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SPEED PERCEPTION 1: Drivers' judgements of safety and speed on urban and rural straight roads.

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Abstract

This project was undertaken to evaluate the role of the type of road and road width, roadside development, travel speed, driving experience and the sex of the driver on estimates of safety and travel speed. A preliminary study showed that laboratory testing using 16mm movie film stimulus materials was suitable for testing road speed perception. Three factorial design experiments were performed using urban, rural and semi-rural road scenes in which the independent variables were systematically manipulated. Slash-line responses of safe operating speed and travel speed estimates in km/h were collected from 108 licensed drivers, recruited as subjects. Free speed measurements were also collected at each test site where practical. The results showed that the presentation speed had the strongest effect on the subjects' judgements. The type of road also influenced speed perception while roadside development effects were dependent upon the type of environment (urban or rural) and the road category. Driver experience did not unduly affect the results, although the sex of the driver had a slight influence on the data. Recommendations are made for further research in this area to establish potential countermeasures against speeding.

Keywords

SPEED, PERCEPTION, HIGHWAY, CARRIAGEWAY, PAVEMENT, ENVIRONMENT, MAN, WOMAN, EXPERIENCE(HUMAN), RECENTLY QUALIFIED DRIVER, LABORATORY, SAFETY

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Preparation of stimulus materials was aided considerably thanks to Professor R.H. Day and the Department of Psychology staff at Monash University. In particular, Mr. Ken Hall and Mr. Vladimar Kohout arranged for the loan of the Bolex camera and Mr. Richard Hobbs, Senior Technical Officer, constructed the vehicle mount used on the research vehicle.

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EXECUTIVE SUMMARY

Design criteria used by engineers for determining speed limits in Australia assume that various road characteristics and roadside features influence speed on the road.

There is considerable research evidence that the perceptual features of roads and their surrounds can influence road crash rates and vehicle performance. However, not much is known about how these features affect the perception of speed on the road.

Speed perception involves different levels of human information processing. These include higher-order cognitive decisions by drivers about travel speed, as well as the relatively automatic (less conscious) processes involved in sensory perception.

Research evidence suggests that manipulating the visual cues involved in sensory perception on the road may lead to long-term improvements in road behaviour.

The Research Project

This research project set out to develop a suitable means of assessing the sensory perception of speed on the road and to evaluate the effects of several road and roadside features on the speed judgements of drivers.

A literature review highlighted various methods of testing road speed perception. In addition, a number of road, environment and human factors, likely to influence the sensory perception of speed, were also identified.

A validation study was performed initially to see whether speed perception on the road could be simulated accurately in an experimental laboratory.

Twelve road sites were selected around Melbourne that encompassed a range of different roads and roadside environments. Free speed traffic patterns were collected at these sites.

Passengers in a research vehicle were asked to make safe operating speed assessments and to estimate travel speed at each of the 12 sites. Similar responses were also made by other subjects in an experimental laboratory using 16mm film segments of the same sites, taken from the driving position of an automobile.

The results of this study were encouraging. The pattern of responses in the laboratory was almost identical to those collected on the road. However, safety responses in the laboratory were heightened presumably because of a reduction in road feedback information.

Laboratory Experimentation

Three multi-factorial laboratory experiments were then undertaken involving rural, semi-rural and urban road environments. The role of road category, road width, roadside development, travel speed, driver experience and driver sex were all systematically evaluated on estimates of safety and travel speed.

One hundred and eight licensed drivers with varying degrees of driving experience were recruited and tested using the laboratory testing method developed in the previous study.

The data collected were analysed using analysis of variance and omega-squared statistics.

The Main Findings

The strongest effect observed was for travel speed. Film presentations below the speed limit were judged to be too slow while presentations above the speed limit were assessed as too fast in terms of what was a safe operating speed for the subjects. This result was not unduly affected by the area but was influenced, to some degree, by the type of road and roadside environment, and by the sex of the driver on occasions.

This result was consistent with previous speed estimation findings and confirmed the need for moving stimulus materials in any speed perception experimentation.

The type of road also influenced speed perception. Roads with a higher design standard and greater width generally resulted in higher estimates of safety and greater under-estimates of travel speed. This finding, however, was also a function of the region and whether the road was divided or not

There was some suggestion that the particular lane of travel may have also influenced speed perception, although further research is required to confirm this finding.

Roadside environment effects were very much dependent on the environment under test.

In rural environments, roads without roadside trees were perceived as safer, and travel speeds under-estimated much more, than those heavily treed. This was especially so for faster travel speeds.

For semi-rural environments, though, roadside trees generally had less influence on speed perception. Moreover, their effect was dependent on the type of road and, seemingly, on the degree of urban development as well.

Urban roadside environments were noticeably different to rural and semi-rural settings, comprising either residential or commercial or industrial developments. Residential settings were perceived to be slightly safer than industrial and commercial settings, although these differences were only very small.

The effect of commercial and industrial complexes was to decrease the estimates of safety for 4-lane and 2-lane roads but to increase safety estimates on divided roads.

This result was explained by the increased spaciousness of service roads and off-street parking, often found at commercial and industrial complexes located on major divided arterials.

Driver effects in these experiments were minimal. First year drivers responded similarly to experienced drivers, suggesting that speed perception was not dependent on the amount of driving experience.

Thus, any on-road speed differences apparent between novice and experienced drivers more likely involve cognitive or driving skill differences, rather than a fundamental difference in the way these two groups process sensory information.

The sex of the driver had some effect on both safety and speed estimates in rural areas and at high travel speeds. While this may have been a chance finding, it deserves testing further in future speed perception research.

Other Findings

The safe operating speed response was a suitable means of assessing speed perception. The data obtained was reliable and consistent and the results from this technique could be interpreted simply and meaningfully.

Estimates of travel speed and free speed measures on the road were more difficult to interpret in terms of driver perceptions. However, they compliment the safe operation speed responses and facilitate a more detailed account of the role of perception in driving.

The free speed data generally supported the perceptual results for type of road and roadside environment, especially when the mean speed values were equal to or lower than the speed limit.

This suggests that perceptual countermeasures will be most effective at reducing vehicle speeds on the road when drivers' speed perceptions are not overly safe.

Additional Research Required

Recommendations are made for additional research in road speed perception.

Follow-up experimentation, involving other likely perceptual variables and resolution of the anomalous findings, is necessary before a range of countermeasures against speeding can be determined and tested.

Further urban research is also required to identify all the perceptual factors involved in the speed zone index and to formulate a mathematical procedure to arrive at an unbiased estimate of travel speed.

1. INTRODUCTION

The Federal Office of Road Safety commissioned RACV Limited in April 1986 to undertake a study of the effects of perceptual changes on drivers' speed estimates. The study was aimed at identifying how the environment influenced speed behaviour through a driver's perception of the road ahead.

The long-term aim of the study was to identify environmental countermeasures that could be used to control speed behaviour in addition to education and law enforcement. The study also set out to further increase the general understanding of the role of driver perception in speed behaviour on the road.

1.1 STUDY OBJECTIVES

The three objectives specified by the Federal Office of Road Safety for the speed perception project were:-

To establish which factors influence speed choice at sites representative of a variety of situations in appropriate urban and rural areas in Australia.

To measure and report upon the operating speeds and other relevant traffic characteristics at the selected sites.

To report upon the relationship, if any, between the factors identified and the speed and traffic characteristics observed.

The project was to be a preliminary evaluation of the effect of perceptual changes on drivers' speed judgements. Emphasis was to be placed on developing a suitable methodology for the evaluation and testing of some of the more important road and environment factors.

Hence, a minor literature review was required to highlight possible independent and dependent variables. In addition, testing was needed to validate the testing procedure prior to full experimentation.

1.2 STATEMENT OF THE PROBLEM

The role of speed in road crashes has attracted considerable debate over the years. Those sharing the enforcement point of view argue that road crashes would be minimised if everyone obeyed the present speed limits imposed on our roads (McMenomy, 1984; Vulcan, 1986).

The fact is, of course, that a large proportion of motorists consistently drive above the legal limits (Mostyn and Sheppard, 1980; Cowley, 1980; Elliot, 1981; Sanderson and Corrigan, 1984; 1986). Hauer, Ahlin and Bowser (1982), Armour (1986) and Shinar and Stiebel (1986) showed that enforcement could lead to speed reductions when it was intermittent but then the effects tended to be localised. Elliot (1981) argued that a "personal limit" existed where drivers are controlled by what they perceive to be a safe speed, rather than the legal limit. Hogg (1977) further claimed that motorists are not convinced of any relationship between exceeding the speed limit and crash involvement and, hence, do not believe it is necessary to keep to the posted speed limit. This evidence led McLean (1977) to suggest the need for alternative forms of speed enforcement.

In a submission to the House of Representatives Standing Committee on Road Safety (1984), Swann claimed that people drive according to their perception of the road conditions. Lay (1984), too, argued that motorists' perceptions have a primary influence on travel speeds. If this is the case, it may be possible to change road conditions to influence the perception of what is a safe operating speed. Conceivably, this would result in drivers selecting a lower travel speed.

