registration* of traffic signs by drivers by stopping them after they had driven past a warning sign and questioning them about the content of the sign. The results of studies employing this approach, called the 'roadblock paradigm', indicated a very low rate of memory for road signs. The earliest studies obtained recognition and recall results ranging from 17% to about 75%, averaging 50% (Johansson & Rumar 1966, Johansson & Backlund 1970). In New Zealand, Sanderson (1974) reported sign registration levels ranging from an average of 3.5% for a text 'children' warning sign to 41.2% for a new symbolic 'children' warning sign. Subsequent studies conducted worldwide reported even lower levels of sign registration: 2% to 20% for single signs and 34% for serially repeated signs (Milošević & Gajić 1986), 40% for moose warning signs (Åberg 1981, cited in Macdonald & Hoffmann 1991), and less than 10% during daylight hours to a maximum of 18% at night (Drory & Shinar 1982, Shinar & Drory 1983). Some studies reported higher levels of sign registration for drivers with less than 5 years experience, 39% compared to 26% for drivers with 10 or more years of driving (Macdonald & Hoffmann 1991, Milošević & Gajić 1986), but other studies found opposite effects of experience (Åberg 1981, cited in Macdonald & Hoffmann 1991, Johansson & Backlund 1970). There were also indications that the urgency or action potential of warning signs tended to increase the likelihood of them being noticed by drivers (and hence their memorability); however there was also an acknowledgement that some degree of memory decay was inevitable and that the 'emotional disturbance' produced by the stopping of drivers at roadblocks resulted in some retroactive interference with the memory for recently passed road signs (Johansson & Backlund 1970, Fischer 1989).

2.1.2 Glance legibility and recognition

Other researchers concentrated on the differences between symbolic traffic signs (pictographs) and word signs and what types of warnings are processed most quickly by drivers (Dewar 1976, Dewar et al. 1976, King 1975, Purduski & Rys 1999, Whitaker & Stacey 1981). The general approach was to present static images of the signs, either in isolation or embedded in street scenes, for different intervals ranging from 250 to 5000 msec and record participants' verbal response times to identify the signs, called *glance legibility*. These studies produced a mixture of results when the signs were examined in isolation although Dewar and his colleagues (Dewar 1988, Dewar et al. 1976, Ellis & Dewar 1979) reported generally faster verbal response times, greater legibility distances, and higher recognition under degraded conditions (e.g. fog) for symbolic (pictograph) traffic signs, as compared to word signs, particularly when the visual scene in which the sign was embedded was complex. Shoptaugh & Whitaker (1984) found no difference between symbol (pictograph) and word signs in indicating direction, although verbal responses to prohibitive word signs were faster than any other (perhaps related to the design of their study i.e. prohibitive signs required a simple 'no' reaction v. a choice reaction to the other signs).

2.1.3 Sign conspicuity and attention

Another approach has been to examine how the reflectivity, size, and placement of signs affect their ability to attract a driver's attention. In this regard, Cole & Hughes (1984) made the distinction between *attentional conspicuity* and *search conspicuity* in processing information in complex visual environments such as road scenes (Cole & Hughes 1984, Hughes & Cole 1984). These studies compared what drivers verbally reported as attracting their attention as they drove (attentional conspicuity) to instructions to report verbally all the traffic devices (and disc target signs) they saw. Cole & Hughes (1984) found that while 'visual clutter' affected both search and attentional conspicuity, attentional conspicuity was affected to a greater extent (e.g. in arterial roads and shopping centres as compared to residential roads). In these studies, the attentional conspicuity of traffic control devices (traffic signs, traffic signals, and road delineation chevrons) fared no better than 15% to 20% of driver reports, reporting only 10% of the traffic control devices present (Cole & Hughes 1984, Hughes & Cole 1984).

Summala & Hietamäki (1984) also investigated the attentional conspicuity of warning signs by measuring average vehicle speeds and speed changes at a specified roadside location in the presence of various hazard signs. Their results indicated that drivers' immediate reaction to various warning signs did not differ. Increasing their conspicuity (by placing a flashing light on top of the sign), however did produce greater reductions in vehicle speeds (Summala & Hietamäki 1984). The difficulty with the use of average speeds was that it did not allow any indication of what proportion of the drivers failed to notice the sign as opposed to how many noticed the sign and chose to disregard it (some drivers actually increased their speeds through the test area). Similarly, Otani et al. (1992) found that drivers older than 60 were more likely to ignore warning signs, although it was not clear whether these drivers failed to see the signs, chose to disregard the signs, or failed in their attempt to take appropriate action.

2.1.4 Sign comprehension

An early study on how well the intended meaning of warning signs was understood by drivers, or *comprehensibility*, was undertaken in Britain soon after British road signs were converted to symbolic signs in the early 1960s (Mackie 1966, 1967). The levels of comprehension differed across the sign types and motorists' ages but averaged only 50% accuracy. Of particular concern were signs that produced substantial numbers of responses that were the opposite of the intended meaning (e.g. overtaking permitted v. no overtaking). More recently, international studies have shown that motorists routinely have difficulties understanding the meaning of warning signs indicating 'slippery when wet', 'road narrows', 'steep descent', 'pavement ends', and 'truck crossing' with correct response rates ranging from 6% to 40% (Cooper 1989, Dewar et al. 1997, Zakowska 2001). Researchers have noted that comprehension of warning signs is typically correlated with years of driving experience given that drivers with greater experience correctly recognise and state the meaning of warning signs significantly better than drivers with less experience (Al-Madani 2000). However, in a survey of drivers' comprehension of railroad grade crossing warnings, Richard & Heathington (1988) found that drivers under 19 and older than 54 had significantly lower comprehension and recognition of the warnings than other drivers. Other studies have failed to find any significant effects of driver age, crash history, gender, or marital status on traffic sign comprehension (Al-Madani & Al-Janahi 2002).

2.1.5 Semantic priming and driver reactions

Fischer (1992) argued that the true measure of a warning sign's effectiveness is not recall, recognition, or naming, but the "extent to which, in operational terms, sign content affects drivers' preparedness for and subsequent responsiveness to events" (p. 232). To use his example, it is not important whether drivers recall seeing a sign warning of wild reindeer crossing the road, but whether having seen the sign, they respond faster or more appropriately to the sight of wild reindeer crossing the road. As an alternative to the memory, detection, and average speed paradigms, Fischer posed as a hitchhiker and observed how drivers reacted to warning signs (pedestrian crossing and road junction warnings) and whether they could report having seen them 100 m after passing the signs. Fischer noted that although 56% of the drivers were able to recall the signs, fewer than half reduced their speed (44% for pedestrian crossing, 34% for road junction). Of considerable interest, however, was the fact that only 25% of drivers reduced their speed and were able to recall having seen the signs. In other words, considerable numbers of drivers reduced their speed without any recollection of having seen the sign they passed moments before (39% for pedestrian crossing and 43% for road junction). Fischer concluded that recall of a hazard warning sign is not necessarily the best indication of its effect on driver behaviour.

As mentioned earlier, the finding that some drivers make appropriate vehicle control adjustments without being able to recall having seen a warning sign can be interpreted as evidence that some warning signs may function at an unconscious or automatic level. To investigate the implicit processing of road sign information some researchers have employed a *priming* paradigm (Crundall & Underwood 2001). In a typical priming experiment, two stimuli (usually words) are presented in quick succession. The first stimulus (the prime) is usually presented for very brief periods, and the participant is instructed to respond to the second stimulus (the probe) in some way (answering a question about it or classifying it). Priming is shown by facilitation in responding when the prime is identical with the probe (*repetition priming*) or semantically related to the probe (*semantic priming*). In the case of hazard warning signs, a driver's speed of braking to reindeer crossing the road might be said to be primed if it is facilitated or faster by virtue of a prior sign warning of reindeer (whether or not the driver recalled having seen the sign). Castro, Horberry, & Gale (1999, cited in Crundall & Underwood 2001) found repetition priming of written road signs but not semantic priming. Crundall & Underwood also found repetition priming for symbolic road signs as well as semantic priming of road scenes by symbolic road signs in experienced drivers. Inexperienced drivers' responses to the probe stimuli tended to be slower than the experienced drivers (179 msec), showed a negative repetition priming effect (the primes slowed their responding to the probes), and showed no semantic priming of road scenes. They concluded that repetitive priming of hazard warnings showed that there could be some advantage in employing repetitive warning signs and that the priming paradigm could be a valuable tool with which to explore the automatic or implicit components of the driving task.

2.1.6 Subjective utility

In contrast to the large number of studies of drivers' attention, comprehension, and reaction times to hazard warning signs, there have been almost no investigations of drivers' attitudes towards warning signs, i.e. their *subjective utility*. In a study of Swedish drivers' judgements of optimal and actual road sign frequency, Böök & Bergström (1993) found that warning signs were rated as having the lowest subjective frequency of all types of road signs, but had a desired frequency second only to road guidance and prohibitive signs. Although 'type of road' and permissive signs were rated the lowest in terms of their perceived utility, some types of warning signs (i.e. unspecified danger, circulation place, and cyclist warnings) were in the bottom quartile of sign utility values. This is in contrast to give way, road works, and children playing warnings which were rated in the top quartile of sign utility values. Interestingly, although speed limit signs were judged to be of high utility and have been observed to be highly memorable in studies of sign recall, pedestrian crossing signs which obtained among the highest utility ratings are typically associated with the lowest levels of recall (Böök & Bergström 1993). The reason for this dissociation of recall and perceived utility (importance) is not clear, but may be related to the difference between a generalised sense of social desirability as contrasted to the information needs associated with a specific traffic location.

2.1.7 Economic utility

In addition to subjective utility, warning signs can also be assessed in terms of their *economic utility*. In an economic analysis of warning sign utility, Jørgensen & Wentzel-Larsen (1999) calculated that although warning signs may reduce speeds and increase safety at a particular stretch of road, the objective driving costs (time costs per distance) will outweigh the benefits associated with reductions in crashes at the site. It was not until they broadened their analysis to the road system as a whole that warning sign installation made economic sense: i.e. their analysis indicated that it is more economical for drivers to overestimate risk than to underestimate it by the same amount across the road transport network.

2.1.8 Crash studies

Another way to assess warning signs is in terms of their effectiveness as measured by reductions in crashes. As with warning sign utility, relatively few studies are available with which to judge specific types of warning signs. In a major survey of hazard sign projects on rural highways in the United States, Smith et al. (1983) developed estimates of crash reductions obtained at hazardous locations where a hazard sign was erected. Their results, organised by the type of sign and the percent reduction in crashes, are shown in Table 2.1. The authors noted, however, that the same degree of crash reduction might not be obtained at less hazardous locations. As can be seen in the table, their analysis indicated that the greatest potential for crash reductions, particularly fatal and injury crashes, was at hazardous corners.

Table 2.1 Crash reduction percentages for six warning signs (adapted from Smith et al. 1983).

Warning sign	Mean Percent Crash Reduction			
	Total	Fatal	Injury	Property damage
Intersection	5	5	5	5
Route guidance	5	5	5	5
Narrow bridge	5	5	5	5
Slippery when wet	5	15	10	5
Curve	10	15	10	10
Curve with speed	20	30	25	20

A subsequent study by Creasey & Agent (1985) compared reviews of the research literature, state road surveys, and before-after studies of warning sign projects and derived somewhat higher estimates of 40% reduction in crashes at intersections and 30% reduction at curves. In a more extensive survey of projects and road safety experts, Agent et al. (1996) developed separate crash reduction figures across a wide range of hazard warning types. The results of their analysis are shown in Table 2.2, and although the specific estimates from the various sources may differ somewhat, there appears to be consensus on the rough order and magnitude of the crash reductions afforded by various types of hazard warning signs. More recently, a study of warning signs erected in advance of dangerous curves and junctions, supported these earlier studies' crash reduction estimates of approximately 30% (Giæver 1997, cited in Jørgensen & Wentzel-Larsen 1999).

Table 2.2 Hazard warning sign crash reduction estimates (adapted from Agent et al. 1996).

Survey estimates		Lit. review estimates		Researcher estimates	
Type of sign	% reduction	Type of sign	% reduction	Type of sign	% reduction
General	23	General	30	General	25
Curve warnings	32	Curve warnings	37	Curve warnings	30
Intersections	36	Intersections	32	Intersections	30
Bridges	34				
Railroad crossing	29			Railroad crossing	30
Pavement condition	18	Pavement cond.	18	Pavement cond.	20
Pedestrian crossing	15				
School zone	14				
Animal	8	Animal	5	Animal	15

Other applications of hazard warning signs, however, may not be as effective as those described above. Carson & Mannering (2001) reported that they found that no significant relationship existed between the installation of ice warning signs and the frequency and severity of ice-related crashes. They noted that it may have been the lack of consistency in the placement of ice warning signs, rather than characteristics specific to the signs themselves, that served to reduce their effectiveness. Similarly, a large-scale crash reduction study of cross traffic warning signs found reduced accident frequency at some locations, but no significant change at others (Gattis 1996). The researchers suggested that these differences may also have been due to inconsistent placement and use of the signs at different locations. There is also evidence that conspicuity of warning signs and ability to produce reductions in vehicle speeds do not always translate into reductions in crashes. Lighted, animated deer crossing signs implemented in Colorado were found to reduce vehicle speeds by 3 mph (4.8 km/h), but no change in the rate of deer-involved vehicle crashes occurred as a result (Pojar et al. 1975).

