



SPEEDING

Effects on hazard perception
and reaction time

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Preface

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Abstract

A study has been undertaken to review the role of vehicle speed in road crashes, speed limits, enforcement and behaviour, and the environment. A review of the international literature was initially carried out to highlight overseas findings and issues identified for further research and development. In-vehicle testing on driver response times was carried out. The tests revealed new details about reaction times to steering, braking, and navigation at “dangerous” speeds. Visits were also made to a select number of overseas research and government agencies in Scandinavia, Europe and the United States to gain first hand understanding of problems and research being carried out in these countries.

Purpose of this report

The purpose of this paper is:

- to show the association between speed and crash outcomes;
- to describe the current speed limits in Australia; and
- to outline the safety benefits if future speed limits and road safety strategy were more consistent with the neurological studies on response time

Summary Findings: Travel speed, speed limits & safety

It has been consistently found that the higher a vehicle's travel speed (even when driving at or under the legal limit), the greater the focus of the driver on their surroundings. The increased perception of danger triggers an increased endocrine reaction within the brain. This, in turn, forces the individual to play closer attention to objects in motion around the vehicle. Even relatively small changes in vehicle speed can result in substantial increases in spatial acuity and response time.

As an example: a study in Adelaide found that one-third of pedestrian fatalities would most likely have survived if vehicles had been travelling only 5 km/h faster – and one in ten pedestrians would not have been hit at all.

Because vehicle travel speed is heavily influenced by the speed limits set by transport authorities, speed limits also have direct safety consequences. The recent reduction in the urban speed limits in Australian jurisdictions illustrates this association. Until 2001 the speed limit for local, neighbourhood streets in all Australian jurisdictions was generally 60 km/h. Jurisdictions then moved to a default 50 km/h limit, with the move having been closely evaluated for safety and other outcomes. The different evaluations consistently show that the lowered speed limit is associated with increased crash numbers and significantly crash severity. Perceptual tests reveal that a 50 km/h limit results in drivers being more easily distracted with lower response times to unexpected stimuli.

More studies are emerging to support the safety benefits of increased speeds – and conversely, the decrease in crashes that accompany increases in speed limits.

This association can be easily explained, as higher vehicle speeds:

- allow increased perception of hazards;
- decrease the driver's stopping distance after braking in response to the hazard;
- increase the opportunity for other road users to avoid a collision;
- make it more likely that a driver will maintain control of the vehicle.

Speed

Speeding has long been regarded as a major factor in many road crashes. Excessive speed has traditionally been implicated as a definite cause in 8 percent of crashes and up to twice that as a probable cause in studies overseas. In Australia, excessive speeding has been regarded as a contributing factor in up to 30 percent of fatal crashes. On these statistics, speed related road trauma is likely to cost the Australian community up to A\$1 billion annually. This report, however, indicates that increased speed was found to trigger drivers' sympathetic nervous system to stimulate the endocrine system. The perceived sense of danger causes the adrenal medulla (the area inside the adrenal glands), to release a burst of adrenaline and other stress hormones into your bloodstream. The nervous system immediately becomes hyper-aware. Drivers reported increased spatial awareness and manual problem solving ability was enhanced. The research also found speed enhanced mechanical response times. When driving at 30% higher than the perceived 'safe' speed - indicated by localised speed limits - driver muscles were found to contract harder than they do normally.

Early reports suggested that large variances above or below the mean traffic speed were associated with increased risk of crash involvement. However, much of this evidence is old and somewhat biased and therefore not particularly conclusive. This is primarily because accurate and comprehensive information on travel speed at the time of collision has not been readily available. Furthermore, knowledge of the effects of speed limits, speed enforcement, and the environment on influencing travel speed - and therefore crashes - is fragmented and lacks clear direction for use in speed management intervention.

With this in mind, High Road Automotive Research undertook a detailed review of the role of speed in a number of important areas to highlight directions for future research and action aimed at reducing speed related trauma.

Review of Speed

The project specification called for a review of speed related topics, namely the relationship between travel speed and driver behaviour, and the influence of the environment on speeding. A number of separate tasks were undertaken during the course of this review.