Such an approach, however, necessitates understanding the role of environmental cues and their interactions in a driver's speed decisions. To date, however, very little is known about the influence of the road and surrounding environment on a driver's perception of speed.

1.3 SPEED AND CRASH INVOLVEMENT

Studies which evaluated the relationships between speed and crash involvement and severity are limited and generally refer to work undertaken in the 1960s. More recent studies have not investigated the relationships per se but have concentrated on the effects of speed limit changes.

The basic research undertaken for rural highways by Solomon (1964) illustrated that there are relationships between crash involvement and speed and, in particular, the danger of large deviations in individual vehicle speed from the average speed of traffic. These relationships take the form of a U-shaped curve with an involvement rate higher for very low and very high speed drivers and with minimum involvement rates at, or marginally above, the average speed (see Figure 1.1).

The exact relationship was difficult to establish from this initial research because estimates of speed had to be taken. The Research Triangle Institute (1970) extended this early research by using actual measured speeds and showed the shape of the relationship was not nearly as pronounced as that first suggested by Solomon. West and Dunn (1971) took the research one step further and showed different involvement rates when including and excluding turning vehicles. If there are few turning vehicles, the curve is extremely flat and there is little difference in involvement rate for speeds up to 25 km/h from the average speed. This relationship reported by West and Dunn is illustrated in Table 1.1.

FIGURE 1.1

Involvement rate by travel speed, day and night

(Solomon, 1964)

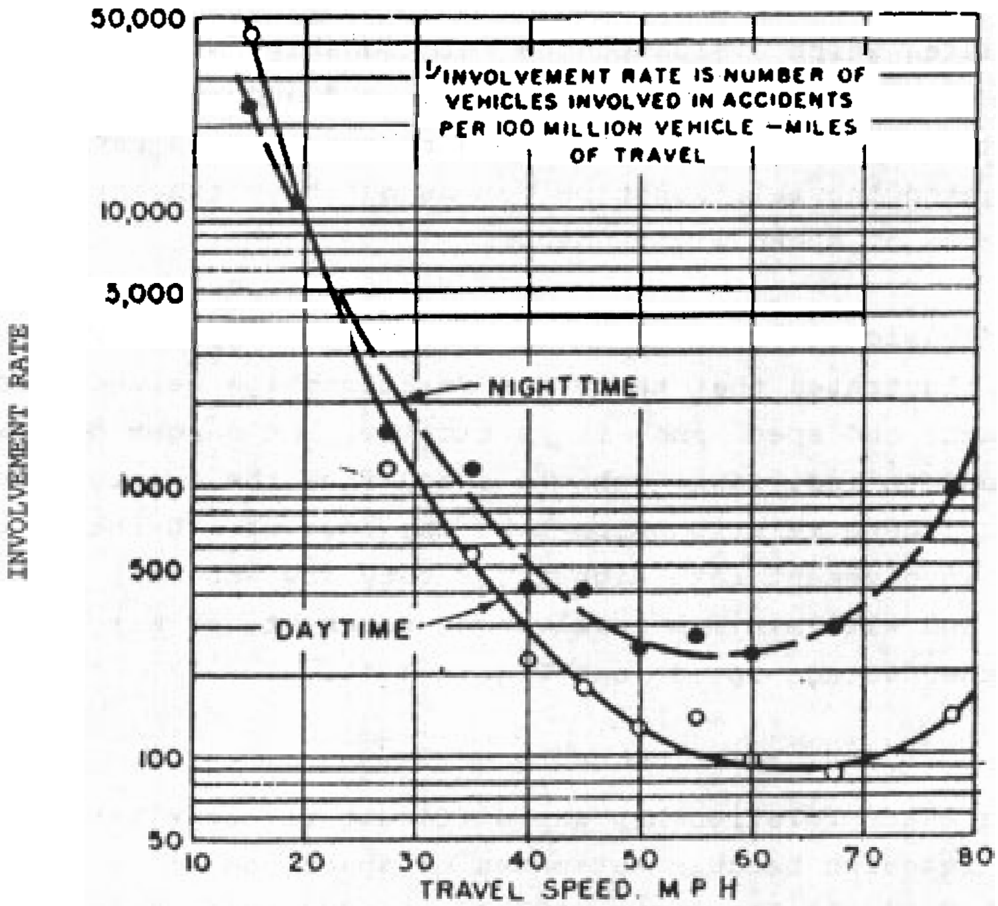


TABLE 1.1

RELATIONSHIP BETWEEN SPEED AND CRASH INVOLVEMENT

(from West and Dunn, 1971)

Speed Deviation (mph)	Involvement Rate per Million vehicle miles	
	Including Turning Crashes	Excluding Turning Crashes
Less than - 15.5	42.3	6.3
- 15.5 to - 5.5	2.3	.7
- 5.5 to + 5.5	1.6	.8
+ 5.5 to + 15.5	1.5	1.0
More than + 15.5	8.5	6.9

Munden (1967) also reported a U-shaped relation between crash rate and relative speed, similar to that reported by Solomon. Munden's finding differed from the previous research, however, as he compared the crash rates of people who drove relatively fast with those who drove relatively slowly. Nevertheless, the different studies are still complimentary.

Hauer (1971) supported the crash involvement curves derived by these researchers by showing that the rate of overtaking in traffic was also a U-shaped function of traffic speed. Hauer related the crash involvement rate to the rate of overtaking and concluded that on highways with both lower and upper speed limits, the lower limit can be two or three times more effective than the upper limit in reducing overtakings and crash involvement rates.

Cumming and Croft (1971) reviewed much of the literature on speed control and concluded that there is an intimate relationship between the rate of crash and the speed deviation of vehicles from the mean speed. In addition, they claimed a correlation between crash severity and speed where severity increased with speed. If the objective of speed control is to reduce the number of crashes, the aim should be to reduce speed variation. However, if it is to reduce crash severity, the aim then should be to reduce the absolute speed. Lave (1985), in fact, argued that variance, not speed, was the critical factor in road deaths in the USA.

1.3.1 Speed and the Number of Crashes

A number of countries have subsequently amended speed limits on rural highways and several have investigated the effect of reduced speed on crash involvement rate (Organization for Economic Co-operation and Development, 1972; Johnston, White and Cummings, 1973; Nilsson, 1977, 1981; Johnson 1980; Salusjarvi, 1981; Hearne, 1981; Christiansen, 1981; Lassare and Tan 1981).

Individually, these studies may be of limited value because of various shortcomings, such as relatively short periods of observation before and after speed changes, lack of rigorous analysis of the before- and after-crash data, and questionable statistical validity of the effects attributable to speed reduction. However, the weight of evidence suggests that, where speeds have been reduced by speed limits, there has been a reduction in the total number of crashes. Furthermore, there appears to have been a reduction in the level of injury with speed reductions as well.

1.3.2 Speed and Crash Severity

The dissipation of energy resulting from any collision can be expressed by the relationship between vehicle mass and speed. Wadsworth (1966) showed that kinetic energy is generated by the moving vehicle by the square of the speed rather than speed itself. This means that increased speed increases the severity of a collision and most probably increases the associated level of injuries for vehicle occupants, although the exchange of energy between vehicle and occupants can also influence the severity of injuries sustained.

Solomon (1964) concluded that this increase was extremely rapid at travel speeds in excess of 60 mph (96 km/h). It was also shown that the probability of a fatality increased markedly for speeds above 70 mph (112 km/h). Bohlin (1967) reported that the relationship between injury risk and speed was curvilinear with an increase in probability of the injury being greater at higher impact speed. Bohlin further showed that the relationship can be changed by the wearing of seat belts.

1.4 POSTED SPEED LIMITS

Speed limits traditionally consist of general rules that apply in discrete areas, such as urban or rural settings. Where these limits vary due to roadway, traffic or adjacent land use conditions, the practice is known as speed zoning (NAASRA, 1980). Limits themselves can either be specified as absolute, being the maximum speed at which a vehicle is permitted to travel, or prima facie, being the speed above which a driver would have to prove that the speed was not incompatible with prevailing conditions.

Absolute maximum speed limits can exert a greater influence on the distribution of speeds than a prima facie limit. Cleveland (1970) and Cumming and Croft (1971) reported reductions in the number of excessively speeding vehicles when appropriate absolute limits were chosen, although the average speed was not affected very much. This has not been proven yet for prima facie limits (Herbert and Croft 1979).

Traditionally, speed limits have been set at or near the 85th percentile speed of traffic, that is, the speed at or below which 85% of motorists choose to travel. This choice stems from research undertaken by Witheford (1970) who stated that:

> *"the 85th percentile speed is that most desirably approximated by a speed limit. Because of the general straight and steep slope of the typical speed distribution below the 85th percentile, a speed limit set only a little lower will cause a large number of drivers to be violators".*

Joscelyn, Jones and Elston (1970) undertook a national survey of practices used to establish maximum speed limits, together with a major review of the various techniques for establishing speed limits. From a screening analysis, it was suggested that three methods were worthy of further consideration for full scale implementation. These included the theory of speed distribution skewness (Taylor, 1965), cost orientation (Oppenlander, 1966), and the 85th percentile method.