2.2 Alternative warning methods

2.2.1 Variable message signs

In recent years, alternative approaches to indicating potentially hazardous situations have been explored. One such approach has been the use of variable message signs (VMS), also known as changeable message signs or dynamic message signs. As the names suggest, VMS signs can display different messages, or no message, at different times. VMS signs can be either light reflecting or light emitting, and are capable of displaying a range of symbols and characters to inform drivers about road conditions and potential hazards. While most VMS applications have been used to convey directional and traffic information to drivers (Chatterjee et al. 2002), other applications have included variable speed limits, work zone detours, closed bridges, or ice on curves. VMS formats have received a great deal of interest because of their presumed ability to attract drivers' attention by displaying flashing or animated symbols, as well as their ability to display time-specific or event-specific information (e.g. school crossings and traffic congestion) (Garber & Srinivasan 1998). Figure 2.1 shows examples of vehicle-activated VMS warnings that have been tested in Great Britain (Winnett & Wheeler 2002) and Figure 2.2 shows the range of VMS hazard warnings tested in Europe (Tignor et al. 1999).

Figure 2.1 Vehicle-activated VMS warnings (left to right) curve warning, crossroads warning, and VMS in the 'Off' state (from Winnett & Wheeler 2002).

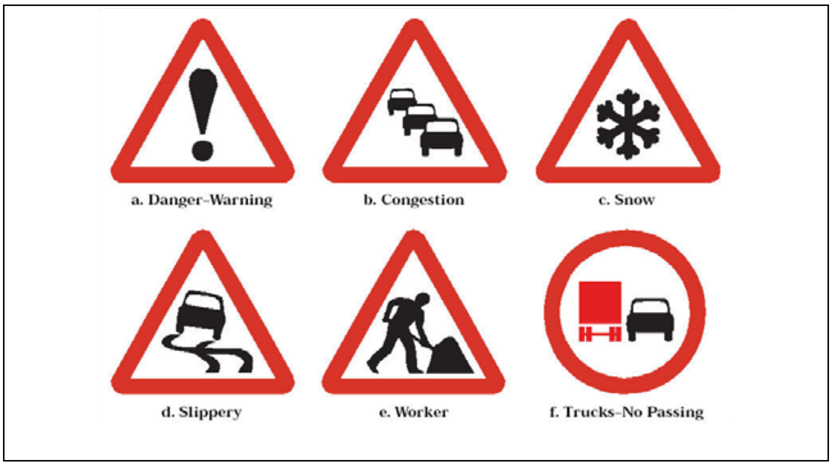


Figure 2.2 VMS hazard warning types tested in Europe (from Tignor et al. 1999).

In one of the earliest applications of VMS warnings, a single VMS warning placed in advance of a work zone reduced speeds of cars by 4.5 km/h and trucks by 2.25 km/h (Benekohal & Shu 1992). Subsequent trials of work zone VMS warnings have shown even greater levels of speed reduction (14.7 to 18.81 km/h), even when the signs were used for periods of up to seven weeks (Garber & Srinivasan 1998). In cases where VMS signs have been used to indicate slippery road conditions, average vehicle speeds were found to decrease by 0.9 to 1.8 km/h with the greatest effect obtained under night time conditions (Rämä & Kulmala 2000, Rämä 2001). The effectiveness of the signs, in terms of speed reduction, was found to decrease over time with an average 0.3 km/h smaller effect the second winter season they were used (Rämä & Kulmala 2000). When the VMS signs were set to display in a flashing mode the degree of speed reduction was magnified (an additional 0.5 to 1.3 km/h) but the investigators recommended against this mode of display owing to problems with drivers misunderstanding the meaning of the flashing mode. In the same study, Rämä and Kulmala (2000) tested a minimum headway VMS and obtained a significant reduction in the occurrence of headways shorter than 1.5 sec.

In a study in the United States, a VMS warning was programmed to display the word 'SLOW' to vehicles exceeding the speed limit on the approach to a pedestrian crossing. The VMS did not, however, result in any reduction of vehicle speeds, and was less effective than removable pedestrian islands and pedestrian crossing signs erected at a companion site (Kamyab et al. 2002). In contrast, vehicle-activated VMS curve and junction warnings in Great Britain were found to produce significant reductions in vehicle speeds of up to 7 mph (11 km/h) (Winnett & Wheeler 2002). Opinion surveys of 450 drivers in the areas where the signs were installed indicated 'overwhelming approval' of the signs and most had made the connection between their own speed and the signs being triggered.

VMS warning signs that include a reduced speed limit have been found to be more effective than VMS hazard warnings by themselves, but not as effective as speed reduction VMS signs alone (Rämä 2001). When stopped approximately 2.5 km after passing a speed reduction VMS sign, an impressive 91% of drivers recalled the speed limit. When asked what they assumed to be the reason for the reduced speed limit the most frequent answer was that the sign was variable, followed by weather and road conditions, and don't know (11%). This compared to a recall rate of only 66% for the slippery road condition VMS (Rämä 2001). However, some indication exists that the presence of VMS signs can reduce the number of drivers able to recall fixed warning signs located in the vicinity of the VMS (Rämä et al. 1999). In New Zealand, VMS school zone warning signs incorporating a reduced 40 km/h speed limit were successfully trialled at five sites in Christchurch (Neil 2002, Osmers 2001) and guidelines established for their implementation elsewhere (LTSA 2002).

2.2.2 Perceptual countermeasures

Another alternative approach to hazard warnings has been based on implicit cues designed to reduce drivers' speeds by increasing subjective speed or perceptually highlighting potential hazards (Charlton 2003b, Fildes & Jarvis 1994, Godley et al. 1999). Rather than attempt to increase the conspicuity or comprehensibility of a warning message, these treatments are designed to function at an implicit or 'automatic' level and afford a desired change in speed or lane position in advance of a potential hazard. Perceptual countermeasures have been tested in the laboratory (Charlton 2003b, Charlton et al. 2001, Godley et al. 2002) and implemented on public roads at hazardous intersections, curves, pedestrian crossings, and overtaking lanes (Charlton 2003a, Fildes & Jarvis 1994).

In a simulator study of perceptual countermeasures at curves, warnings consisting of either pavement markings or chevron sight boards were found to decrease drivers' speeds by 11.5 km/h, a reduction of 5.5 to 7 km/h more than conventional hazard warning signage at the same locations (Charlton 2003b). In a field trial of highway work zone warnings, transverse bar treatments were found to reduce average speeds only slightly, but did produce a large reduction in the standard deviation of vehicle speeds (Meyer 2000). The characteristics of the speed changes throughout the test sites led the researchers to conclude that the transverse bar treatment produced both a perceptual effect and a warning effect, and that these effects were additive (Meyer 2000). Further, while the effects on speed did not persist downstream of the treatment, the treatment effects did remain stable over a three month period. In another field trial employing pavement markings as a warning on freeway exit ramps with horizontal curves, significant reductions in the number of passenger vehicles and large trucks exceeding the posted advisory speeds were obtained (Retting et al. 2000). While perceptual countermeasures such as these do produce significant changes to drivers' speed and lane position, they may not afford particularly good attentional conspicuity, comprehensibility, or recall, or when drivers are asked about them (Charlton 2003a, Fildes & Jarvis 1994).

Figure 2.3 A converging chevron perceptual countermeasure in Japan (Meyer 2000) and a partial herringbone pattern in the Waikato University driving simulator.

2.3 Need for the present research

Given the findings regarding the subjective utility, economic utility, and potential to reduce crashes, it is of considerable interest to determine which types of hazard warnings work best and under what conditions. Relatively few international studies have been conducted to evaluate or compare the effectiveness of the hazard warnings currently in use. Not surprisingly (because they are relatively recent innovations), there are also few studies of the effectiveness of the newer hazard warning alternatives, VMS and perceptual countermeasures. Following the installation of vehicle-activated VMS curve warning, junction warning, and safety camera signs in Great Britain, Winnett & Wheeler (2002) reported a statistically significant 30% reduction in crashes (over what would have been expected without the signs). In an analysis of the effectiveness of warnings employing perceptual countermeasures, Griffin & Reinhardt (1996) reported that chevron markings implemented at various locations in Japan produced crash reductions ranging from 25% to 50% and that transverse bar markings used at many locations in Great Britain reduced crash rates by 5% to 50%. Griffin & Reinhardt concluded that perceptual countermeasures worked primarily as a warning device (rather than perceptual illusions of speed) and could be highly effective, particularly in areas associated with high vehicle speeds.

Few New Zealand studies are available with which to evaluate the effectiveness of hazard warning signs. In part, this is because many interventions at crash black spots will undertake multiple improvements simultaneously, erecting warning signs, changing road geometry, and increasing enforcement. In a study of the effectiveness of the installation of chevron sight boards at bends a 10% reduction in crashes was obtained at the 9 sites studied (LTSA 1996). When the analysis was broadened to 103 sites where multiple treatments were undertaken (chevrons, traffic signs, and raised reflective pavement markers), an overall crash reduction rate of 49% was achieved (37% reduction in daytime crashes and 67% reduction in night time crashes).

As should be apparent from the review of the literature associated with the evaluation of hazard warning signs, there is no universally agreed upon criterion for measuring warning signs’ effectiveness. All of the measures have advantages and disadvantages and cannot by themselves provide a comprehensive picture of their effects on drivers.

One of the most straightforward measures of warning signs’ effectiveness would appear to be their relationship to crashes. The drawback to using crash reduction as a criterion of a warning signs’ effectiveness is that crashes are relatively rare, multi-factorial events. Although the collection of crash data associated with changes to warning signage is valuable, only rarely are signs the only feature of the driving environment to be changed during a safety intervention. In any crash a range of driver, vehicle, and road factors are intertwined and it is typically not possible to apportion the causative role to the various factors after the fact. Further, because the relatively low rate of occurrence of crashes at a given site, several years may be required to determine whether the introduction of a sign or other road treatment has had a beneficial effect with any degree of statistical confidence. Finally, there are ethical issues involved in the replacement of existing warnings with new signage and using the health and lives of drivers as a measure of effectiveness.

A second measure that has been used to assess warning signs’ effectiveness is changes in drivers’ speeds. Yet given its apparently straightforward link to the ostensible purpose of introducing warning signs, why has driver speed been used as a measure of effectiveness in so few studies of warning signs? The answer comes in part from the fact that in many situations and for many drivers, the potential hazard indicated by the warning may not require a reduction in speed. While a few warnings do incorporate an explicit speed reduction recommendation (e.g. curve warnings), most warnings are designed simply to draw the potential hazard to drivers’ attention. The changes to speed and lane position will depend on the conditions such as current speed, visibility, and the behaviour of other road users. This fact makes it difficult to compare the relative effectiveness across different sign types and is perhaps the reason for the ambiguous results obtained by the few studies where speed has been used as a measure of effectiveness (Martens 2000).

The most often used measure of warning signs’ effectiveness has been the degree to which drivers notice them. Several methods have been used to obtain a measure of sign conspicuity, including concurrent verbal reports obtained while drivers are driving or watching movies of driving scenes and recall or recognition questions regarding signs recently passed by drivers intercepted on the roadway. When recall and recognition measures have been used, a range of short-term memory phenomena may have an adverse impact on drivers’ verbal reports. These may include the retention interval, differences in the encoding and retrieval contexts, and the effect of the presence of police or other traffic officers used to effect the roadblock. The memorability of warning signs may well be an important characteristic in cases where drivers need ready access to the information contained on a recently passed sign in order to make an effective driving decision, but memorability is not a direct measure of whether a driver has noticed a sign.

Verbal reports of what is noticed during a driving task provide a somewhat better indication of sign conspicuity, but the research has shown that drivers’ detection of road signs can be substantially different depending on their focus of attention and any explicit or implicit instructions provided to them (Hughes & Cole 1986, Martens 2000). Substantially different results have been obtained for protocols that encourage drivers to report anything that attracts their attention (a measure of object conspicuity) versus protocols that ask drivers to report all instances of particular types of targets such as warning signs or traffic control devices (search conspicuity). Whereas search conspicuity tasks typically produce higher rates of sign detection, questions have been raised about how drivers' subjective classification strategies affect the reporting frequencies for different sign types and how representative the search paradigm is of actual driving. Further, some researchers have noted that the rate of verbal reports may be affected by workload so that when drivers are under high mental load they may stop talking or provide incomplete verbal reports (Martens 2000). Yet researchers have shown no appreciable differences in sign detection rates between participants driving, watching a movie, and being passengers (Hughes & Cole 1984, Martens 2000) indicating that the mental demands of the driving task do not adversely affect verbal reports.