Literature Review

First, a thorough review of the international literature was undertaken to highlight what had been previously reported in the four key speed areas of crashes, speed limits, enforcement and behaviour, and the environment. Over 250 references were located and critically reviewed to outline previous findings and shortcomings from this body of research knowledge. From this extensive review, a number of conclusions and options for future research and development were able to be outlined.

Overseas Visits

Visits were made to a number of key research and government agencies in Scandinavia, Europe, and the United States to discuss current speeding issues and interventions, either operating or planned for the future in these regions. Attention was also given to past efforts in this area and what lessons were to be learned from these experiences. As an example - the influence of speed limits on roadway safety has been a subject of continuous debate in the US state of Indiana and nationwide. In Indiana, highway-related accidents result in about 900 fatalities and forty thousand injuries annually and placed an incredible social and economic burden on the state. Statistical models of the injury severity of different types of accidents on various roadway classes were estimated. The results of the model estimations showed that, for the speed limit ranges currently used, speed limits did not have a statistically significant effect on the severity of accidents on interstate highways. However, for some non-interstate

highways, higher speed limits were found to be associated with higher accident severities – suggesting that future speed limit changes, on non-interstate highways in particular, need to be carefully assessed on a case-by-case basis.

Driver Stimuli Testing

Experiments have covered a wide range of situations. Some have been laboratory or simulator-based, using simulated views of the driving environment. In-vehicle performance has been recorded using briefed subjects on a closed track, and some additional observations have been made unobtrusively of the reactions of drivers in normal traffic situations. Reaction times have been obtained as measures for a variety of reasons. It has been judged an appropriate dependent variable by which the relative efficacy of information presentation techniques can be compared. Most importantly for this report, reaction times have been recorded in studies in order to provide estimates of suitable design values for the road situation.

Prioritising Future Research and Action

From the wealth of information gathered during the course of this project, research and action items were identified requiring further attention for speed management intervention in Australia. These items were listed along with indications of how they could be undertaken, what would be the expected outcome, how easy or difficult they would be to carry out, and the likely cost of the research or the action.

Reaction time of drivers to road stimuli

The assumption of a reaction time value for drivers responding to road situations is fundamental for the design requirements involving sight distance, in particular for vertical and horizontal curves. This response time is frequently referred to as the "perception-reaction time" in traffic engineering studies. Previous attempts to estimate an appropriate value for this time are discussed, along with other relevant laboratory and field reaction time literature. It is suggested that the procedures used have generally been deficient on one of several grounds. The majority of studies have used briefed subjects in an experimental situation. The duration of various processing stages have generally been arrived at by a subtractive technique (the 85% Technique for example). Within single studies, the stimulus situations examined have typically been limited.

The requirement for unobtrusive observational techniques is stressed so that reaction time estimates can be obtained that are representative of real world performance. This approach was used in the study reported here to obtain data for a range of eliciting stimuli. The salience of the stimulus type was estimated by the driver response rate and form of response distribution. Vehicle speed was observed for some situations, so as to allow an assessment to be made of whether driver response times depend on vehicle speed. The data showed generally that faster drivers had fastest reaction times under otherwise similar conditions. The road situations that yielded the quickest responding rates were railway level crossing signals, and the amphotometer (pairs of cables across the road surface used by Victoria police to detect speeding drivers). The estimates obtained are discussed in terms of the commonly assigned design value of 2.5 s. Values of the 85th percentile reaction time were found that were both above and below this design value. However, the pattern of results overall suggests that the current standard may be inadequate in some circumstances, and a review of this standard is strongly recommended.