Their preferred technique analysis showed a strong relationship between deviation of the speed of the crash vehicle from the mean speed of the traffic stream (Joscelyn et al 1970). The analysis also showed that the cumulative crash rate was relatively independent of speed until the 85th percentile value, after which it rose exponentially. The study recommended that maximum speed limits should be based on the 85th percentile of the observed travel speeds.

A more recent alternative to the 85th percentile speed approach is a cost-benefit analysis. Cowley (1981) suggested that speed limits could be set at speeds which minimise overall transportation cost. The European Conference of Ministers of Transport (1977) discussed cost-benefit analysis with respect to general limits, reviewing previous studies and discussing the benefits and disbenefits of the method. It was concluded that the cost-benefit approach would have to be developed further before it could be effectively evaluated.

1.4.1 The Speed Zone Index

There are often occasions where free speed studies cannot be undertaken to assess the 85th percentile values. In these situations, Traffic Commission Victoria (1976) outlined a method of estimating the likely 85th percentile speed, based on an evaluation of various factors that supposedly influence the subjective assessment of speed. These factors include such things as roadway characteristics, alignment, shoulder construction and width and roadside development. The speed zone index is subsequently determined after assessing the existence and likely effects of these factors at a particular road site.

The speed zone index, therefore, acknowledges the role of perceptual factors in speed determination on the road. **This view** is also shared by the National Association of Australian State Road Authorities (1980) and Lay (1984). Unfortunately, however, the method adopted for arriving at the 85th percentile speed using the speed zone index relies upon "several years of experience" in interpreting the likely perceptual effects. A more objective and rational approach would be desirable to minimise the possibility of bias.

1.5 DEFINING SPEED PERCEPTION

The word "perception" has different connotations for different people and professions. On one hand, perception has been used to refer to the relatively automatic sensory processes of an individual interacting with his or her environment. In this sense, it is the first stage of the psychological process that occurs between human stimulation and response, and can be referred to as the sensory perceptual stage (See Figure 1.2).

Alternatively, perception has also been used to describe the deliberate and conscious thought processes involved in human response, involving an individual's beliefs, motivations and desires. Perception here involves higher order decision making processes where the social consequences of an action can influence the ultimate response. For convenience sake, this is referred to as the cognitive perceptual stage.

The speed at which a driver chooses to travel can clearly involve both of these perceptual constructs. While sensory perception will determine from the outset what information is available to a human operator in a particular stimulus situation, the internal states or social forces can nevertheless influence the form of the ultimate response to that information.

Given that sensory perception is the basis for a human response in his or her environment, manipulating the visual cues involved in sensory perception on the road could lead to long-term improvements in road behaviour. This project is specifically aimed at testing sensory perceptions, and concentrates on the effect the driving environment has on the input processes of a driver's judgement of speed on the road.

1.6 PREVIOUS RESEARCH IN SENSORY PERCEPTION

There is only a limited number of studies that have investigated the sensory aspects of speed perception. These are summarised below, along with a theoretical account of the role of movement in the sensory perception of speed.

1.6.1 Visual Performance Studies

Denton (1971, 1973) reported that speed judgements in a driving simulator and on the road were highly dependent on the nature of the visual pattern presented to the driver's eye. Transverse line treatments were introduced at selected roundabouts in the United Kingdom to induce drivers to slow down during their approach to these intersections. Evaluation studies (Denton, 1973, 1976; Rutley 1975; Helliar-Symons, 1981) reported subsequent reductions in speed, speed variation and lateral position, although the speed effects of this treatment tended to dissipate somewhat with time (Denton, 1973; Rutley, 1975).

More recently, Cairney and Croft (1985) and Cairney (1986) reported two studies which investigated the effects of various environment and road factors on drivers' speed judgements. Unfortunately, these studies used static photographs of roads and subjects made verbal speed limit responses; the results, therefore, are difficult to interpret solely in terms of sensory perceptions of speed. Nevertheless, with slight modification, the approach adopted in these studies could prove a useful means of investigating road speed perception.

1.6.2 Absolute Judgements Of Speed

There have been a few studies which investigated a driver's ability to estimate his or her own travel speed. Hakkinen (1963) found that speed judgements were under-estimated by subjects responding to films and by passengers in actual traffic situations in the medium and high speed ranges. Salvatore (1968, 1969) and Reason (1974) reported that subjects consistently under-estimated speed across a 20 to 60 mph (32 to 96 km/h) velocity range in both vehicles and simulators. **Both Hakkinen** and Salvatore, furthermore, showed that errors of estimation increased substantially when sensory inputs (visual, auditory, kinesthetic, tactile and vestibular) were withheld.

Evans (1970a, 1970b) found that slow speeds were, in fact, well under-estimated whereas high speeds were only slightly under-estimated in vehicle tests on the road. Moreover, he found that the perspective view presented to subjects in laboratory tests of speed estimation was critical for replicating road speed judgements. Any test of speed perception, therefore, needs to take account of the absolute level of speed involved and the presentation method of moving road environments.

1.6.3 Retinal Streaming

The concept of "retinal streaming" was proposed by Gibson (1950, 1958, 1968) and Calvert (1954) as an explanation of the cues used in perceiving speed. In essence, retinal streaming explains how the visual pattern presented to a moving observer varies from a stationary image at the point of fixation of the eye (the fovea on the retina) to a blur of increasing magnitude the further the distance from the fixation point. Thus, it provides a means of interpreting velocity information directly from visual stimulation in the periphery of the eye.

The notion of "retinal streaming" in depth perception has been criticised (Johnston, White and Cummings, 1973; Regan and Beverley, 1978; 1982). However, most authors agree that some form of relative coding on the retinal surface of the eye is an extremely important cue for the perception of speed (Gibson and Crook, 1938; Gordon, 1966; Moore, 1968; Lee and Lishman, 1977; Harrington and Wilkins, 1980).

Gordon (1966) and Moore (1968) described the consequences of a moving image on the road in terms of velocity gradients on the retina of the eye. They argued that the perception of velocity on the road can be determined solely from the integration of movement information on the retinal surface. These theoretical accounts of speed perception are in general accord with Gibson's (1950) motion parallax concept in depth perception.

2. POSSIBLE CUES FOR SPEED PERCEPTION

There are many possible factors in the environment that are likely to exert some influence on a driver's perception of speed. Jennings and Demetsky (1983) listed 16 road and environment variables that they claim will influence driving behaviour on the road (see Table 2.1). A detailed literature review was subsequently undertaken to indicate the likely effects of these variables for speed perception.

TABLE 2.1
POSSIBLE ROAD AND ENVIRONMENT VARIABLES
(from Jennings & Demetsky, 1983)

ROAD or ENVIRONMENT FACTOR
time of day
roadway grade
radius of curvature
length of curve
lane and road width
existing pavement markings
shoulder width (if any)
nature of adjacent lane
intersecting roadways or driveways
- in curve
- before curve
- after curve
traffic volumes
average speeds of traffic
delineator spacing (if any)
delineator type and number (if any)
condition of delineators
weather conditions
sight distance

2.1 DATA SOURCES

The evidence of road and environment factors likely to influence speed speed perception was drawn from three separate data sources, namely crash data, free speed data measured on the road, and performance data from road and laboratory testing.

The first two categories involved mainly correlational studies, where environmental effects were deduced from vehicle behaviour observed on the road. Hence, it is impossible to establish definitive causal relationships from these studies. The third category of data includes both correlational and experimental results and was more likely to be relevant to this study.

In any event, the findings from all three data sources were only used for evaluating which variables were likely to be of interest and for generating hypotheses for further testing.

2.2 URBAN AND RURAL ENVIRONMENTS

There are several reasons why speed perception is likely to differ between these two environments. First, speed limits are generally different for urban and rural roads. Road design incorporates proposed speed limits and other major urban-rural environment differences. Hence, urban and rural roads differ considerably in terms of their engineering and community expectations (Lay, 1984).

Hungerford and Rockwell (1981) and Jennings and Demetsky (1983) noted that travel on rural roads was noticeably different from that on urban streets in that speeds were generally higher, traffic volumes were much lower and the severity of crashes increased. Sanderson and Corrigan (1984, 1986) also demonstrated that many drivers disproportionately violated urban speed limits than rural limits.

The length of the trip and the number of passengers can also vary between rural and urban journeys. Joscelyn et al (1970) and Hirsch (1986) reported that trip distance and purpose significantly affected speed, although the number of passengers gave conflicting results. This may have resulted from the different samples of drivers and environments used in these studies.

The longer journeys associated with rural travel are more likely to induce speed adaptation and driver fatigue. Mast, Jones and Heimstra (1966) showed that driver tracking error and speed control were significantly different in the last hour of a six hour continual tracking task. Safford and Rockwell (1966) reported that speed control diminished with time over a 24 hour driving task, but interestingly, a rest period of only a few minutes was sufficient to offset these effects in the short-term. These data probably reflect pure driver fatigue influences.