Detection of a sign, however, may not provide any indication of whether its intended meaning is understood. Measurement of sign comprehension is perhaps the oldest criterion of warning signs' effectiveness, and remains second only to sign conspicuity in terms of the focus of published research. Researchers have shown that sign comprehension is often different when signs are assessed as isolated symbols or are placed in context via pictures of roadside scenes (Dewar 1988). Similarly, the time available to drivers to interpret the sign, as when a driver is passing a sign, would appear to have an appreciable effect on comprehension accuracy, yet is an aspect that has been the subject of little or no explicit research.

Finally, although valuable, verbal report and comprehension paradigms have limitations given that drivers cannot report implicit perceptual information, information which may nonetheless serve a useful warning function. For this reason, recent investigations of the role of implicit information in warning signs are of considerable interest (Crundall & Underwood 2001, Fischer 1992). Research protocols such as the priming paradigm may provide an important criterion with which to evaluate the effectiveness of hazard warning signs.

In the light of the review of the published literature associated with the evaluation of hazard warning signs, the focus of the next stage of the research programme was to assess hazard warning signs currently in use in New Zealand, employing the key measures identified in the literature (e.g. conspicuity, memorability, comprehensibility, and priming). A second goal was to assess the consistency and sensitivity of the measures themselves, and in doing so make recommendations regarding a method for evaluating hazard warning signs in New Zealand, providing regulators and road controlling authorities with a means to ensure that drivers can quickly perceive and easily understand the meaning of hazard warning signs.

3. Selection, field observation, and laboratory testing

3.1 Selection

One of the first objectives of the research was to select a set of candidate hazard warnings for analysis. Initially, it was hoped to select the set of signs from three general categories associated with:

- road geometry (e.g. curves, concealed intersections, steep grades),
- road conditions (e.g. uneven, slippery, or degraded road surfaces),
- traffic conditions (e.g. delays or congestion, road works, heavy or oversize vehicles, pedestrian crossings).

In order to identify hazard warning signs to be included in the study set, a brief overview of hazard warning research and design options was prepared along with a survey asking about the perceived effectiveness of various warning signs. The survey was then distributed to a sample of road safety experts in New Zealand.

3.1.1 Method

The survey presented a subset of existing hazard warning signs selected from the current *Manual of Traffic Signs and Markings* (MOTSAM) inventory of New Zealand traffic warning signs and asked the respondents to:

- rate the signs' effectiveness on a 10-point scale ranging from 'least effective' (1) to 'most effective' (10),
- rank the signs as regards the desirability of including them in the laboratory study,
- identify any alternative formats such as alternative symbols, variable message signs, or perceptual countermeasures, to be included in the study.

The survey was distributed to six members of the project Steering Committee comprised of representatives from LTSA and Transit NZ central and regional offices, Christchurch City Council, and Opus International Consultants. The survey was also completed by another nine respondents with long-standing experience in road safety and/or traffic engineering issues.

3.1.2 Results

Of the 23 hazard warning signs included in the survey, nine were signs for which there was considerable consensus among the respondents' inclusion rankings. These nine signs are presented in the order of the survey respondents' inclusion rankings in Table 3.1. Also shown in the table are the respondents' average and median effectiveness rankings for those nine signs and the alternative sign formats suggested.

Table 3.1 Hazard warning signs identified by the survey respondents.

Sign		Inclusion rank	Mean effectiveness rating (median)	Formats of interest
	TW1 Roadworks	1	4.54 (5)	Standard, large dimension, & flashing VMS
	PW32 School	2	5.23 (6)	Standard, yellow-green, large dimension, & flashing VMS
	PW30 Pedestrian crossing	3	4.62 (4)	Standard & yellow-green
	PW 17 Curve	4	5.38 (5)	Standard & chevron sight boards
	RC4 Chevron sight board	4	–	Black & white Black & yellow
	PW41 Slippery surface	4	5.38 (6)	Standard (v. red temporary version)
	TW4 (temporary)	4	–	Standard
	PW29 Pedestrians	5	4.23 (4)	Standard & yellow-green
	TW15 Flagman	6	5.00 (5)	Standard & flashing VMS

The set of signs nominated by the survey respondents showed several noteworthy features. First, although road condition (slippery surface) and road geometry (curve) signs are represented in the set, most of the warning signs fall into the category of traffic conditions. Further, five of the signs refer to hazards located in precise or predictable locations, whereas four of the signs refer to potential hazards that may or may not be present at a given time or precise location. For example, signs for road works, school crossings, pedestrian crossings, flagmen, and curves can be interpreted as warning drivers of a hazard present in a specific location, and once the driver has passed that location, the hazardous situation is presumably terminated. In contrast, the slippery surface, children, school, and pedestrian signs refer to potential hazards associated with a general area and it is not always clear when the driver has progressed past the hazardous area.[1]

Also noteworthy is that none of the respondents expressed any interest in assessing perceptual countermeasures (e.g. transverse lines, herring bones, or edge line treatments) as warnings. In contrast, their interest in assessing electronic sign formats (i.e. flashing variable message signs (VMS)) as warnings was uniformly high. Also of interest were alternative colours used for hazard warning signs. In the case of slippery surface signs there was interest in comparing the yellow permanent sign (PW41) with the red temporary version of the same sign (TW4). In the case of the school zone, pedestrian crossing, and pedestrian signs there was interest in comparing the standard yellow/orange colour with a yellow-green format which is being implemented at many locations associated with vulnerable road users.

3.2 Field observation

The next objective of the research was to collect field observations of drivers' immediate reactions to the hazard warning signs identified by the survey respondents. The purpose of the field observations was to provide an objective indication of the signs' effectiveness to supplement the respondents' ratings, and further refine the set of signs to be used in the laboratory testing. Given the limitations of an observational study, covert measurement of the vehicle speeds before and passing a hazard warning sign was undertaken to assess drivers' reactions to a range of existing hazard warning signs. Although there was no way to determine whether the observed speeds were the result of driver attention, decision making, or some other factor, field observation appeared to present the best means of assessing driver reactions without contaminating reactions in the process of measurement.

3.2.1 Method

Field observation of driving behaviour for the nine signs identified by the survey respondents began in February of 2004. Vehicle speeds were collected at 11 locations in the Waikato district using a Marksman LTI 20-20 laser speed gun (Laser Technologies Ltd). Speeds were recorded 150 m (approx. 5.4 sec.) before the sign and 30 m after the sign (approx 1.08 sec.) at open road sites and 75 m (approx. 5.4 sec.) before the sign and 15 m (approx. 1.08 sec.) after the sign at urban (50 km/h) sites. Data were collected in a convenience sample of 30 drivers at each site, with the stipulation that only freely moving (non-platooned) vehicles' speeds were recorded. Data were collected for all sign types except for the TW15 flagman sign for which we were unable to safely and unobtrusively position ourselves to collect vehicle speed data. For several sign types, data were collected at both rural and urban locations in order to capture any differences associated with the underlying speeds (as well as traffic density and visual clutter). For the PW32 school sign, data were also collected at the end of the school day, during times these signs might be considered to be most relevant by drivers. Finally, speed data for

[1] Of course this distinction is not always clear-cut; it can be argued that road works signs sometimes refer to an area and that school warning signs often refer to a discrete area that is visually evident (school grounds).

the TW4 temporary slippery surface sign were collected given the interest shown by the steering committee in this version of the sign.

3.2.2 Results

The speeds recorded for each location, from a total of 330 vehicles, are shown in Table 3.2 (p. 29). As can be seen in the table, the sign type associated with the greatest speed reduction was the rural roadworks sign (TW1), followed by the combined presence of PW17 and RC4 chevron curve warning signs. Repeated-measures analyses of variance indicated that the speed reductions at only two of the locations were statistically reliable; the rural road works sign ($F_{(1,29)}$ = 19.15, $p < 0.01$) and the urban slippery surface sign ($F_{(1,29)}$ = 4.28, $p < 0.05$). While the speeds observed at the urban school zone during school dismissal hours also approached statistical reliability ($F_{(1,29)}$ = 3.59, $p < 0.068$), none of the other signs was associated with reliable changes in speed. It should be pointed out, however, that other features of the road environment (besides the warning signs of interest) may have had an effect on the drivers' speeds. Although we took considerable effort to select sites that were located well away from other road and traffic features that might affect drivers' speeds (roundabouts, curves, traffic control devices, etc.), the likelihood remains that variables such as road width, sight distance, and traffic density may have contributed to the speeds observed. In the case of the rural roadworks and curve warnings, the larger relative speed reductions observed for these signs may have been obtained in part because of the 100 km/h speed environment for these signs; i.e. the scope for large reductions may simply have been greater relative to signs in a 50 km/h speed environment. Many of the signs observed were associated with little or no reduction in vehicle speeds, and in some cases (e.g. urban road works and rural school zone sign), were associated with an average increase in vehicle speeds.

Finally, worth noting are the somewhat large standard deviations, particularly for the curve warnings and the urban roadworks signs. While they are certainly due in part to the limited size of the sample, they may also reflect the differential effectiveness of these signs, perhaps competing with other road features (e.g. traffic, buildings, pedestrians, etc.) for drivers' attention. Further, separating the effect of the signs from the potential hazards themselves on the drivers' speeds is not possible. For example, in the case of the curve warnings, earlier work in our laboratory has shown that some speed reduction occurs even at an unmarked curve because of the perceptual features of the curve (Charlton 2003b).

A general correspondence existed between signs rated as most effective by the survey respondents and the signs associated with the largest reductions of speed during the field observations. The signs receiving the highest mean effectiveness ratings, i.e. the curve warning and PW41 slippery surface (urban) signs, were associated with the second- and third-largest percent reductions in speed. The sign receiving the fourth-highest effectiveness rating, the TW1 road works sign, was observed to have the highest speed reduction percentage in a rural setting, although it was much less effective in the urban environment. Similarly, the second-lowest rated sign, the PW30 pedestrian crossing, was associated with a slight speed increase rather than a speed decrease in the field observations.

Table 3.2. Vehicle speed data from field observations at 11 hazard warning locations.

Sign code	Description	Vehicles sampled	Before sign		After sign		Mean speed reduction*	SD	% speed reduction*
			Min speed	Max speed	Min speed	Max speed			
TW1	Roadworks (100 km/h zone)	30	83	111	80	104	3.10	3.88	3.21
TW1	Roadworks (50 km/h zone)	30	38	66	37	61	-0.37	5.23	-1.57
PW32	School (70 km/h zone)	30	60	84	54	84	-0.13	3.55	-0.35
PW32	School (50 km/h zone)	30	46	66	46	64	0.23	3.05	0.18
PW32	School - sampled 1430-1530 (50 km/h zone)	30	48	64	47	66	0.40	2.92	0.69
PW30	Pedestrian crossing (50 km/h zone)	30	47	64	46	66	-0.03	2.22	-0.14
PW 17 & RC4	Curve - left 85 km/h advisory (100 km/h zone)	30	73	116	73	111	2.07	5.97	1.98
PW 17 & RC4	Curve - right 85 km/h advisory (100 km/h zone)	30	65	116	67	115	2.10	6.57	1.89
PW41	Slippery surface (100 km/h zone)	30	85	117	87	117	0.13	1.38	0.13
PW41	Slippery surface (50 km/h zone)	30	47	71	47	71	0.81	1.79	1.23
TW4	Slippery surface – temporary (100 km/h zone)	30	71	109	67	109	0.90	3.26	0.84

* Positive numbers refer to decreases in speed while negative numbers (negative speed reduction) refer to increases in speed.

A case can be made, however, that warning signs are most needed at locations where the potential hazards are not obvious to the driver, or where vehicle speeds at the site pose a potential hazard. There is some support for this argument in our field observations: average vehicle speeds at the sites of the PW30 pedestrian crossing and urban PW32 school signs were well above the 50 km/h speed limit, at 55.73 km/h and 55.30 km/h respectively. The field observation, and the issues associated with its interpretation do, however, illustrate the need for alternatives to measurement of vehicle speeds in order to assess the effectiveness of hazard warning signs.

3.3 Laboratory testing

The next objective of the research was to test the hazard warning signs selected by the survey respondents (and the format variants of interest) in the laboratory and compare them by means of several of the measures of effectiveness described in the literature: sign conspicuity, sign memorability, sign priming, and sign comprehension.

3.3.1 Method

3.3.1.1 Participants

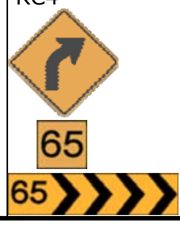
A convenience sample of 33 participants with full Class B New Zealand driver licences, 14 men and 19 women, was recruited from the region. Two of the participants, one man and one woman, were excused from the experiment (because of language problems in one case, and a misunderstanding of the instructions in the other). The ages of the remaining participants ranged from 18 to 58 years old with a mean of 28. The number of kilometres driven per week reported by the participants ranged widely from a minimum of 20 km to a maximum of 400 km for an average of 211 km (SD = 107.04). The number of crashes in the past 12 months reported by the participants ranged from 0 to 4, with an average of 0.42 crashes (SD = 0.99), and the reported number of infringement notices in the past 12 months ranged from 0 to 3, with an average of 0.39 infringements (SD = 0.80).