Triggs (1986) described speed adaptation as the effect where prolonged exposure to vehicle speed causes subjects to under-estimate their speed judgements. It is the feeling of practically stopping when slowing down to pass through a country village, even though travel speed is still substantial. Speed adaptation differs from driver fatigue in that adaptation does not necessarily occur with driver tiredness. Nevertheless, it does tend to occur only after long periods of fairly constant high speed travel (Reason, 1974) and thus is often compounded with driver fatigue effects.

Any study which addresses the role of the road and its surrounds in speed perception, therefore, should be concerned with the influence of urban and rural environments. Moreover, as "urbanness" and "ruralness" are not discrete categories, but rather end points on a road environment continuum, it would be useful to consider a range of road environments for speed perception comprising various combinations of urban and rural features.

2.3 ROAD ALIGNMENT

In a review of the relationship between road geometry and single vehicle crashes, Sanderson and Fildes (1984) reported that the most consistent associated road feature was horizontal curvature (see Table 2.2). In most instances, decreasing the radius of curvature led to an increase in run-off-the-road crashes. The frequency of curves did not appear to influence crash rates, although there was some suggestion that an unexpected sharp curve may be crash inducing (Raff 1953).

Studies which evaluated vertical curvature effects were inconclusive. Some studies suggested a relationship with road contour, although no relationship was found for camber or superelevation. The results for gradient, however, were mixed, seemingly dependent on the measurement technique employed. More will be said of gradient further on.

Sanderson and Fildes (1984) analyzed single vehicle crashes in Victoria between 1978 and 1982 and found that 47 per cent occurred on bends and 53 per cent on straights. They concluded that while single vehicle crashes on curves were over-represented in the statistics, crashes on straight roads were still a significant problem in this Australian State. Similar results have also been reported for other Australian States (Cowl and Fairlie, 1970; Peter Casey and Associates, 1979).

The performance literature also suggests considerable differences in driving performance between straight and curved sections of roadway. Gordon (1966b), Blaauw and Riemersma (1975) and Shinar, McDowell and Rockwell (1977) all reported significant differences in driver eye movements between straight roads and curves. They noted that visual fixations for straights was much more static and generally involved longer distance fixations.

STUDIES	TRAFFIC VOLUME	NUMBER OF LANES	ROAD WIDTH	DELINEATION	INTERSECTIONS	HORIZONTAL CURVATURE	CURVE FREQUENCY	VERTICAL CURVATURE	SIGHT DISTANCE
RAFF (1953)	YES	YES	YES	-	YES	YES	NO	NO	NO
COWL & FAIRLIE (1970)	-	-	NO	SOME	SOME	YES	-	-	
GUPTA & JAIN (1975)	-	-	NO	-	-	YES	-	NO	YES
AGENT & DEEN (1975)	YES	YES	YES		-	YES	-	SOME	-
COOPER (1980)	SOME	SOME	YES	-	-	YES	-	YES	
WRIGHT & ZADOR (1981)	-	-	YES	-	-	YES	-	YES	-
HALL & ZADOR (1981)	-	-	-	-	-	YES	-	YES	-
McBEAN (1982)	-	-	SOME	YES	-	YES	-	NO	YES but curvature

YES = relationship confirmed NO = no relationship

Table 2.2 Summary of accident causation studies which implicate road geometry with crashes (from Sanderson & Fildes, 1984).

Triggs, Harris and Fildes (1979), Fildes (1979) and Triggs, Meehan and Harris (1980) reported differences in delineation requirements for roads of differing vertical and horizontal curvatures. They argued that these differences reflect differing visual requirements between crests and sags in the road. Fildes (1987), in fact, demonstrated differences in the perspective road geometry as a vehicle approached a road curve and claimed that the visual demands in the approach zone of a road curve (straight section) are noticeably different to those in the curve itself.

Hence, any study of the likely road or environment influence on driving needs to take account of differing road alignments. Straight sections appear to be visually less complex for drivers and would be a logical starting point for research in this area.

2.4 ROAD CATEGORY AND LANE WIDTH

The crash data on the role of the number of lanes and lane widths reveals some interesting trends. Raff (1953) reported that wide pavements and shoulders were associated with lower crash rates on two-lane curves in the USA, although he failed to find any strong association on tangents. More recently, Evans (1985) argued that fatality rates in the USA differ by a factor of four or more depending on the type of road involved.

Peter Casey and Associates (1979), however, found no conclusive evidence concerning relative safety and number of lanes on straight sections in Australia. However, there was some suggestion of an increase in fatal crashes on straight narrow roads of sub-standard rural widths, and motorways tended to have less fatals than other highways.

Solomon (1964) found that two-lane roads had a head-on crash rate five times that of four-lane sections, and four-lanes less than 15 feet (5.4m) wide were twice as likely to have a head-on crash than four-lanes greater than 15 feet (5.4m) wide. He reported no consistent relationship between median width and head-on collisions, although the presence or absence of a median had a strong crash effect. It is very difficult to ascribe perceptual effects from these data, however, because of the likely relationship between lane encroachment and crash involvement.

The performance data here is much more relevant. A positive relationship was reported between vehicle speed and street width in several studies (Oppenlander, 1966; Leong, 1966; Smith and Appleyard, 1981). Moreover, Vey and Ferrari (1968) found greater speed, less headway and less speed and headway variance for 11`3" (3.4m) lanes over 9`9" (3.0m) lanes across two comparable road bridges in Philadelphia. Smith and Appleyard (1981) report a direct relationship between drivers' speed and "apparent width" which encompasses the influence of the immediate surrounding environment on the actual road surface (a perceptual interpretation of a geometric feature).

McLean and Hoffman (1972) found that drivers adopted different steering strategies for narrow lanes at high speeds than for more moderate lane widths and speeds. Joscelyn et al (1970) suggested that drivers in multi-lane roads adjusted their speed in accordance with vehicle speeds in the slower parallel lane, although they only reported data from other studies to support this claim.

A correlation was also suggested between vehicle speed and street or block length (Leong, 1968; Loder and Bailey, 1980; Smith and Appleyard, (1981). However, this is probably related more to sight distance than street length per se. The smoothness of the road surface was found to be directly related to vehicle speed (Oppenlander, 1966; McLean, 1982) but not crashes (Raff, 1953). McLean (1982) also reported mean free speeds about 15-20 km/h lower on unpaved two-lane roads than on equivalent paved surfaces.

There is considerable evidence then of an association between road category and lane width with free speed and crash involvement. Given that variations in lane width and the number and type of lanes has a marked influence on the geometric perspective view presented to a driver moving along the road, it is quite probable that these features will also influence speed perception.

2.5 ROAD MARKINGS AND DELINEATION

While road markings and delineation are normally used to define lane width, they are also adopted more generally for improving the visibility of the road ahead. Gordon (1966), Riemersma (1979) and Godthelp, Milgram and Blaauw (1984) argued that the edgelines of the road are used by drivers to control heading direction, vehicle speed and travel path. Thus, the type of line marking may well influence perception of the road ahead.

Witt and Hoyos (1976) reported that a varying pitch broken edgeline in the approach to a road curve resulted in drivers adopting a more suitable speed profile while negotiating a curve in a vehicle simulator. Rockwell, Malecki and Shinar (1974) also reported that novel pavement markings can influence perceived speed and roadway width on curves, although they noted these influences may be site specific and might not necessarily hold with time (Hungerford and Rockwell, 1980).

As noted earlier, Denton (1974), Agent (1980) and Helliar-Symons (1981) found that perceived speed could be modified by transverse stripes across the road in the approach zone to intersections. However, only the speed variation reductions were still evident at sites 18 months after installation. Road markings, then, seem to influence speed judgements for curved road sections and at intersections.

Lum (1984), however, found no effect of narrow longitudinal pavement markings (with raised pavement markers) on either the mean speed or speed distributions on straight sections of road at residential sites. Others also have shown no difference in speed on straight roads for wide edgelines (Cottrell, 1985) or special treatments in mountainous areas (Garber and Saito, 1985). It would appear that the major benefit for edgelining on straight sections of two-way rural roads is for maintaining a safe position within the lane itself (Triggs and Wisdom, 1979; Triggs, 1986; Cottrell, 1985). Evidently, edgelines on straight sections do not really add very much to the perspective view of the road presented to the driver.

Guideposts with reflectors have been shown to have a marked influence on curve detection (Triggs, Harris & Fildes, 1979; Fildes, 1979; Triggs, Meehan and Harris, 1980; Nemeth, Rockwell and Smith, 1985), night-time run-off-the-road crashes (Neissner, 1983) and curve negotiation strategy (Hungerford and Rockwell, 1980). Under some circumstances, posts and post height can influence straight road guidance at night (Godthelp and Riemersma, 1982; Blaauw, 1985). However, there were no studies found which specifically evaluated the effects of guideposts on vehicle performance during the day, presumably because these delineation treatments are mainly reserved for improving night-time curve negotiation performance. Nevertheless, the relative movement characteristics of guideposts in a driver's view of a moving roadway, suggest it could be worthwhile testing the influence of guideposts on the perception of speed.