3.3.1.2 Apparatus

The experimental apparatus consisted of high-resolution video sequences and still images of road scenes projected as life-sized images in front of the participants who were seated in the University of Waikato driving simulator. The simulator consisted of a complete automobile (BMW 314i) positioned in front of an angled projection surface. For the present experiment, the projection area was 1.97 m in height (measured from the top of the car bonnet), 2.63 m wide, and was angled back 10 degrees from the bottom to the top of the projection surface.

The video sequences were taken of roads within a 120 km radius of the laboratory using a car equipped with fixed camera mounts and high-resolution digital video camera. The video footage was edited into 46 daytime video segments containing the hazard warning signs of interest, as well as a representative mix of other signs, traffic control devices, road users, etc. Because of the nature of some of the hazard warnings of interest, 12 of the video segments were taken at open road speeds (100 km/h). The remaining video segments were taken in 50 km/h speed zones. The video segments were then sorted to form two collections of scenes, each containing the same types of hazard warning signs and equated for road locations, speed zones, amount of roadside signage and development, traffic control devices, traffic density, pedestrians, and lighting conditions. Each collection included multiple instances of the 16 sign types and formats identified by the survey responses, as well as a range of other hazard warnings. The 16 target sign types and formats are shown in Table 3.3.

Table 3.3 Sixteen target hazard warning sign types and formats.

Sign types	Sign formats				
Pedestrian crossing (PW30)	Standard orange: 850 X 850 mm 	Yellow-green: 850 X 850 mm 			
Slippery surface (PW41 & TW4)	Standard orange: 850 X 850 mm 	Red (temporary): 850 X 850 mm 			
Roadworks (TW1)	Standard red: 850 X 850 mm 	Large dimension: 1200 X 1200 mm 	Flashing VMS: 1200 X 1200 mm 		
School (PW32)	Standard orange: 850 X 850 mm 	Yellow-green: 850 X 850 mm 	Large dimension: 1200 X 1200 mm 	Flashing VMS: 1200 X 1200 mm 	
Curve (PW 17 & RC4)	Standard orange: 1060 X 1060 mm 	Black & white RC4: 600 X 2440 mm 	Orange & black RC4: 600 X 2440 mm 	Standard orange + black & white RC4 	Standard orange + orange & black RC4 

Note: The dimensions above are the sign's measured height and width; the outside edge of diamond-shaped 850 mm signs measured 600 mm, 1060 mm signs measured 750 mm along their outside edge, and 1200 mm signs measured 850 mm along their outside edge. Supplementary plates are not included in the dimensions.

For two of the sign types, the four formats of the PW32 school warning and the three formats of the TW1 roadworks warnings, an additional video sequence for each was designated as a control repetition sequence and digitally altered to produce versions containing each format variant of the sign. Thus, three control repetition sequences for the TW1 warning, identical except for the format of the road works sign, and four control

repetition sequences for the PW32 warning, identical except for the format of the school sign, were prepared for each collection. The video sequences in each collection were then randomly ordered and assembled to form three unique 'video reels' for each collection, each 16 minute reel containing a total of 46 hazard warning signs.
Sixteen still photos, each containing one of the target hazard signs, were then extracted from the video sequences comprising the first reel (with the exception of the control repetition sequences). Another 16 still photos containing 16 different hazard warning signs were extracted from video 'out-takes', video footage that had been removed from the video sequences during the editing process but containing similar road, traffic, and roadside characteristics. The resulting collection of 32 photos thus contained 32 different hazard warning signs, the 16 target signs shown in video sequences and 16 'distractor' signs not included in the video sequences. An identical process was followed for the second video reel. An additional 8 still photos containing the hazards relevant to the target warning signs (i.e. road works, children outside a school, and pedestrians at pedestrian crossings) were selected from the second reel. Eight still photos containing hazards relevant to the distractor warning signs (e.g. rail crossing, flag man, fire truck, school bus, new road seal, etc.) were extracted from video out-takes. This resulted in a collection of 48 photos associated with the second video reel, 32 photos containing hazard warning signs (targets and distractors) and 16 photos of hazard scenes (relevant to target and distractor signs).

3.3.1.3 Procedure

See Figure 3.1 (p.34) for summary.

Participants were informed that the purpose of the experiment was "to find out more about the attitudes and driving habits of road users in New Zealand" and that they would be asked to watch two short videos of New Zealand roads in the driving simulator and tell the experimenter what they noticed as they drove the simulator. Before beginning the videos, the participants completed a brief demographic questionnaire. The participants were then seated in the driving simulator and instructed how to 'steer' a yellow circle which was superimposed on the video sequences to appear on the road approximately 15 m ahead. The participants could move the yellow circle left or right throughout the video sequences by turning the steering wheel and were instructed to keep the circle lined up with the centre line of the road (or the edge line if they felt it to be easier). This tracking task was included to approximate the attentional demand of steering a car. The participants were then shown a short, 5 minute, practice video to familiarise themselves with the steering task.

Before being shown the first video, the participants were also told that the experimenters were interested in "what people notice on different sorts of roads: traffic conditions, signs, pedestrians, potential hazards, and so on," and instructed "as you drive we would like you to let us know what you notice by pressing the brake pedal with your foot and saying aloud the name of anything that attracts your attention". The first 16 minute video reel was then begun and the participants' steering actions and brake pedal presses were captured by the computer while their verbal comments were recorded by the experimenter listening over a car intercom. The number and type of items reported by the participants were used as a measure of the hazard signs' attentional conspicuity, relative to other features contained in the road scenes. The three different versions of the first video reel (different orders of the video sequences) were counterbalanced across the participant order.

At the completion of the first video reel the participants were given audio and visual instructions that they were about to be shown a series of still photos, some from the video they had just viewed, and some selected from similar videos. They were instructed to click the headlight/wiper control located on the right-hand side of the steering wheel if they recognised the photo from the video, or the turn indicator control on the left-hand side of the steering wheel if they did not recognise the photo. The participants were allowed to practise moving the controls and then asked to respond to each photo as quickly as they could. The first collection of 32 photos (16 scenes containing target signs and 16 scenes containing distractor scenes) was then presented. The photos were advanced automatically upon the participants' response, each photo separated by a 500 msec black screen with a white fixation cross in the centre. The participants' yes-no recognition responses and response times were recorded by the computer as a measure of the signs' implicit memorability.

At this point in the procedure, the participants were allowed a 5 minute rest break, if they so desired, to exit the simulator and stretch their legs. Following the break, the participants were given new instructions before beginning of the second 16-minute video reel. The participants were told to steer the yellow circle as before, and to "press the brake pedal whenever you notice a hazard or hazard warning sign as you drive and name it aloud". As with the first video reel, the participants' steering actions and brake pedal presses were captured by the computer while their verbal comments were recorded by the experimenter. The number and type of items reported by the participants were used as a measure of the hazard signs' search conspicuity. The three different versions of the second video reel (different orders of the video sequences) were counterbalanced across participants.

Following completion of the video reel the participants were again given audio and visual instructions that they were about to be shown another series of still photos, some from the video they had just viewed, and some selected from similar videos. They were reminded to click the right-hand control side of the steering wheel if they recognised the photo from the video, or the left-hand control if they did not recognise the photo, and to respond to each photo as quickly as they could. The collection of 48 photos (16 scenes containing target signs, 8 scenes containing target hazards, 16 scenes containing distractor signs, and 8 scenes containing distractor hazards) was then presented. The photos were ordered so that the hazard scenes always followed the scenes containing the appropriate hazard warning signs. As before, the photos were advanced automatically upon the participants' response, each photo separated by a 500 msec black screen with a white fixation cross in the centre. The participants' yes-no recognition responses and response times for the scenes containing hazard signs were recorded by the computer as a measure of the signs' explicit memorability. In addition, the recognition responses and response times for the hazard scenes were recorded as a measure of the signs' priming of appropriate hazards.

Following completion of the photos, the participants were shown a final set of nine photos and asked to verbally state the meaning of the warning signs shown in the photos. The photos were advanced by the experimenter at a rate of 2.5 sec per photo. The participants' answers were recorded by the experimenter and subsequently scored as correct or incorrect as a measure of the signs' comprehensibility. The structure and sequence of the laboratory tasks, and the relevant measures to be collected, are shown in Figure 3.1.

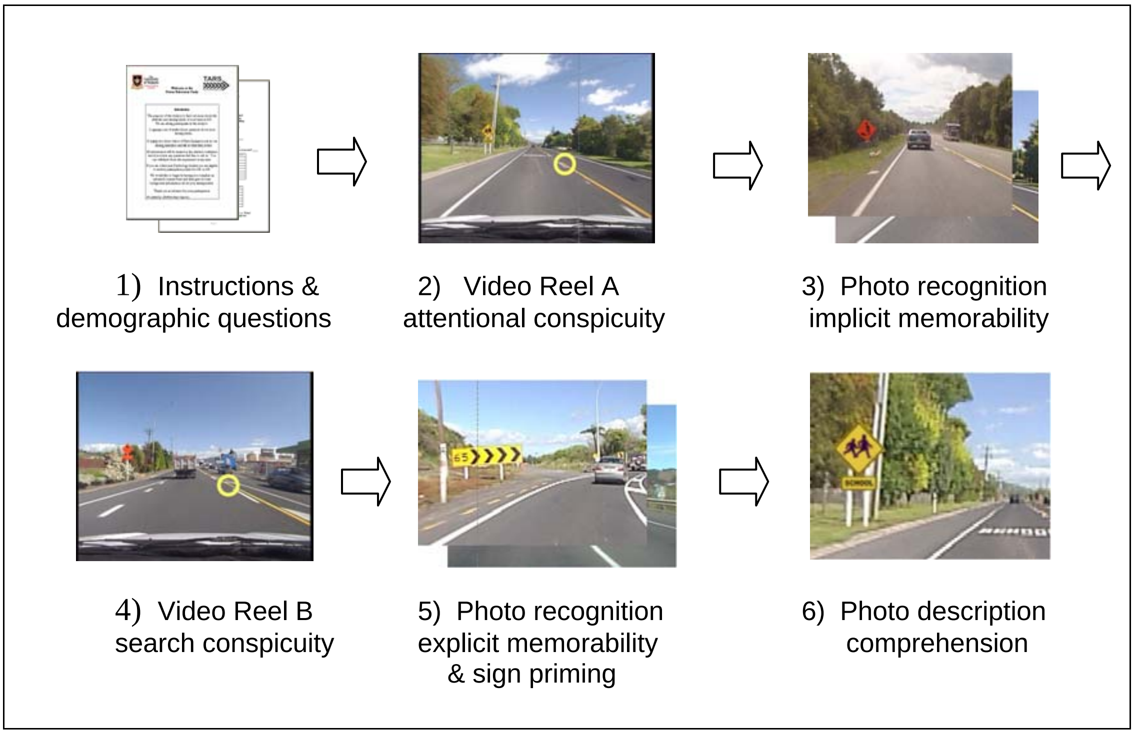


Figure 3.1 Order of the experimental tasks and the measures collected.

3.3.2 Results

3.3.2.1 Sign detection

During the first video detection task (attentional conspicuity) the participants identified an average of 61.55 items (SD = 30.38) ranging from a minimum of 8 items to a maximum of 140 items. The types of items reported included:

- signs (an average of 49.92% of the total items),
- other traffic (15.30%),
- roadside objects (15.04%),
- traffic control devices (12.82%),
- pedestrians & cyclists (10.85%),
- road features such as intersections, bridges, and pavement markings (6.48%).

Hazard warning signs constituted an average of 32.31% of the total items reported by the participants (and 66.45% of the total number of signs reported).

During the second video detection task (search conspicuity) the participants identified an average of 51.13 items (SD = 23.66) ranging from 10 to 96 items. The types of items reported included:

- signs (an average of 47.88% of the total items),
- other traffic (21.48%),
- roadside objects (7.70%),
- traffic control devices (8.17%),
- pedestrians & cyclists (11.50%),
- road features such as intersections, bridges, and pavement markings (7.90%).

Hazard warning signs constituted an average of 39.32% of the total items reported by the participants (and 83.83% of the total number of signs reported).

The difference in the total number of items reported for the two video sequences was not statistically reliable, $F_{(1,30)} = 3.25$, $p > 0.08$. The increases in the proportion of items detected that were hazard signs, and the proportion of detected signs that were hazard signs were statistically reliable, $F_{(1,30)} = 4.21$, $p < 0.05$ and $F_{(1,30)} = 22.59$, $p < 0.001$, respectively. There were no statistically reliable differences between men and women participants in the number of items reported (either in total or in each task) (*Fs* < 1.89, *ps* > 0.05); nor were there any significant correlations between the number of items detected and the participants' ages or their amount of driving (*rs* < 0.255, *ps* > 0.20).

Of the hazard signs presented in the two video tasks (excluding signs in the repeated control sequences), the participants' average detection percentages increased from 38.51% in the first video detection task to 42.60% in the second task. A repeated-measures analysis of variance indicated that this increase was statistically reliable, $F_{(1,30)} = 7.72$, $p < 0.01$. Across the seven types of target hazard warning signs, a significant Sign X Task interaction, $F_{(6,25)} = 51.00$, $p < 0.01$, indicated that the change in detection rates was not uniform across the sign types. Figure 3.2 shows the average detection percentages for four of the sign types (excluding the control repetition sequences).