2.6 SIGHT DISTANCE AND GRADIENT

Road design assumes that sight distance is a critical factor in setting speed limits (Joscelyn et al 1970, NAASRA 1980). Leong (1968) reported a positive correlation between spot speed and sight distance while Olson, Cleveland, Fancher, Kostyniuk and Schneider (1984) also noted a similar relation between sight distance and crashes. However, this latter study did not control for other speed factors like traffic density (Galin 1981) and, therefore, the results must be treated cautiously.

In his review of the spot speed literature, Oppenlander (1966) placed sight distance amongst the significant but less important variables, compared to traffic density. McLean (1982) claimed that sight distance restrictions induced a small reduction in the speed adopted by the faster travelling drivers, but had little, if any, effect on the speeds of other drivers. However, he argued that it is difficult to separate sight distance effects from other effects of the changing road geometry.

In an early crash data study in the USA, Raff (1953) found no correlation between grade and crashes. This study, however, looked at a range of geometric variables and could not have accurately controlled for gradient effects alone in road crashes. Road gradient was cited as a factor in influencing observed spot speed by Oppenlander (1966), but Troutbeck (1976) was not able to clearly differentiate it from sight distance effects. In short, it is difficult to separate the effects of gradient alone from sight distance in the speed literature.

All things considered, there does appear to be some evidence that the amount of sight distance and gradient may be a factor in speed judgements, although there is some dispute over its relative importance.

2.7 OTHER TRAFFIC AND DENSITY

The Australian Road Design Handbook (NAASRA 1980) states that the volume of traffic will influence a driver's chosen speed. Traffic volume and density, both in the direction of travel and in the opposite direction, have been associated with varying vehicle spot-speeds (Oppenlander, 1963, Rankin & Hill, 1974; Armour, 1983). In general, increasing the amount of traffic leads to reduced travel speed, although flow density can be a compounding factor here.

Crash rates generally increased with increasing traffic volume on straight roads (Raff, 1953; Peter Casey & Associates, 1979). However, these studies did report a threshold effect at high volumes, presumably because traffic flows became severely restricted. Worsey (1985) also found a similar crash rate increase, although he did not observe any threshold ceiling.

This may have been due to minimum traffic volume levels observed in the study.

Traffic volume, however, does seem to exert a marked effect on the speed behaviour of drivers on the road and is likely to have some influence on a driver's perception of the road ahead. The National Association of Australian State Road Authorities (NAASRA, 1980) suggested the nature of the traffic mix can influence speed. However, there was no relationship observed for heavy vehicle volumes on free speed (Duncan, 1974), or for the percentage of commercial vehicles on crash rates (Raff, 1953). Generally, there appears to be a lack of conclusive evidence on the effects of the traffic mix and further research is needed for clarification.

2.8 NIGHT AND DAY

Night and day driving conditions represent extremes in a driver's visual information continuum. The illumination levels at night are some 200 times less under headlamps than daylight conditions and background information is almost completely absent (Fildes, 1979). Interestingly though, driving speeds tend to be higher at night (Organization for Economic Co-operation and Development, 1980). This may help to explain the high propensity of fatal and serious injury crashes that occur during darkness (OECD, 1980; Joscelyn et al 1970) and those involving young drivers (Drummond, 1985).

A number of factors have been associated with different driving performance during night conditions. OECD (1980) reported abnormally large speed differences at night in bad weather. Triggs and Berenyi (1982) found that subjects made more accurate judgements of rural road travelling speed at night. They attributed this to the increased angular speed of elements visible to the driver which, under headlights, are much closer than normal and form streaming patterns produced by reflectorized road delineators. Sanderson (1985) reported no difference in crashes on freeways in Melbourne that were both lit and unlit, supporting the notion of perceptual narrowing at night.

Elliot (1981) surveyed various groups of Australian drivers to formulate hypotheses regarding their speeding behaviour. He found that drivers were actually encouraged to travel at higher speeds at night because the road somehow seemed safer. However, verbal reports are inherently unreliable for perception studies as many of these influences occur without the driver's knowledge. The role of night driving in speed perception, then, requires further investigation, although initially, perhaps not as important as the effects of the road geometric variables.

2.9 ROADSIDE DEVELOPMENT

Roadside development can be broadly defined as any aspect of the environment close enough to the roadway to influence driving. NAASRA (1980) claimed that the roadside environment will influence traffic speed and this has particular importance for traffic engineering and planning (Brindle, 1980). The "Woonerf" (building total environment) in the Netherlands, for instance, uses benches, different pavings, winding vehicle paths and other physical and perceptual effects to reduce vehicle speed in a car and pedestrian environment. (Refer also Boeminghaus Bever-Jaenichen, Ernest (1984).

Wilson (cited in Joscelyn et al 1970) found that roadside culture and establishments resulted in lower spot-speeds on four-lane highways. Smith and Appleyard (1986) also reported that house setback distance was positively correlated with urban car speeds. They hypothesized that an urban "walled in" effect was operating on the driver and considered building type to be an important consideration in urban speed behaviour.

Rankin and Hill (1974) did not find land use alongside their test roads to affect travelling speed, although it was noted worthy of more detailed investigation. Part of the failure of land use to be a significant variable in this study may have been due to the very broad based categories used and the failure to control for factors such as traffic volume. This lack of variable control was, in fact, noted in explaining their differing results on the significance of road shoulder, width, and condition in speed determination.

Early research such as that cited in Joscelyn et al (1970) and Leong (1968) found shoulder width and condition to be correlated to free speed. In reanalysing Leong's data, Troutbeck (1976) however, was unable to find any effect for these factors and claimed Leong's result was spurious. A correlation between crash rates and shoulder paving was found by Turner, Fambro and Rogness (1981) when they applied a more rigorous categorization of variables than that used in the earlier studies. The rationale used by Turner et al was that road shoulders occur in such a variety of types that careful classification is necessary. However, care must be taken when using shoulder crash studies to assess speed as different types of shoulders, paved, gravel and so on may have different crash potential in themselves.

Rural roads with no prominent side features have been associated with lower speed judgements than similar treelined roads (Shinar, McDowell & Rockwell, 1974). Triggs (1986) suggested that this effect may be due to either increased peripheral stimulation or motion parallax effects. Whatever the case, it is apparent that this variable needs to be considered fully in any investigation of speed perception. Building set-back would also seem to warrant further study, although the evidence to date does not suggest the same for shoulder width.

2.10 DRIVING EXPERIENCE

Evans and Wasielewski (1983) reported a direct relationship between the amount of acceptable headway and youth, while Cowley (1983) linked speeding with young males. Free speed surveys by Seal and Ellis (1979) and Wasielewski (1984) in the USA show that younger drivers tend to travel at faster speeds. However, this was not observed for first year drivers in South Australia (Johns, 1981) or Victoria (Manders, 1983) where inexperienced drivers are constrained to lower maximum speed limits. Thus, these results are not directly comparable with the overseas

Driving experience has been found to influence the perception of road hazards (McKeown, 1985). Inexperienced drivers also responded differently (slower) to dangerous situations (Quimby and Watts, 1981) and adopted less safe visual strategies (Mourant and Rockwell, 1972). In controlling deviations in straight line driving, Riemersma (1982) explained observed differences as due to the use of different strategies by young and experienced drivers in making use of lateral speed cues.

These results then suggest that the amount of driving experience may have perceptual consequences for speed assessment on the road. It would be worthwhile including this variable in any subsequent speed perception experimentation.

2.11 WEATHER

Morris, Mounce, Button and Walton (1977) reported that rain had a substantial effect on the visual performance of drivers in a rain simulator during both daylight and night time conditions. The degradation in performance was a function of the rain rate, drop size and vehicle speed but not affected by wiper speed above 50 cpm. Unfortunately, it is difficult to interpret this study in terms of the likely on-road effects of weather on speed behaviour.

Levin (1977) found that subjects assessed poor weather conditions as less safe for driving on a subjective scaling test. This result has instinctive validity and is supported by the higher proportion of fatal crashes recorded during wet weather on highways in New South Wales over the period 1968 to 1977 (Peter Casey & Associates 1979). However, these effects may not be wholly speed related. Oppenlander (1966) reviewed studies which found inclement weather in association with lowered spot-speeds, although Olson et al (1984) found no significant differences between speeds at selected sites on wet and dry days.

These differences may be due, in part, to the variability of the road conditions examined by these researchers. By its nature, it is difficult to measure weather quantitatively on the road. Hence, the results could reflect reduced visibility as well as altered handling characteristics of the vehicle when braking and cornering on slippery roads. Inclement weather may also interact with other road conditions (such as night vision) leading to an increase in road crashes for night driving in wet conditions (OECD, 1980).

Overall then, there is some suggestion that weather conditions may unduly influence a driver's speed perception, although weather needs to be carefully controlled in any experimental investigations. It is conceivable that the perceptual image may be adversely influenced by the amount of light available during inclement weather and this relationship needs to be tested further.

2.12 PARKED VEHICLES AND PEDESTRIANS

The evidence available on the effects of parked vehicles and pedestrians on speed behaviour and crashes is not particularly convincing. Loder and Bayly (1980), for instance, suggested that parked cars and the presence of pedestrians are a major threat to safety. However, they only presented a small amount of evidence showing an increase in the crash rate and no suggestion of how these factors influence vehicle speed.