As can be seen at the left of the figure, the average detection percentages for both formats of the 'pedestrian crossing' warning (PW30) were equivalent for the attentional conspicuity task (video task 1) but the yellow-green format showed a distinct detection advantage during the search conspicuity task (video task 2). This difference was reflected in a significant Task X Format interaction statistic, $F_{(1,30)} = 13.03$, $p < 0.001$. A similar pattern was observed for the two 'slippery surface' warning formats (PW41 and TW4), with an advantage for the red temporary sign format during the search conspicuity task. Once again, a repeated-measures analysis of variance produced a significant Task X Format interaction statistic, $F_{(1,30)} = 10.52$, $p < 0.01$.

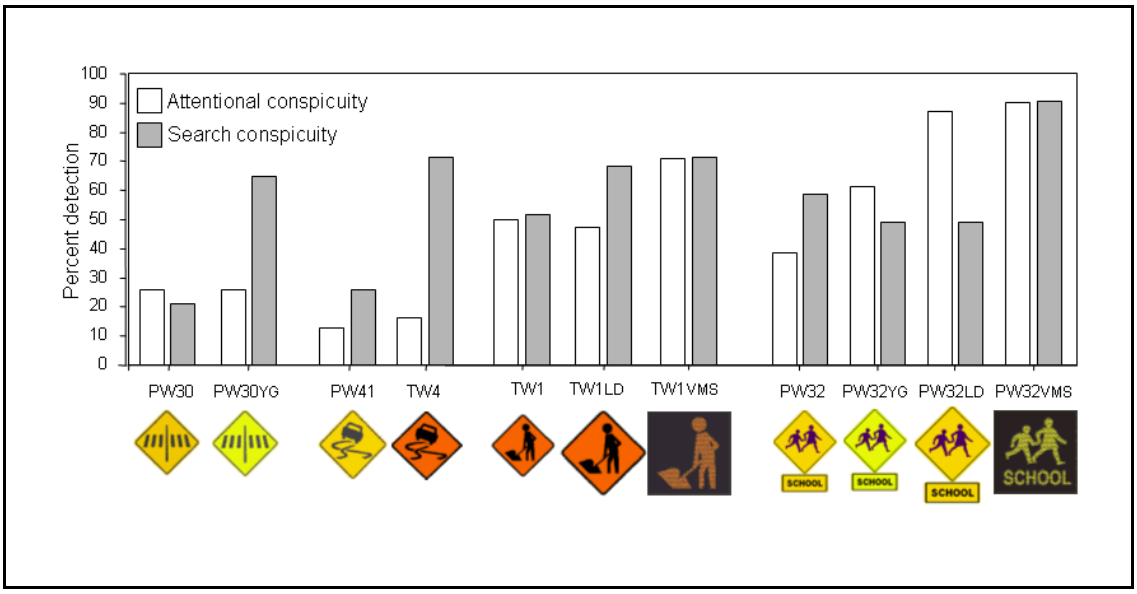


Figure 3.2 Average detection percentages for four hazard warning sign types.

The road works warning signs (TW1) were associated with higher average detection percentages during the attentional conspicuity task, as compared to the pedestrian crossing and slippery surface warning signs, and generally equivalent average detection percentages during the search conspicuity task. A repeated-measures analysis of variance indicated a significant Task effect on detection percentage, $F_{(1,30)} = 8.67$, $p < 0.01$, but no statistically reliable effect of the three formats or interaction between task and format.

The four formats of the school warning sign (PW32) produced a somewhat more complex picture and a significant Task X Format interaction, $F_{(3,28)} = 5.45$, $p < 0.01$. Considering first the format differences during the attentional conspicuity task, it can be seen that the detection percentage generally increases as the sign format moves from the standard orange, to yellow-green, to large dimension, to the flashing VMS format. Analysis of variance indicated that the difference between the formats was statistically reliable $F_{(3,90)} = 11.43$, $p < 0.001$.[2] Post-hoc pairwise comparisons of the formats (Least Significant Difference test) indicated that participants' detection of the standard orange format was significantly lower than each of the other three formats (*ps* < 0.01) and that the yellow-green format was significantly lower than the flashing VMS format ($p < 0.05$).

During the search conspicuity task there was also a significant difference between the four school warning formats, $F_{(3,90)} = 4.99$, $p < 0.01$, albeit not in the same pattern as observed for the first task. Individual post-hoc pairwise comparisons indicated that the flashing VMS format had the highest detection percentages: significantly better than the large dimension and yellow-green sign formats, *ps* > 0.001; and marginally better than the standard orange format, $p < 0.07$). The differences between the standard orange,

[2] Because the data for the individual task analyses did not meet the homogeneity of variance assumptions of analysis of variance, the analyses of format effects were also calculated using a Friedman non-parametric test. This test also indicated a significant format effect for the attentional conspicuity task, Chi-Square = 41.62, *df* = 3, $p < 0.001$ and for the search conspicuity task, Chi-Square = 13. 82, *df* = 3, $p < 0.01$.

yellow-green, and large dimension formats were not statistically reliable. The reason for the relatively low response rates associated with these sign formats is not entirely clear, although anecdotal comments offered by the participants at the time indicated that while they may have noticed some of these signs, they did not feel that they constituted a ‘hazard’ or ‘hazard warning’.

The average detection percentages for the curve warning signs are presented in Figure 3.3. The curve warnings differed from the signs described above in that they could occur by themselves or in combination and were presented in 100 km/h speed environments. The curve warnings also differed in their placement relative to a curve; PW17 arrow warnings were located some distance ahead of the curve (depending on the difference between the approach and advised curve speeds) and the RC4 chevron warnings were placed at the tangent point of the curve itself, directly ahead of the approaching traffic. As can be seen in the figure, the curve warnings had some of the lowest average detection percentages of the signs tested, ranging from 10.48% to 29.03% in the attentional conspicuity task and 14.52% to 48.39% in the search conspicuity task.

Assessing the individual signs’ effectiveness first, there was a statistically reliable Task X Sign interaction in detection rates, $F_{(2,29)} = 3.62$, $p < 0.05$. This was principally the result of the significant difference between the attentional and search detection percentages for the PW17 curve warning, $F_{(1,30)} = 9.42$, $p < 0.01$. There was also a significant difference between the search detection percentages for the three signs, $F_{(2,60)} = 10.80$, $p < 0.001$, and post-hoc pairwise comparisons indicated that the PW17 sign was reliably detected more often than either of the two chevron curve warnings ($p < 0.01$), and that the orange-black RC4 chevron sign was detected more frequently than the black-white RC4 chevron ($p < 0.05$). As can be seen in the figure, the effect of combining the signs was to increase the participants’ detection of the signs; the presence of the initial sign (PW17) tended to increase the detection percentages of the subsequent chevron signs, and the presence of the chevrons ahead increased detection percentage for the PW17 in the attentional task. Statistical analysis indicated that the increases in detection percentages associated with paired signs were reliable for the attentional task only, $F_{(1,30)} = 3.77$, $p < 0.06$, there was no reliable effect of pairing in the search task nor any Pairing X Sign interaction.

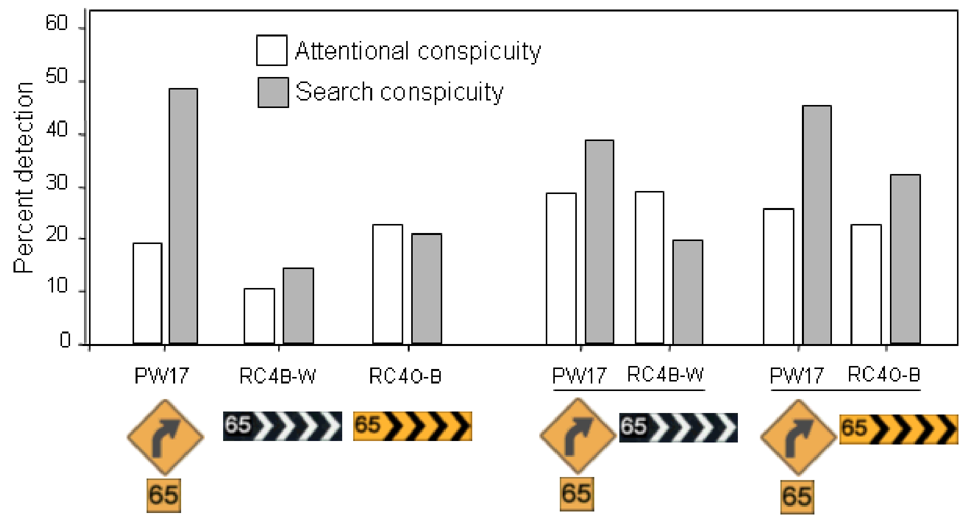


Figure 3.3 Average detection percentages for curve warning signs.

As mentioned earlier, two of the sign types, the four formats of the PW32 school warning and the three formats of the TW1 road works warnings, were included in control repetition sequences during both the attentional and search conspicuity tasks. Perhaps due to their repetition, these video sequences were associated with very high detection percentages, an average of 80.18% during the attentional conspicuity task and 81.11% during the search conspicuity task. There were no statistically reliable differences in detection percentage between the signs or their various formats in either task. The control repetition sequences were of interest due to the opportunity they afforded to compare the relative speed of the signs' detection. Participants' detection speeds, however, were relatively uniform across the signs and their various formats, averaging 3.01 sec (SD = 0.79 sec) for the attentional conspicuity task and 2.54 sec (SD = 0.57 sec) in the search conspicuity task. This task difference in detection speeds was statistically reliable, $F_{(1,21)} = 8.21$, $p < 0.01$, but there were no statistically reliable differences in detection speed between signs, formats, nor any interactions between signs, formats, and task type.

3.3.2.2 Sign memorability

There were two measures of sign memorability:

- implicit memory - recognition of items selected from the video sequences used in the attentional conspicuity task (and presented following completion of that task),
- explicit memory - recognition of items selected from the video sequences used in the search conspicuity task (presented following completion of that task).

The top panel of Figure 3.4 shows the participants' correct recognition percentages for the 16 scenes (containing hazard warning signs) drawn from the video sequences (correct detections) and the correct rejection percentages for the 16 distractor images (containing different hazard warning signs) across the two memory tasks. A multivariate repeated-measures analysis of variance indicated that there was a significant task effect (implicit memory v. explicit memory) on the participants' recognition performance across all sign types, $F_{(2,28)}$ = 11.33, p < 0.001, primarily due to a lower percentage of correct rejections in the explicit memory task, $F_{(1,29)}$ = 4.79, p < 0.05.

There was also, however, a significant Task X Sign interaction, $F_{(5,26)}$ = 3.89, p < 0.01, indicating some differential effects across the individual sign types. Examining the pattern of recognition across the individual sign types, there was a significant task effect for scenes containing PW30 pedestrian crossing signs $F_{(1,30)}$ = 8.03, p < 0.01, with a higher percentage recognised in the explicit memory task (79.03%) than for the implicit memory task (59.68%). There was no significant difference between the orange and yellow-green formats, nor any interaction between sign format and task type. For the slippery surface signs (PW41 & TW4) and the school warning signs (PW32) there were significant format effects ($F_{(1,30)}$ = 12.90, p < 0.001 and $F_{(3,28)}$ = 5.22, p < 0.01 respectively), but no reliable differences between the two tasks or interactions between tasks and formats. In the case of the slippery surface signs, scenes containing the orange PW41 were more often correctly recognised (79.03%) than scenes containing the red temporary TW4 sign (51.61%). Scenes containing the yellow-green school warning were recognised least often (59.68%); significantly lower than scenes containing the standard orange format (90.32%), the large dimension format (85.48%), or the flashing VMS format (83.87%), paired comparison ps < 0.01.

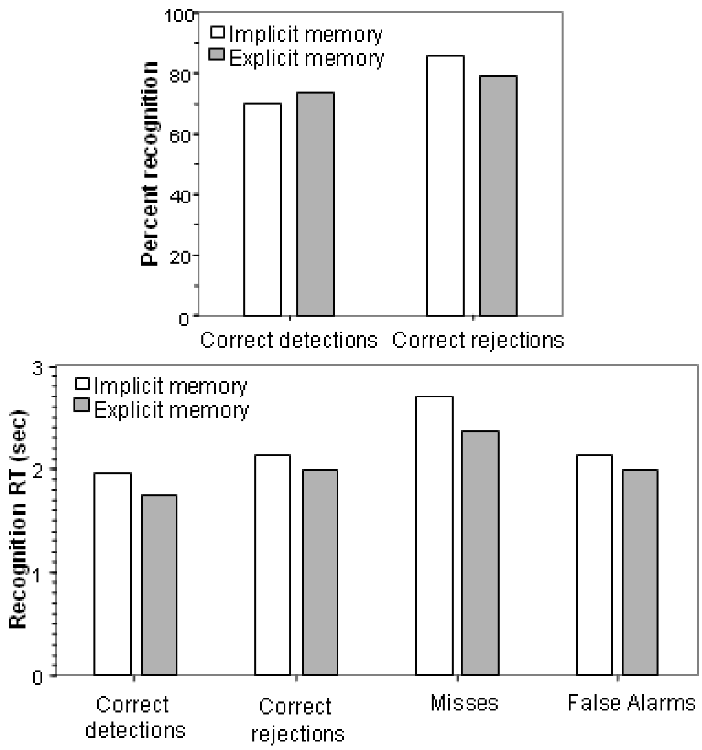


Figure 3.4 Participants' average recognition accuracy (top panel) and recognition response times (lower panel) for the 32 still photos.

Participants' recognition of scenes containing the road works and curve warning signs showed significant Task X Format interactions ($F_{(2,29)}$ = 3.75, p < 0.05 and $F_{(4,27)}$ = 3.93,

$p < 0.01$, respectively). For both the road works and curve warning signs, this interaction was the result of significant differences between sign formats in the implicit memory task ($F_{(2,60)} = 5.06$, $p < 0.01$ and $F_{(4,120)} = 8.70$, $p < 0.001$ respectively), but no differences in recognition between the various sign formats during the explicit memory task. Scenes containing the large dimension road works sign were more memorable (87.09%), than either the standard sized format (74.19%, $p < 0.05$) or the flashing VMS format (72.58%, $p < 0.01$). Scenes containing the orange-black RC4 signs or a combination of PW17 and orange-black RC4 curve warnings had the highest rates of correct recognition (77.42% and 70.97% respectively). These scenes were recognised significantly more often than scenes containing the PW17 and black-white RC4, either individually (54.84% and 40.32%) or in combination (67.74%) (pairwise comparison *ps* < 0.01).

The lower panel of Figure 3.4 shows the recognition reaction times for participants' recognition judgements for the scenes containing the signs from the video sequences and the distractor scenes. As the figure shows, the fastest reaction times occurred for 'correct detections' (scenes correctly recognised from the videos), and the longest reaction times occurred for the participants' 'misses' (scenes from the video that participants failed to recognise). A multivariate repeated-measures analysis of variance indicated an overall task difference in recognition reaction times ($F_{(1,22)} = 6.01$, $p < 0.05$), primarily due to the difference in the reaction times for correct detections: 1.96 sec for the implicit memory task and 1.75 sec for the explicit memory task. ($F_{(1,29)} = 7.35$, $p < 0.01$). Recognition reaction times were fairly comparable across the range of sign types and formats and there were no interactions between sign type and task.

3.3.2.2 Sign priming

The participants' recognition performance was also of interest inasmuch as it enabled an analysis of sign priming, the degree to which hazard warning signs facilitated participants' recognition decisions for scenes containing the hazards indicated by the signs. During the explicit memory task, half of the recognition scenes containing signs were followed immediately by scenes containing the hazards to which the signs referred (including scenes from the video sequences as well as scenes containing signs and sign-appropriate hazards not included in the video sequences). The participants' recognition percentages and reaction times for the priming trials (the sign scenes and the hazard scenes that followed them) are shown in Table 3.4. As can be seen in the table, the participants' recognition rates and reaction times to the hazard scenes primed by sign scenes were markedly better than the recognition accuracy and reaction times to non-primed sign scenes. Interestingly, this priming effect was apparent even for the distractor scenes (scenes not from the video sequences); the accuracy and speed of correct rejections was faster for the primed hazard distractors than for non-primed distractor scenes. A multivariate repeated-measures analysis of variance indicated that the priming effect on recognition accuracy and reaction times was highly reliable, $F_{(4,27)} = 25.83$, $p < 0.001$.

Table 3.4 Priming of hazard scenes by hazard warning signs.

Reaction	Non-primed scenes		Primed hazard scenes	
	% correct	Recognition RT (sec)	% correct	Recognition RT (sec)
Correct detections (scenes from video)	73.79	1.746	88.71	1.369
Correct rejections (scenes not from video)	79.03	1.989	85.89	1.659

Another view of the hazard signs' priming capacity is shown in Figure 3.5. The participants' recognition reaction times associated with correct detections (sign and hazard scenes from the video sequences) for two of the signs with comparable formats, i.e. the three TW1 road works warning formats and three of the PW32 school warning formats. A multivariate repeated-measures analysis of variance performed on the data in Figure 3.5 indicated a significant Sign X Priming interaction, $F_{(1,10)} = 6.73$, $p < 0.05$, where the scenes containing the TW1 road works sign primed its corresponding hazard scenes more effectively than scenes containing the PW32 school warning. The analysis also indicated a significant Format X Priming interaction, $F_{(2,9)} = 6.20$, $p < 0.05$, with the large dimension sign format associated with the greatest priming effect (and the VMS format providing the lowest priming). There was no Sign X Format or higher-order Sign X Format X Prime interactions.

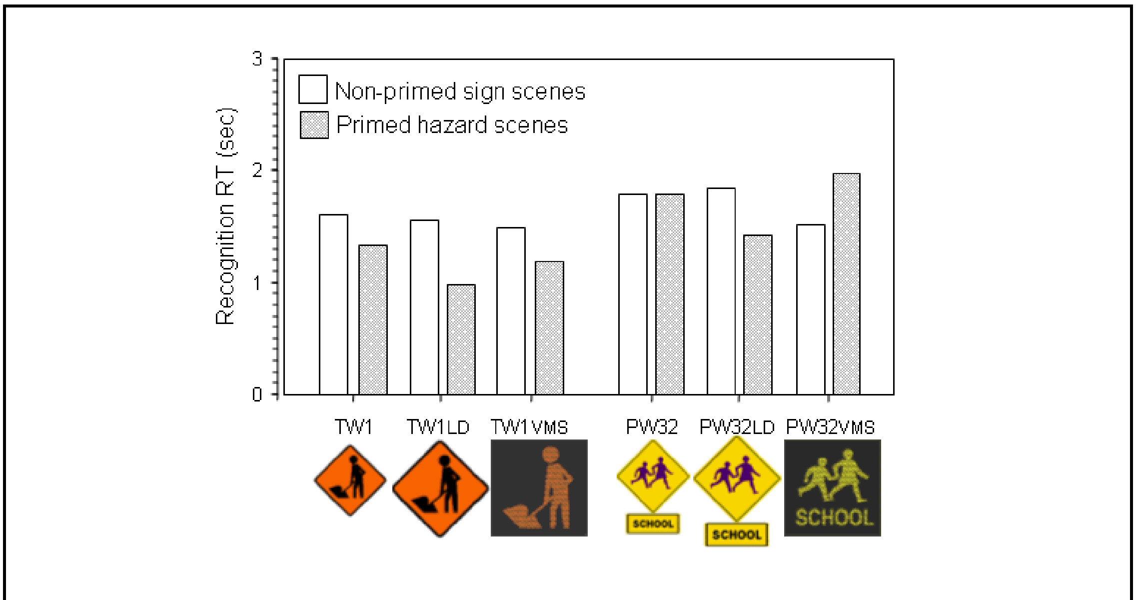


Figure 3.5 Priming of hazard scenes for two sign types.

3.3.2.3 Sign comprehension

Two measures of sign comprehension were collected:

- dynamic comprehension: the participants' correct identification of a sign during the search conspicuity video sequence (for detected signs),

- static comprehension: the participants' correct identification of a sign when presented in a still image at the end of the experimental session.

Figure 3.6 shows the percentage of participants correctly identifying nine of the hazard warning signs during the video sequences (dynamic comprehension) and during the still photo identification test at the end of the experimental session (static comprehension). As can be seen in the figure, static comprehension was superior to dynamic comprehension in all cases, although overall comprehension accuracy was lower than expected. An analysis of variance indicated a significant difference between the two measures of comprehension, $F_{(1,28)} = 12.41$, $p < 0.01$.

Of greatest interest, however, are the differences between the nine warning signs. A Chi square statistic calculated on the static comprehension measure indicated a significant difference between the nine signs, Chi square = 18.36, $df = 8$, $p < 0.05$.[3] During the search detection task some participants incorrectly identified school warnings as pedestrian crossings, school crossings, or congested area warnings. The two formats of the slippery surface sign, which only 50%-70% of the participants correctly identified in the video, were variously identified as windy road warnings (PW41 format), road works warnings (TW4 format) or simply as 'some warning sign'. The flashing VMS formats were sometimes identified simply as 'a flashing sign ahead', and thus what, if any, warning function they held for the participants must be inferred from the hazard detection (search conspicuity) task.

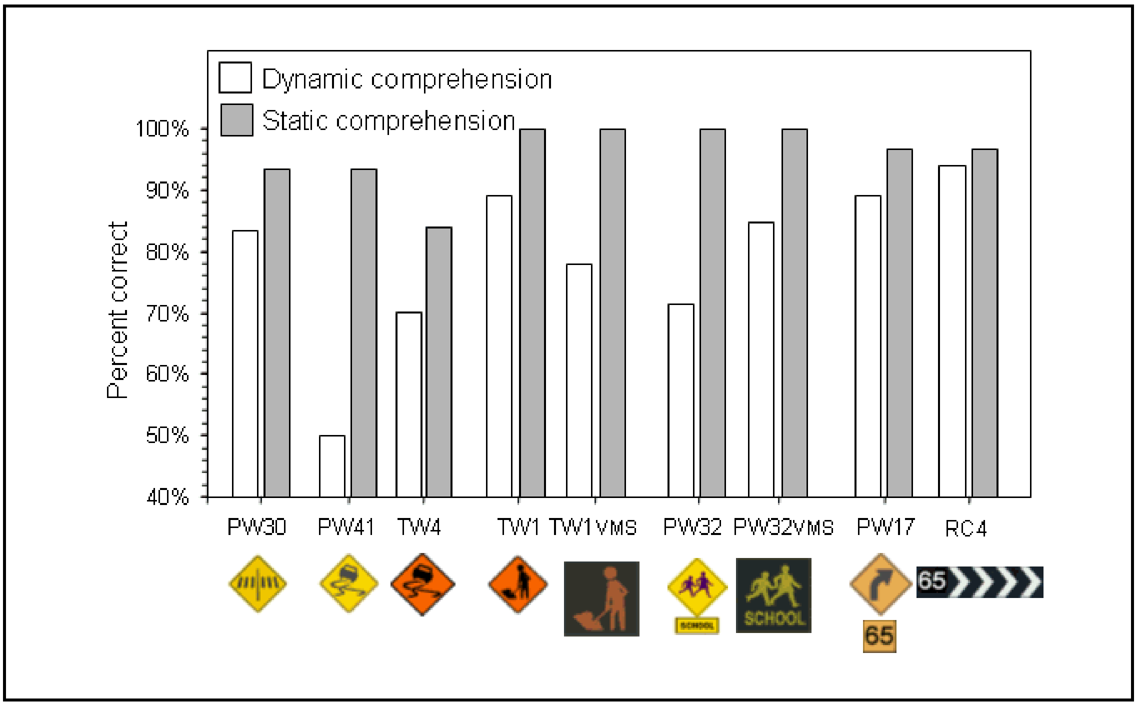


Figure 3.6 Participants' dynamic comprehension (during video presentation) and static comprehension (during still photo presentation) for nine warning signs.

[3] Because of the pattern of missing observations for the dynamic comprehension measure (30.5% of the signs were not detected), it was not possible to calculate a Chi square statistic to assess the difference between the signs. When missing observations were coded as incorrect, a significant Chi square of 37.95, $p < 0.001$ was obtained, supporting the relationship between the pattern of missing observations and dynamic comprehension scores.

3.3.2.4 Warning sign rankings

In order to compare the warning signs across the full range of measures described above, each of the signs was ranked according to its relative performance for each of the seven measures collected:

- attentional conspicuity,
- search conspicuity,
- implicit recognition,
- explicit recognition,
- priming,
- dynamic comprehension,
- static comprehension.

Table 3.5 shows the resulting rankings of the signs, with best performing signs receiving a ranking of '1', as well as a normalised overall score and overall ranking for the signs. The road works and school warning signs appeared to be the most robust of the sign types, garnering the top half of the rankings with the exception of the standard format school warning. Comparing the various sign formats, the two large dimension signs, road works and school warnings, were placed at the top, followed by the VMS formats for the same two warnings. The yellow-green formats of the pedestrian crossing and school warnings appeared to perform better than their standard orange counterparts, as did the orange and black chevron curve warning compared to the black and white version. Both formats of the slippery surface signs, the permanent orange warning and the temporary red warning, were among the worst of the signs across the range of measures collected.

When the laboratory results are compared with the effectiveness ratings obtained from the survey of road safety experts, there is only partial correspondence. The PW17 curve warning and the PW41 slippery surface warning received the highest effectiveness ratings from the respondents and these signs were among the lowest-performing signs across the seven measures collected in the laboratory. Similarly, the TW1 roadworks warning received one of the lowest effectiveness ratings, yet performed in the top third of signs in the laboratory. The respondents did, however, correctly predict the relatively poor performance of the PW30 pedestrian crossing and the standard PW32 school signs. Looking at the average speed reductions obtained from the field observations, there is once again only partial correspondence with the laboratory results. Comparing the rankings in Table 3.5 to the average percent speed reductions observed in the field prior to beginning the laboratory study, the signs associated with some of the largest reductions in speed were the combined PW17 and RC4 curve warnings followed by the TW4 slippery surface warnings. Yet, in terms of the conspicuity measures collected in the laboratory, these signs were relatively poor performers. The TW1 roadworks and PW32 school warnings, which performed well in the laboratory, also performed well in the field observations, but only under some conditions (rural roadworks and urban schools).