Smith and Appleyard (1981) showed that vehicle speed was positively correlated with "apparent width" which they argued was strongly influenced by the presence of parked vehicles. However, Joscelyn et al (1970) claimed that objects on road shoulders had little effect on free speed unless the lane width in total was less than 20 feet (6.2 m). Surprisingly, Thompson, Fraser and Howarth (1985) reported that driving behaviour was only marginally modified in the presence of pedestrians. Roadside children had no effect on vehicle speed, although small reductions were observed for large groups of pedestrians in Nottingham in the UK.

Samdahl (1986) evaluated the effectiveness of a neighbourhood road safety campaign in New South Wales, Australia. He reported instances of minor speed reductions in particular local streets following the intensive campaign to reduce pedestrian casualties. However, they acknowledged that these speed changes may have been due to other factors such as weather or parking which were outside the control of the survey. More alarmingly though, they also reported instances where drivers drove closer to the children after the programme than before, futher confirming that the presence of pedestrians seems to have little influence on driver behaviour.

More work is clearly required to determine the likely effects of parked vehicles and pedestrians on a driver's speed on the road, and especially whether the two interact in the perception of speed.

2.13 SUMMARY

The review of the literature on the effects of road and environment factors on crashes and speed behaviour has produced some interesting findings. Table 2.3 summarises these effects and assigns priorities to those factors likely to exhibit sensory effects in the perception of speed. There are TEN road or environment factors of immediate prime interest:

Urban and rural environments, as well as combination environments of urban and rural features.

Road alignment including straight and curved sections.

Road category such as freeways, arterials, collectors or local streets. Sealed and unsealed roads could also be included for rural environments.

Lane width, especially roads that have exceptionally narrow or wide travel lanes.

TABLE 2.3

SUMMARY OF THE EFFECTS REPORTED OF THE ROAD AND ENVIRONMENT FACTORS REVIEWED

Factor	A	B	C	Priority
Urban/rural environment	yes	yes	some	high
Road alignment	yes	yes	some	high
Road category	yes	yes	some	high
Lane width	yes	yes	some	high
Roadside development	yes	yes	some	high
Driving experience	yes	yes	unsure	high
Traffic density	yes	yes	unsure	high
Slight distance	yes	some	unsure	high
Parked cars & pedestrians	some	some	unsure	high
Day and night vision	some	some	unsure	high
Delineators (guide posts)	unsure	yes	some	med
Weather (light conditions)	yes	some	unsure	med
Road markings	unsure	some	some	low
Traffic mix	unsure	some	unsure	low
Gradient	unsure	some	unsure	low

A = crash statistics

B = performance studies

C = perceptual studies

Roadside development comprising those offering both "walled in" and spacious effects.

Driving experience and, in particular, the effects of first year of driving compared to those with considerable experience.

Traffic density below levels that severly restrict free travel speed.

Sight distance in relation to road geometry and traffic headway.

Parked vehicles and pedestrians of all ages.

Day and night vision.

Other factors, such as guidepost delineators, the weather and the amount of daylight may also be useful variables to explore. The former, in particular, could offer a relatively inexpensive and quick solution to particular hazards for the perception of speed, if shown to be an effective countermeasure. Except for particular installations, road markings, the type of traffic mix and gradient effects by themselves are less interesting variables for the perception of speed on the road.

3. THE MEASUREMENT OF SPEED AND PERCEPTION

As noted previously, only a handful of studies published have attempted to measure the sensory perception of speed. The majority of speed studies in the literature concentrated on assessing vehicle behaviour on the road which compounds sensory effects with decision making processes. Thus, it is difficult to interpret these studies solely in terms of sensory perception.

A review of the literature, involving the various methods and problems associated with the measurement of speed and perception, was undertaken to arrive at a suitable means of testing speed perception for this project.

3.1 ON-ROAD STUDIES

On-road measures generally have the advantage of high face validity in road experimentation because they evoke normal driving stresses. They are, nevertheless, disadvantaged in perceptual investigations in that visual effects are mixed with driving skill responses. In other words, input relations are difficult to assess using dynamic output measurement.

Moreover, control of the various factors likely to influence driving performance in a particular trial is much more difficult to achieve on the road with differences in light, weather, and surrounding traffic. Hence, on-road tests are always more likely to give spurious findings in perceptual studies. Chapanis (1967) and Forbes (1972) discuss many of the advantages and problems associated with both laboratory and field experimentation.

Many researchers, then, have opted to study road perception in a laboratory environment, and have found that certain behaviour in the laboratory can predict behaviour on the road (McRuer and Klein, 1975; Witt and Hoyos, 1976; Evans, 1970b; Noguchi, 1977). Of course, any experimental research needs to be ultimately validated on the road using driver performance studies of some kind. In this respect, the laboratory experiment can be an important first step in understanding the role of sensory perception in driving and, therefore, has practical applications for improved road safety.

3.2 SPEED ASSESSMENT IN THE LABOROTORY

Denton (1971) and Watts and Quimby (1979) argued that laboratory simulation is a suitable means of investigating perceptual aspects in driving. Denton found that road deceleration could be accurately represented by a moving road conveyor belt with the subject seated in a car simulator. Watts and Quimby further reported that a car body response capsule with movie film presentation gave identical risk assessments of particular road sites as those obtained in road vehicles when realistic road noise and vibration were also included in the simulator. **While the car body would no doubt help to create a** realistic driving atmosphere, neither of these two authors showed any real need for this elaborate and expensive subject console for their tasks.

Salvatore (1968, 1969), Evans (1970a, 1970b), McLane and Wierwille (1975) and Noguchi (1977) all investigated the effects of laboratory simulation on speed estimates. In general, high consensus was found between movie film judgements in the laboratory and estimates made on the road, providing care was taken to replicate the perspective road view (Salvatore, 1969; Evans, 1970b). When auditory and vibration inputs were withheld in some of these studies, over-estimation tended to increase (Salvatore, 1969; Evans, 1970a; Noguchi, 1977). McLane and Wierwille (1975), however, did not find any statistical difference with their speed estimates in a driving simulator when auditory cues were not given.

These studies, then, suggest that laboratory presentation may be a suitable method for investigating sensory speed perception. While a full simulation involving realistic road noise and vibration would be preferable to replicate road conditions perfectly, a less realistic simulation may also be possible, providing care is taken to ensure the road perspective view is accurately presented to the subjects.

In any event, it would be worthwhile conducting preliminary trials on the road and in the laboratory to validate any experimental method in speed perception.

3.3 STATIC AND DYNAMIC DISPLAYS

The choice of whether to use static or dynamic stimulus materials in laboratory based road experiments is ultimately dependent on the particular experimental task employed. Static presentations of road curves has been used for road curve direction assessments (Triggs, Harris and Fildes, 1979; Fildes 1979; Triggs, Meeham and Harris, 1980), curve exit angle judgements (Fildes and Triggs, 1982) and curvative assessment (Fildes and Triggs, 1983, 1985). It was argued that these judgements are based predominantly on two-dimension static glimpses on the road, and therefore, amenable to static simulation in the laboratory (Fildes, 1987).

Cairney and Croft (1985) and Cairney (1986) argued that matching the speed distributions of judgements of static road scenes in the laboratory with free speed distributions on the road would validate the stationary presentation method for speed perception. However, one would never know if the laboratory data was necessarily representative of the way drivers perceive speed on the road. It may be that subjects are just responding to what they believe is required of them in the laboratory environment. Besides, there is no reason to expect sensory perceptions of speed to correlate perfectly with free speed data on the road, given that drivers may moderate their speed behaviour on the road for other psychological or social reasons.

It was argued earlier that the perception of speed predominantly involves motion parallax and other dynamic retinal processes (see section 1.4). Speed assessment needs to take into account the implicit motion cues available on the road. Indeed, in a recent review of the speed estimation literature, Triggs (1986) found that almost all of the studies reported involved a moving road environment. It seems inconceivable, then, that a single static presentation of road scenes would be sufficient for the realistic assessment of speed perception in the laboratory.

3.4 FREE SPEED DATA ON THE ROAD

While the technique adopted by Cairney and Croft (1985) of matching laboratory judgements with free speed road data was criticised earlier as a means of validating their static slide presentation method, it is still useful for highlighting perceptual and behavioural speed differences. Thus, it is necessary to review briefly the important aspects of collecting free speed data on the road. Sanderson and Corrigan (1984, 1986) describe a method often used by traffic engineers.

The criteria for collecting free speed data on the road needs to ensure continuity of road characteristics along the road section of interest and should be free from any substantial roadside obstructions. In addition, there should also be sufficient length between major intersections for free speeds to be achieved. Following identification of potential sites, the actual measurement location is finally determined by safety considerations to both operator and passing traffic.

Speed measurements can be taken with the radar located in the rear of an unmarked parked vehicle. In this way, motorists are not warned of the presence of the radar and do not change their speed. Wherever possible, the stationary vehicle should be placed where motorists expect parked vehicles. However, if adjacent parking is not available, the meter should be located on the nature strip and camouflaged by adjacent trees or shrubs. At each location, 100 speed measurements of cars or their derivatives are recorded in the appropriate travel direction.

3.5 SPEED MEASUREMENT IN THE LABORATORY

There are at least three different types of measures used for assessing speed in the laboratory. These include physical responses, speed limit responses and direct subjective responses of speed or safety.

3.5.1 Physical Measures of Speed

By far the most common method of eliciting laboratory responses is the method of adjustment. The subject is provided with a responding device such as an accelerator or a steering wheel or moves a lever to represent his or her judgement of a particular stimulus event (Denton, 1971; Rockwell, Malecki and Shinar, 1974; McLane and Wierwille, 1975; Witt and Hoyos, 1976; Riemersma, 1982). While these measures have considerable face validity in driving, they are expensive to set up and in some circumstances, compound perceptual and driving skill effects.

3.5.2 Numerical Measures for Speed

Speed responses in terms of estimated travel speed (miles or kilometres per hour) have been collected by Hakkinen (1963, Salvatore (1969) and Evans (1970b). This approach is preferable for speed perception as it does not require a driving response. However, subjective number continua have been shown to be non-linear (Anderson, 1970, 1981; McBride, 1982) and, therefore, can introduce undesirable response bias in speed level data.

Cairney and Croft (1985) asked subjects for three variations of speed limit responses for each road site they presented. These included what the speed limit should be, what their maximum operating speed would be, and what the speed of the other traffic would be.

In addition, they asked their subjects for judgements in terms of only four response categories; 60, 75, 90 or 100 km/h. While this was a particularly restrictive set of responses, it was also likely to evoke a socially acceptable response. The experimental environment and the nature of a personal assessment of something rather contentious in our society (the number representing the speed limit for a particular road in Victoria) could moderate a subject's speed judgement. A more subtle assessment of speed is less likely to be biased in this manner.

Furthermore, there is some doubt about a driver's ability to assess speed limits accurately. Moslyn and Sheppard (1980) reported that many motorists (especially women, young drivers and those driving low distances annually) were not aware of how to recognise which speed limit applied to a particular stretch of road. Hence, speed limit judgements under these circumstances are not likely to yield meaningful data.

3.5.3 Subjective Magnitude Scaling

A third approach for eliciting responses in perceptual experiments uses subjective scaling techniques where subjects rate the magnitude of sensation in terms of a scale of their subjective impression. Numbers have been used for magnitude estimation of road curvature (Fildes, 1987; Fildes and Triggs, 1983; 1985) and cross model matching has been applied for speed assessment (Riemersma, 1984). Both of these measures were adapted from techniques developed by Stevens (1961, 1962, 1974) as direct measures of sensation when establishing his power law between physical and psychological events.

More recently, however, the validity of the power law has been challenged (Triesman, 1964; Anderson, 1970, 1981; McBride, 1982). These authors stress the need for magnitude scales to be free of numbers. A slash line response was developed where subjects mark across a line between two extreme values to represent a particular sensation of an event. The data using this response scale has been shown to be less biased than number scales (Anderson, 1981; McBride, 1982).

Levine (1977) used a similar technique to indicate the degree of safety a subject felt for a particular speed and road environment in a simulated driving task. Watts and Quimby (1979), too, used a mechanical derivation of the line-mark technique for assessing subjective risk in a variety of road situations in a vehicle simulator. This technique is simple to construct and is most suitable for assessing the effects of the environment on a driver's perception of speed.

3.6 SUMMARY

This review of the literature on the measurement of speed and perception shows that:

On-road measures are not appropriate for sensory perception studies as they tend to compound input effects with driving skill responses.

Laboratory experimentation can be useful for highlighting visual perception aspects of driving, providing care is taken to simulate carefully the image presented to the driver.

A validation study between road and laboratory tests would be worthwhile when setting up a new study technique to illustrate any likely differences in the results between both methods.

Moving stimulus materials are preferred over static scenes for speed estimation because of the likely reliance on dynamic retinal processes and cues. Movie film presentations have some minor advantage over other dynamic displays.

Comparing free speed data with perceptual data is useful for highlighting differences between sensory perceptions and behavioural consequences.

While three methods of speed measurement in the laboratory are available, a subjective measure not involving numbers appears to be the best technique available for comparing relative effects of the environment on speed perception. However, an estimate of travel speed may also be necessary to compare subjective and objective speed.

Speed limit responses are not particularly desirable dependent variables because they are likely to evoke a socially acceptable response bias.

4. RESEARCH STRATEGY

The preceding introduction and literature review of possible cues and assessment methods for speed perception enabled a detailed description of a research strategy.

4.1 LABORATORY EXPERIMENTATION

The literature review suggested that speed perception could be well simulated in a relatively simple laboratory environment. The degree of simulation will depend on the accuracy of the view presented to the subject as well as the amount of non-visual driving information presented (notably vehicle sound, vibration and lateral acceleration). As a pre-test to detailed experimentation, a validation study was required to confirm the accuracy of the laboratory presentation method.

4.2 STIMULUS PRESENTATION

Two choices were considered for presenting stimulus materials to the subjects, namely static or dynamic road scenes. While stationary presentations are simple and more controlled for laboratory experimentation, they do not provide the motion cues seemingly important for the perception of speed. Hence, dynamic presentations were preferred for this research.

Moving road environments can be generated from either movie film, video or computerised geometric productions. The last category requires expensive graphics and high resolution screens for presentation. Video filming was the most simple and inexpensive means of reproducing a moving road environment but was limited in terms of the size of presentation, resolution of fine road details and difficulty in controlling for perspective image size.

Thus, moving road scenes were subsequently generated using 16 mm colour films taken from close to the driving position of a typical Australian automobile. This means from the right-hand side of a car positioned left of the centreline of the road.

4.3 FREE SPEED VEHICLE DATA

Free speed data was collected to highlight perceptual and behaviour differences. Free speeds were measured using a Gatso Mini (across the road) radar by an observer seated in an unmarked vehicle at the side of the road. This method was shown to have least influence on the speed of vehicles being measured (Sanderson and Corrigan, 1984, 1986).

Procedures for collecting and presenting the data were compatible with the methodology recommended by the Advisory Committee on Road User Performance and Traffic Codes (ACRUPTC). Sample sizes of around 100 vehicles were adopted.

4.4 INDEPENDENT VARIABLES

Fifteen road or environment factors were identified as likely to influence the sensory perception of speed to some degree (see Table 2.3 on page 28). Of these, the effects of the first 5 variables were considered here, namely;-

Urban and rural environments,
Road category,
Lane width,
Roadside development, and
Driving experience.

These factors seem to exert consistent effects on free speeds on the road and were noted as having been involved in road crashes. Furthermore, they constitute a base set of variables on which the influence of some of the remaining factors can be added at a later time.

4.5 CONTROLLED FACTORS

The factors not manipulated in this study were held constant for experimental control purposes. The following levels of the remaining variables in Table 2.3 were adopted in this research programme.

Road alignment consisted of flat, straight road sections.

Zero traffic density was adopted. This meant a minimum of 5 seconds free headway in either direction was required for both film and on-road tests.

Sight distance at least twice the presentation time for each stimulus scene was maintained. This includes both the road ahead and headway distance for any vehicle travelling in the same direction.

Wherever possible, sites were selected with no parked vehicles or pedestrians. Road tests were included if they only had spasmodic instances of parked vehicles and movement of people.

All sites were filmed during daylight hours with good light to ensure that any texture effects were accurately represented in the stimulus materials. Filming only occurred on days of fine weather with no visible signs of rain or fog.

All sites contained minimum levels of road delineation treatments (centreline and edgelines were permitted, but roadside posts were removed where they interfered with filming or testing).

4.6 PRESENTATION SPEED

The literature review showed that the absolute level of speed tested was likely to influence the subjects' judgements. It is not uncommon for movement experiments on the road to include multiple speed levels to minimise any chance of response bias and to ensure that subjects do not simply respond with a constant speed estimate.

While it would be more desirable to have a range of presentation speeds for each site (absolute speed would then be an independent variable in its own right), this manipulation was of less importance here compared with the five independent variables. However, a minimum of two speeds was necessary to avoid guessing. These speeds were determined by the speed limit for each site, and were arbitrarily set at plus and minus 15 per cent of the posted speed limit.

For the laboratory evaluation study, a single presentation speed was used because of the road trials, sites were selected with differing speed limits and presentation speed was held to the posted speed limit.

4.7 DETAILED EXPERIMENTAL DESIGN

Three categories of environment (rural, semi-rural and urban) were included. Rural and urban environments comprised country and city settings and were relatively clear cut. Semi-rural environments, on the other hand, were defined as rural settings in a built up area, such as on the outskirts of a major city with overhead lighting and speed restrictions.

As it was difficult to generalise across these environments, each (rural, semi-rural and urban) was constrained to a seperate experiment. The variable combinations and factor levels used in each experiment are described fully in Table 4.1.