Table 3.5 Overall rankings for each warning sign.

Sign	Sign rankings for each measure							Normalised	
	Att. consp.	Search consp.	Implicit recog.	Explicit recog.	Priming	Dyn. comp.	Static comp.	Score	Rank
PW30	8	11	12	9	2	5	7	6.34	13
PW30YG	9	7	10	6	5	-	-	4.16	8
PW41	14	12	4	6	-	9	7	6.21	12
TW4	13	6	14	12	-	8	9	7.29	14
TW1	6	4	8	5	4	2	1	3.54	4
TW1LD	5	2	3	2	1	-	-	1.40	1
TW1VMS	4	1	13	1	3	6	1	3.59	5
PW32	7	5	1	4	7	7	1	4.25	9
PW32YG	3	9	10	13	-	-	-	3.57	5
PW32LD	2	8	2	6	6	-	-	2.91	2
PW32VMS	1	2	4	2	8	4	1	3.14	3
PW17	11	10	8	14	-	2	5	5.50	11
RC4BW	12	14	7	11	-	1	5	5.44	10
RC4OB	10	12	4	9	-	-	-	3.57	5

Another goal of the present study was to examine the performance of the various measures themselves. In order to assess the consistency across the measures a non-parametric Spearman cross-correlation was performed on the rankings obtained for each sign across the x measures. Table 3.6 shows the resulting cross-correlation matrix. The analysis indicated good agreement between the two measures of conspicuity, and the measure of static comprehension. Further, the measure of explicit recognition was highly correlated with the measures of search conspicuity and static comprehension. These correlations are indicative of good agreement between these four measures of sign effectiveness.

Table 3.6 Spearman rank correlations (*Rho*) of the sign rankings obtained for the seven measures of effectiveness.

Measure	Att. consp.	Search consp.	Implicit recog.	Explicit recog.	Priming	Dyn. comp.	Static comp.
Attentional conspicuity	1.00	.619*	.212	.515	-.310	.310	.852**
Search conspicuity		1.00	-.033	.731**	.060	-.075	.703*
Implicit recognition			1.00	.341	-.476	.017	.390
Explicit recognition				1.00	-.024	-.192	.747*
Priming					1.00	-1.00	-.707
Dynamic comprehension						1.00	.353
Static comprehension							1.00

* Correlation is significant at the $p < 0.05$ level

** Correlation is significant at the $p < 0.01$ level

Another view of the consistency of the various measures was afforded by a non-parametric Spearman correlation performed comparing each of the signs' rankings for each measure to the overall ranking and a parametric correlation performed on the averages obtained for each performance measure, comparing them to the normalised overall score for each sign. The resulting non-parametric and parametric correlation coefficients are presented in Table 3.7. For both types of correlation, the attentional conspicuity and static comprehension measures appear to be among the most reliable indicators of overall sign performance. These two measures are followed by the explicit recognition, search conspicuity, and implicit recognition measures. The measures of dynamic comprehension and sign priming did not appear to be consistent with the other measures of sign performance. Were we to consider only the two most highly correlated measures, the final rankings of sign performance would change only slightly and the various formats of the road works and school warnings still dominate the top half of the rankings.

Table 3.7 Correlations of individual measures with normalised overall rankings.

Statistical measure	Att. consp.	Search consp.	Implicit recog.	Explicit recog.	Priming	Dyn. comp.	Static comp.
Correlated ranks Spearman's *Rho*	.797	.520	.480	.573	.024	.418	.940
$p <$	.001	.057	.082	.032	.955	.262	.001
Correlated performance Pearson's *r*	.765	.546	.528	.525	.036	.333	.800
$p <$	.001	.043	.052	.054	.933	.244	.001

4. Discussion and implications

4.1 Effectiveness of hazard warning signs

The purpose of this research was to summarise the research findings associated with the effectiveness of hazard warning signs and demonstrate a method for evaluating new and existing hazard warning signs in New Zealand. As seen in the review of the literature, no single measure best reflects the effectiveness of hazard warning signs. The testing protocol used in the present research included a range of measures employed by earlier researchers, as well as some new measures, in an attempt to assess both the hazard warning signs included in the laboratory trials as well as the consistency and sensitivity of the measures themselves.

4.1.1 Attentional conspicuity

Comparing the results obtained in the present research to the earlier findings reported in the literature, there are many points of similarity and some important differences. Considering first the measure of attentional conspicuity, the proportion of participants' reports in the present research for traffic control devices (12.82% of items reported) and hazard warning signs (32.31%) were higher than the proportions previously reported for drivers in field trials (10.2% to 16.9%) or laboratory trials employing video footage (15.1% to 20.9%) (Hughes & Cole 1986). The comparison is somewhat difficult, however, because the content of the driving tasks may have been quite different. The videos used in the present experiment were constructed expressly to contain a range of different hazard warnings and thus may have produced a driving task with a higher density of warning signs than the previous studies. Looking at the percentages of other types of items reported, the participants' reports in the present experiment were generally similar to those reported by previous researchers:

- roadside objects (15.04% of items in the present research as compared to 12.15% in previous research),
- pedestrians and cyclists (10.85% as compared to 11.3%),
- road features (6.48% as compared to 2.9%),
- other traffic (15.30% as compared to 23.3%).

What the present research offers beyond the previous investigations of attentional conspicuity is an assessment of the probability of a particular sign or sign format being noticed by drivers. Previous attempts to compare individual sign types have typically employed memory tasks such as the roadblock paradigm. These studies have reported drivers' recall for various warning signs to range from about 25% accuracy (for low performing signs such as pedestrian crossing and 'general' warning signs to 75% accuracy for speed limit and police control warnings (Johansson & Backlund 1970). The present study measured recognition accuracy rather than recall, and obtained mean accuracy rates of 70.21% for the implicit memory task and 73.79% for the explicit memory task. As with the roadblock/recall paradigm, the recognition task was able to detect significant differences between different sign types and formats. Interestingly, in the present study unfamiliar sign formats (yellow-green & flashing VMS) performed relatively poorly for the implicit memory task (64.9% recognition accuracy) but improved dramatically for the explicit memory task (80.65%). In contrast, the participants' recognition accuracy for standard formats was relatively constant across the two tasks (74.89% v. 74.0%).

4.1.2 Search conspicuity

Previous researchers have pointed out that drivers' detection of road signs can be substantially different depending on their focus of attention and any explicit or implicit instructions provided to them (Hughes & Cole 1986, Martens 2000). The search conspicuity task included in the present research provided a measure for assessing sign conspicuity when drivers are explicitly scanning for hazards and hazard warnings. Although detection percentages for the search task (42.6%) were on the whole higher than for the attentional conspicuity task (38.51%), the finding that detection rates for some signs (e.g. yellow-green and large dimension school zone warnings) actually decreased during the search task was somewhat perplexing. Participants' comments indicated that in some cases these signs were noticed, but weren't considered to be particularly indicative of a hazard and thus weren't reported. In contrast, when the school zone was indicated with the flashing VMS format the participants were much more likely to report the signs' presence. It may have been the case that the flashing format added a heightened sense of potential danger. Previous researchers have reported that the addition of a warning flasher to a children warning sign increased drivers' immediate responses to it, presumably by suggesting a greater degree of caution is required (Summala & Hietamäki 1984). Analysis of changes in speed associated with the children warning signs found although the signs were detected by drivers, they produced only slight decreases in average speeds, but the addition of the warning flasher significantly increased the degree of speed reduction (from an average of approximately 0.5 km/h to 2 km/h) (Summala & Hietamäki 1984). Thus, it is reasonable to assume that the flashing VMS warnings offer at least two beneficial effects, an increased attentional conspicuity and greater likelihood of being interpreted as indicative of a potential hazard. Although the large dimension signs were nearly as effective as the VMS signs in terms of their attentional conspicuity, the VMS signs appeared to provide an advantage in terms of their ability to communicate a potentially hazardous situation.

4.1.3 Sign priming

The analysis of sign priming also afforded some interesting insights into the functioning of hazard warning signs. In the present study, presentation of scenes containing a hazard warning significantly facilitated the accuracy and speed of participants' subsequent recognition of scenes containing the relevant hazards in a continuous recognition task. Perhaps most interestingly, this facilitation occurred not only for recognition of scenes presented in the videos, a form of episodic priming (Ratcliff & McKoon 1988); it also occurred for participants' correct rejections of distractor scenes that had not been included in the videos. The facilitation obtained for the participants' correct rejections of distractor scenes presumably resulted from semantic priming and provides strong support for the notion that warning signs can set the stage for appropriate responding, at an implicit level, through semantic associations acquired for the meanings of the signs (Crundall & Underwood 2001).

4.1.4 Comprehension

The participants' performance on the comprehension measures was somewhat lower than anticipated, particularly for the dynamic comprehension task. One of the poorest performing signs in that regard was the slippery surface sign, which only 50% of the participants correctly identified during the dynamic comprehension test. This result is essentially the same as the one obtained in a United States' study, where the same sign (MUCTD W8-5) was associated with 44.6% comprehension, one of the lowest rates obtained in that study (Dewar et al. 1997). The participants' static comprehension scores were higher than their dynamic comprehension, 96.06% correct as compared to 81.78%, but an argument can be made that dynamic comprehension is more indicative of the comprehension while driving. It follows that when comprehension of a sign is poor, its memorability and likelihood of prompting effective driver reactions will suffer. This is at least partially borne out by the present experiment where signs associated with low dynamic comprehension scores also produced some of the lowest rates of implicit and explicit recognition.

4.1.5 Implications

Of the signs sampled, the road works and school warnings were most often detected, remembered, and understood. The slippery surface signs were associated with some of the lowest detection and comprehension rates, a finding supported by overseas investigators. It is worth noting that other warning signs included in the present study (in addition to the 16 target signs) were also associated with very low detection rates. For example, the horse and rider warning (PW36) was reported by only 22.58% of the participants during the attentional conspicuity task and the pedestrian warning (PW29) was reported by 29.03% of the participants during the search conspicuity task. In contrast, the gravel surface warning (TW5) was reported by 54.84% of drivers in the search detection task. Still other warnings signs appeared to go unreported because the participants chose to note the presence of the hazard rather than the warning sign. The PW39 bump (hump) warning was reported by only 9.68% of the participants, yet 54.84% of the participants noted the presence of the speed bump itself, with none of the participants reporting both the sign and the bump. Similarly, while 17 participants (54.84%) reporting the gravel surface warning, 8 participants (25.81%) reported the gravel surface itself, with 2 participants reporting both the warning sign and the hazard.

Also clear from the findings is that decisions about which format to use will depend on the type of hazard sign. In the case of road works warnings, the flashing VMS format was only slightly more conspicuous than the large dimension sign format, equal in comprehensibility, and perhaps somewhat worse in terms of implicit memorability and ability to prime driver reactions to hazards. For the school warnings, however, the VMS format appeared to convey a greater sense of potential hazard, producing superior search conspicuity and priming as compared to standard and large dimension formats, and was equal in terms of memorability and comprehensibility. The use of coloration, as in the yellow-green pedestrian crossing and red slippery surface signs, appeared to facilitate search conspicuity as compared to the standard orange coloration, but not attentional conspicuity, memorability, or priming. In the case of curve warnings, the orange and black format for the RC4 chevron sign was superior to the standard black and white format in terms of both conspicuity and memorability and enhanced the effectiveness of orange PW17 curve warnings when they were used in combination.

4.2 Evaluating hazard warning signs

The second goal of the research was to establish a systematic method for the evaluation of hazard warning signs. Although the research literature does suggest several general types of criteria for the evaluating effectiveness of hazard warning signs, there has been little consensus on the measures and testing protocols to use. The present study employed a broad range of measures and test methods and used actual New Zealand driving scenes to ensure the best possible external validity of the test scenarios.

4.2.1 Conspicuity

The measure of attentional conspicuity was highly informative and provided one of the clearest indications of differences in sign performance. Whereas previous test protocols relied on verbal reports alone, the present study required participants to indicate the focus of their attention by pressing on the brake pedal and then naming the item. This not only afforded some greater precision in the measurement of what they noticed and when they noticed it, it also provided a response mode that was highly compatible with the driving task. The search conspicuity task provided a different view of sign detection by explicitly orienting the participants' attention towards hazards and hazard warnings. It also carried with it, however, the added criterion that the sign or object had to be judged as indicative of a hazard by the participants. Thus, rather than providing a measure of everything that was noticed, it reflected what was noticed and met the criterion for the class of objects being searched for. In practice, the two measures appeared complementary and should be used in concert in the assessment of road signs, attentional conspicuity providing a good indication of the ability of a sign to attract attention and search conspicuity providing an indication of how the sign was interpreted by drivers (i.e. whether it indicated a hazard).