TABLE 4.1

DETAILED EXPERIMENTAL DESIGN

FOR THE MAIN EXPERIMENTS

Experiment	Road Type	Lane Width	Roadside Development		Experiment Vehicle Travel Speed	Number of Road Sites (all within 2 hrs. drive of Melb.)	Number of Presentations (2 for each type of site)
			SPACIOUS	WALLED			
1. RURAL	divided[2]	narrow[3] wide[4]	sparse[5]	trees[6]	speed limit +/- 15 %	8	16
	4 lane U/D	wide	sparse	trees	speed limit +/- 15 %	4	8
	2 lane U/D	narrow wide	sparse	trees	speed limit +/- 15 %	8	16
	gravel U/D	narrow wide	sparse	trees	speed limit +/- 15 %	8	16
					TOTAL NUMBER OF SITES = 28		
					TOTAL NUMBER OF DIFFERENT FILM PRESENTATIONS = 56		
2. SEMI-RURAL	divided[7]	narrow wide	setback	trees[8]	speed limit +/- 15 %	8	16
	4 lane U/D	wide	setback	trees	speed limit +/- 15 %	4	8
	2 lane U/D	narrow wide	setback	trees	speed limit +/- 15 %	8	16
					TOTAL NUMBER OF SITES = 20		
					TOTAL NUMBER OF DIFFERENT FILM PRESENTATIONS = 40		
3. URBAN	divided	narrow wide	residen.	commerce.	speed limit +/- 15 %	8	16
	4 lane U/D	wide	residen.	commerce.	speed limit +/- 15 %	4	8
	2 lane U/D	narrow wide	residen.	commerce.	speed limit +/- 15 %	8	16
					TOTAL NUMBER OF SITES = 20		
					TOTAL NUMBER OF DIFFERENT FILM PRESENTATIONS = 40		

1 Equal numbers of male and female first year and fully licenced drivers in each experiment; 9 male experienced, 9 female experienced, 9 male first year, and 9 female first year drivers.

2 Narrow ≤ 3 m.

3 Wide ≥ 3 m.

4 Rural divided roads or arterials refer mainly to country freeways

5 Sparse rural roadside development means open country without trees near highway.

6 Treed rural roadside development is typically a road passing through a forest.

7 Semi-rural divided roads or arterials refer mainly to urban freeways.

8 Trees for semi-rural roadside may include shrubs and other low lying foliage.

4.8 STIMULUS MATERIALS

The stimulus materials for each site consisted of a 5 second sequence of 16 mm film, taken from the driving position of an automobile left of the centreline. Figure 4.0 shows the camera in place on the experimental vehicle. **A 10 second section of** blank film was inserted between each test scene to allow the subject sufficient time to respond in a semi-paced manner.

A pseudo-random order of presentation was adopted, where separate rolls of film, each containing a discrete fixed sequence of stimulus scenes, were prepared. Thus, the presentation order within each film was consistent for all subjects, but the order of presentation of each film was systematically varied between subjects. Practice materials and instructions preceded the main experiment to ensure the subjects were familar with the task.

4.9 SUBJECTS

The subject pool consisted of equal numbers of first year drivers and full license holders. Eighteen subjects of each level of driving experience were recruited for each of the 3 experiments, yielding a total of 108 subjects.

The subjects were drawn from within RACV Limited and from specific populations of young drivers outside RACV. As far as possible, subject pools were matched for sex, years of driving experience and exposure. In all cases, subjects were paid for participating in the experiment.

Subjects' vision was screened at the start of the experiment to ensure they had normal vision (1.0 Snellen or better). This included people with and without spectacles to match the normal driving population.

FIGURE 4.0
Research Vehicle with Camera in position

4.10 DEPENDENT VARIABLE

The laboratory method adopted in this research comprised only a visual simulation of the driving task. Thus, a vehicle response measure was not an appropriate or desirable dependent variable here.

A magnitude estimate response effectively overcomes objections to using speed limit responses for this task. However, it is essentially a relative speed measure and may not provide data that can be directly compared with the free speed data from the road. Thus, subjects were asked to make TWO responses to each road scene presented. **The first response was** a slash across a 150 mm line, labelled at each end as either too fast or too slow. A mid-point was also provided but not labelled. The second response was an estimate of what speed the subject believes he or she is travelling at. These responses were used to compare with the free speed data collected at each site.

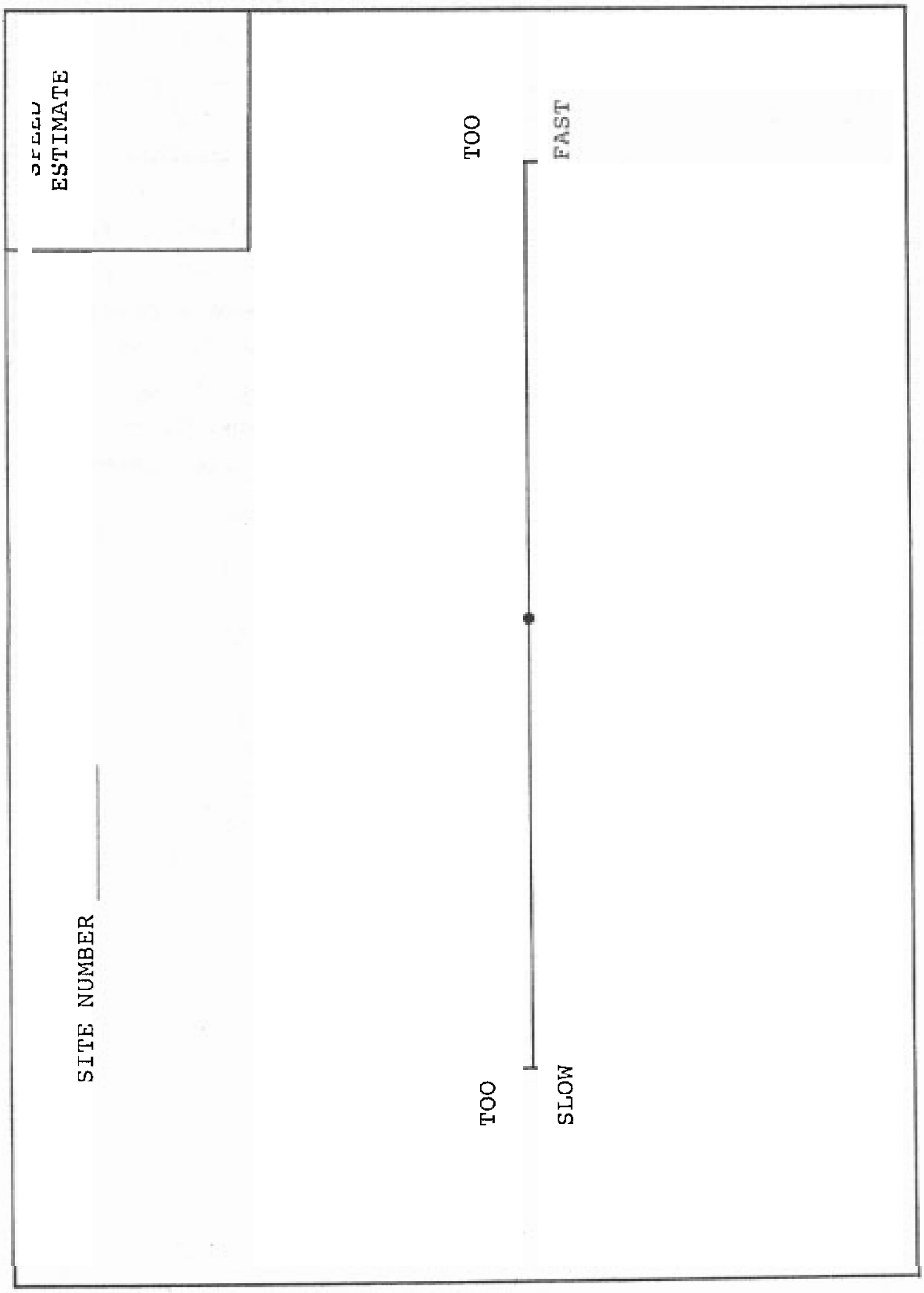
Figure 4.1 shows a sample page from the response booklet used in the experiment. Each judgement was on a separate page to minimise carry-over effects from one judgement to the next.

4.11 DATA ANALYSIS

Statistical analysis of the experimental data involved parametric statistics. Keppel (1982) noted that the most robust test of experimental data is analysis of variance. He also recommended the use of the omega-squared statistic for assessing the relative strength of effect of each of the variables. Both of these omnibus tests of significance were used for data analysis, along with appropriate simple effects analysis where necessary.

FIGURE 4.1

SAMPLE PAGE FROM THE RESPONSE BOOKLET



These techniques allow the full effects of each experimental variable to be measured, as well as any interactions that may occur between the variables. This is considered to be the most precise form of analysis available for these experimental data.

Free speed data were summarised using a standard free speed analysis package and presented in the form of mean, 85th percentile and standard deviation for each variable combination.

Free speed measurements could not be collected at all sites for a number of reasons (eg: sites were by-passed between filming and free speed measurement). In addition, there were variations in the numbers of vehicles at some sites due to the lack of traffic movements and time of the year. A full statistical analysis of these data therefore was not possible and hence only a descriptive analysis of the free speed responses was attempted here.