4.2.2 Memorability/priming

The measures of implicit and explicit memorability provided by the recognition tasks presented a more complicated picture. While reliable sign and format differences were obtained, the results were not always consistent with the other measures or with each other. The reasons for this may be mixed; it was not always clear, for example, whether the participants were using the signs or other information in the scenes to make their recognition judgements. The measures did reveal an interesting effect associated with the novelty of some sign formats in that unfamiliar formats showed implicit-explicit differences in recognition whereas the more familiar formats did not. The implications of this finding for driving are not immediately apparent and merit further research. In contrast, the use of the continuous recognition task to assess the priming effect of warning signs was of obvious practical utility. In the present study the measurement of sign priming was restricted to a small subset of signs, primarily to see if it could be replicated. The effect was shown to be very robust and offers considerable promise in future assessments of hazard sign effectiveness. The measurement of detection speed in the repetition control sequences, however, was not able to detect any significant differences between sign types or formats.

4.2.3 Comprehension

Finally, the measures of dynamic and static comprehension were illuminating. However these results were somewhat disconcerting because of their lower than expected levels. Of the two measures, the static comprehension task provided the greatest concordance with the other measures and with previous research. Dynamic comprehension, however, was apparently a more demanding task and offers some obvious external validity with regard to the behaviour of drivers on the road. As with the priming measure, dynamic comprehension was assessed for a restricted range of signs and formats and could be productively expanded in future investigations.

4.2.4 Implications

The range of measures worked well as a whole in providing a methodology for assessing the relative effectiveness of warning signs. Were one to select a subset of the measures in constructing a testing protocol for signs, at this stage the two measures of conspicuity and the measure of static comprehension would appear to be of the greatest utility. The measurement of sign priming, dynamic comprehension, and recognition memorability (in that order) offer considerable potential benefits, but would require some additional work in refining the test methods associated with their collection.

5. Conclusions

The first goal of the research was to test the effectiveness of hazard warning signs used on New Zealand roads. The following conclusions were reached:

- Of the signs tested, road works and school warning signs were most often detected, remembered, and understood by the participants.
- Slippery surface warnings were associated with some of the lowest detection and comprehension rates.
- The effectiveness of the different formats depended on the type of hazard sign:
  - For road works warnings, a flashing variable message format was only slightly more conspicuous than the large dimension format, equal in comprehensibility, and perhaps somewhat worse in terms of memorability.
  - For school warnings, the flashing variable message format appeared to convey a greater sense of potential hazard, produced superior search conspicuity and priming, and was equal in terms of memorability and comprehensibility.

The second goal was to establish a method of evaluating hazard warning signs for roads in New Zealand, and conclusions made were:

- The range of measures worked well as a whole with the two measures of conspicuity and the measure of static comprehension showing the greatest consistency.
- The measurement of sign priming, dynamic comprehension, and recognition memorability (in that order) offer considerable potential benefits, but would require some additional work in refining the test methods associated with their collection.

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Appendix A Participant instructions and demographic questionnaire

Welcome to the
Driver Behaviour Study

Introduction

The purpose of the study is to find out more about the attitudes and driving habits of road users in NZ.
We are asking participants in the study to:

1) answer a set of multi-choice questions about your driving habits.

2) watch two short videos of New Zealand roads in our driving simulator and tell us what they notice.

All information will be treated in the strictest confidence and if you have any questions feel free to ask us. You can withdraw from the experiment at any time.

If you are a first-year Psychology student you are eligible to receive participation points for 102 or 103.

We would like to begin by having you complete an informed consent form and then give us some background information about your driving habits.

Thank you in advance for your participation.

Dr. Samuel G. Charlton, Project Supervisor

What kind of vehicle do you drive most often?

- ❑ Motorbike
- ❑ Compact car
- ❑ Midsize car or wagon
- ❑ Van or ute
- ❑ Taxi
- ❑ Truck
- ❑ Truck & trailer
- ❑ Other ______________

How many kilometres do you drive in an average week? ______________ km

What is your annual income (approximately?) $ ________________

What is your occupation?

- ❑ Sales
- ❑ Service
- ❑ Clerical
- ❑ Managerial
- ❑ Education
- ❑ Professional/technical
- ❑ Agricultural/fishing
- ❑ Manufacturing/building
- ❑ Transport
- ❑ In school/training
- ❑ Unemployed
- ❑ Retired
- ❑ Work at home
- ❑ Other ______________

In the past year, how many motor vehicle crashes have you been involved in? _______

In the past year, how many driving infringements (including speed camera fines) have you received? _____

What percent of your driving is:

	0%	10-20%	20-30%	40-50%	60-70%	80-90%
To and from work						
Shopping						
Medical						
Education						
Driving as part of job						
Transporting children						
Social and recreation						
Other _____________						

What percent of your driving is between the hours of:

	0%	10-20%	20-30%	40-50%	60-70%	80-90%
6am-10am						
10am-2pm						
2pm-6pm						
6pm-10pm						
10pm-2am						
2am-6am						

What is your age? ________________

Is your household Rural or Urban? (circle one)

What is your gender? M F (circle one)

That is the end of the survey – Thank you very much for your answers.
Let the researcher know that you are finished and they show you how to begin your practise session on the driving simulator.

Be sure to ask if you have any questions whatsoever!

Video Instructions

The videos you are about to watch contain scenes from a variety of New Zealand roads, some of them may even be familiar to you. As you watch the videos we would like you to "steer" the simulator car by keeping a yellow circle displayed on the screen lined up with either the centre line of the road or the edge line, whichever is easier for you at the time. You move the circle to the left and right by turning the steering wheel, just like driving a car. We will measure how well you are able to keep the car lined up with the roads in the video. We are also interested what people notice on different sorts of roads, traffic conditions, signs, pedestrians, and so on. So, as you drive we would like you to let us know when something catches your attention by pressing the brake pedal with your foot and saying aloud the name of anything that attracts your attention. We will write down whatever you tell us by listening to the car intercom. The goal is not to see how much you can name; we want to see what you notice during a typical drive, just as if you were driving your own car. We'll give you a short practice session first, to get the feel of driving the simulated car. After that you will see the two videos which each take about 15 minutes to drive. If at any stage you have a question, just ask aloud and I will answer you over the intercom.

Video #2 Instructions

You are about to watch the second video which also contains scenes of a variety of New Zealand roads. Once again we would like you to "steer" the yellow circle, lining it up with either the centre lane of the road or the edge line, whichever is easier for you at the time. For this video we would like you to press the brake pedal whenever you notice a road hazard or hazard warning sign as you drive and name it aloud. We will write down whatever you tell us by listening to the car intercom.

If at any stage you have a question, just ask aloud and I will answer you over the intercom.

Experimenter Use only

Participant # ______ Reel order # ______ Session 1 Date/Time ________________
(1, 2, or 3)

Comments:

____
____
____
____
____
____

Appendix B

Example observation scoring sheet

Reel A Order 1				
Clip	Event	Time	Reported	Other Items Noticed
A_PW30	Traffic lights	00.01		
	Intersection	00.07		
	Lane merge	00.13		
	Car on right	00.16		
	50kmhr sign	00.21		
	Ped Xing sign	00.28		
	Pedestrian	00.32		
	Ped Xing	00.35		
A_PW17+FRC	70 kmhr sign	00.45		
	Passing lane 1k sign	00.47		
	Curve warning	00.50		
	Orange sign	00.57		
	Chevron sign	00.57		
	Bridge	00.59		
	Green sign	01.09		
	Car on left	01.11		
	Passing lane begins	01.12		
A_PW41	Brown sign	01.30		
	Slippery surf. sign	01.43		
	Passing lane 2k sign	01.46		
A_TW1_STD	Blue/white arrow	02.07		
	Road works sign	02.07		
	30 kmhr sign	02.11		
	Road cones	02.13		
	Blue/white arrow	02.15		
	Driving on shoulder	02.19		
	Road workers	02.28		
	Ped xing sign	02.30		
	Ped xing	02.38		
A_FRC	Orange sign	02.40		
	Chevron sign (flouro)	02.45		
	Bridge	02.47		
	Green sign	02.53		
	Green sign	02.54		
	Blue bypass sign	02.58		
	Left turn lane	03.05		
	70 kmhr sign	03.06		
	Curve warning	03.21		

Reel A Order 1 (cont.)				
Clip	Event	Time	Reported	Other Items Noticed
A_TW1_AV_STD	Road works sign	03.27		
	Road cones	03.34		
	70 kmhr sign	03.41		
	Road cones	03.41		
	Curve warning	03.41		
	Chevron B/W	03.52		
A_PW17	Car on right	04.01		
	Curve warning	04.04		
	curves	04.31		
A_PW32_AV_STD	Chevron B/W	04.43		
	70 kmhr sign	04.59		
	School/child sign	05.01		
	Green sign	05.00		
A_TW1_AV_VMS	Curve warning	05.28		
	Road works VMS	05.33		
	Road cones	05.41		
	Curve warning	05.47		
	70 kmhr sign	05.48		
	Chevron B/W	05.58		
A_TW4	Blue/white arrow	06.14		
	50 kmhr sign	06.15		
	Traffic lights	06.19		
	Lane merge	06.23		
	Slippery surf. sign	06.27		
	50 kmhr sign	06.37		
	Green sign	06.39		
	Turning car	06.42		
	Green sign	06.44		
A_PW32_AV_FLO	Chevron B/W	06.53		
	70 kmhr sign	07.09		
	School/child sign	07.12		
	Green sign	07.12		
A_TW1_VMS	Car braking on left	07.29		
	Road works VMS	07.31		
	30 kmhr sign	07.33		
	60 kmhr sign	07.37		
	Road workers	07.38		
	Intersection	07.40		
	Road workers	07.50		
	Lanes merge sign	07.50		
	Green sign	07.57		

Reel A Order 1 (cont.)				
Clip	Event	Time	Reported	Other Items Noticed
	Lane merge	08.00		
A_PW30_FLO	50 kmhr sign	08.03		
	Car turning	08.09		
	Car pulling out	08.18		
	Ped Xing sign	08.25		
	Ped xing	08.29		
	Car braking ahead	08.35		
	Road works on right	08.38		
A_PW32_AV_OSZ	Chevron B/W	08.54		
	70 kmhr sign	09.11		
	School/child sign	09.14		
	Green sign	09.13		
A_PW32_VMS	50 kmhr sign	09.39		
	Car braking ahead	09.41		
	School/child VMS	09.49		
	Cyclist	09.50		
	Blue/white arrow	10.04		
A_TW1_AV_OSZ	Curve sign	10.24		
	Road works sign	10.29		
	Road cones	10.37		
	Curve sign	10.44		
	70 kmhr sign	10.44		
	Chevron B/W	10.55		
A_PW32_FLO	70 kmhr sign	11.03		
	Green sign	11.04		
	Horse sign	11.04		
	School/child sign	11.06		
	Fire hazard sign	11.06		
	Blue sign	11.10		
A_RC	Guard rail	11.32		
	Bridge	11.39		
	Chevron sign	11.55		
A_PW32_STD	School/child sign	12.23		
	Parked car on left	12.26		
	Chevron B/W	12.34		
	Cyclist	12.35		
	Give way	12.48		
	Intersection	12.48		
	Pedestrian	12.49		
	Pedestrians	12.51		

Reel A Order 1 (cont.)				
Clip	Event	Time	Reported	Other Items Noticed
A_TW1_OSZ	Traffic lights	12.55		
	Intersection	12.55		
	Blue sign	12.58		
	Yellow sign in road	13.03		
	Pedestrians	13.07		
	Barrier on right	13.09		
	White sign on left	13.17		
	Traffic lights	13.19		
	Intersection	13.19		
	Road works sign	13.22		
	Lanes merge	13.27		
	30 kmhr sign	13.29		
	Road works	13.30		
	Cars turning	13.36		
A_PW32_AV_VMS	Chevron B/W	13.45		
	70 kmhr sign	14.02		
	School/child VMS	14.05		
	Green sign	14.05		
A_PW17+RC	Yellow arrow sign	14.24		
	Curve warning	14.33		
	Chevron sign	14.38		
	Curve sign	14.46		
	Green sign	14.48		
	Winding road	15.02		
A_PW32_OSZ	Intersection sign	15.06		
	Car turning left	15.10		
	Truck on left?	15.12		
	80 kmhr sign	15.21		
	School/child sign	15.23		
	Speed camera sign	15.30		
	Orange sign	15.32		
	100 kmhr sign	15.42		

Appendix C

Example video frames of sign types and formats

Example 1. PW30 standard orange.

Example 2. PW30 yellow-green.

Example 3. TW1 standard red.

Example 4. TW1 large dimension.

Example 5. TW1 VMS.

Example 6. PW17.

Example 7. RC4 black & white chevron.

Example 8. RC4 orange & black chevron.

Example 9. PW32 standard orange.

Example 10. PW32 yellow-green.

Example 11. PW32 large dimension.

Example 12. PW32 VMS.

Example 13. PW41 standard orange.

Example 14. TW4 temporary red..