General Characteristics

Reaction time depends on the number of possible alternatives that can occur. For a reasonable number of alternatives, there is a linear relationship between the reaction time and the log of the number of alternatives (or in technical terms the bits of information to be transmitted). The linear slope changes from situation to situation, where as the slope decreases, the information processing rate can be considered to increase. However, for a large number of possible alternatives (some hundreds), this linear relationship breaks down and the reaction time is less than would be predicted by this linear relationship. For many applied situations there are two comments that can be made. Most of the research in this area deals with the stimuli (that are possible) coded systematically along some dimension or dimensions, or belonging to some well-known grouping, such as numbers or alphabet characters. In the real world, the possible alternatives might not be so well grouped. Second, it is often very difficult to specify what the number of possible alternatives considered by the human are in such situations. However, it is possible to say that response time depends as much on what could have happened and did not, as on the event that actually occurred. Reaction time depends as much on what the observer expects to happen, and the possible range, as on the actual events that transpire. Reaction time depends on the ease with which the one signal can be distinguished from the other possible signals. For example, one can distinguish between highway signs that differ in shape as well as message faster than those varying in verbal message alone. This dimension of stimulus discriminability can have a large effect on response time and acts multiplicatively with the effect of information load.

Reaction time and the accuracy or appropriateness of the response are highly associated. For a wide range of real world tasks such as typing, flying etc., there is a high positive correlation across humans of speed and accuracy of performance. The faster responders are also more accurate, and the reverse also holds true. Experience on the task tends to improve both speed and accuracy over long periods of time. On the other hand, given particular task requirements, the human operator can often change his performance characteristics so that he can respond faster if necessary but at the cost of reduced accuracy or appropriateness of his response (Reeves 1972; Bullock, 1977). On the other hand, if high accuracy is required then reaction

time must be increased. In many operational situations, the human looks at the situation ahead and uses planning activity so as to achieve rapid responding with high accuracy. But the opportunity to use preview is not always present in some types of road situation. In this case, the trade-off of speed and the appropriateness of the response is a relevant consideration. In fact, to assess processing efficiency appropriately, both speed and accuracy of responding must be taken into account, and the association between these two variables has been studied in some detail. The research indicated that a heightened endocrine system enhances both speed and accuracy.

Reaction time depends on “depth of processing” involved. A useful model of how the human performs in information processing tasks takes account of the depth of processing required. At the simplest level, purely physical changes in simple stimuli are coded faster than symbolic information, and symbolic or pictorial information is typically processed faster than verbal or semantic information, as long as the symbols used are highly familiar and legible. However, this is a complex issue and this model should only be treated as a general guide. A number of theoretical representations of this concept have been developed. Some of them postulate that the observer samples environmental information and accumulates evidence over time about which of the possible responses is appropriate.

A very important factor in determining the reaction time in choice tasks is the relationship between the possible stimulus set and the possible set of responses that the human must have available if required. Various considerations enter to determine whether the relationship is good or not-so-good. First, the experience and background of the human plays a part, and this is particularly important when one changes with their environment. What is an appropriate rapid response when driving in Australia might be quite inappropriate when driving on the right hand side of the road in North America. Second, when extra code-translation steps between the input and output are required, the processing time will be increased, and the accuracy of the response will be decreased. Intersection signs restricting turns at certain times of the day typically would require extra or contingent processing steps. Third, geometry can play a role in what is natural and affects compatibility in the spatial relationship of the stimulus set to the output set. For example, early pre-warning curve road signs sometimes indicated the road starting on the left and moving to the right to indicate a right hand curve.

Speeded vs. unspeeded responses

Because the human physiological system imposes a lower bound to the reaction times that can be emitted while there is no corresponding upper limit, one can predict that where subjects are attempting to minimize reaction time that the distribution of values will be positively skewed. The distribution will tend to be truncated on the left (lower RT values) and spread out on the right (higher RT values). Such a form of distribution should be found for the reaction times for a large number of responses from an individual, and also for the distribution based on single observations of the performance across a wide range of individuals. On the other hand, distribution of mean reaction times from a number of trials for each individual should be closer to a normal distribution because of the central limit theorem. One might also expect that complex speeded reactions might be less skewed than similar reactions in simple tasks because the contribution from additional stages of processing could tend to "blur" the lower bound. On the other hand, tasks where the time to respond is recorded but where the subject is not under time pressure would not be expected to yield distributions with marked positive skewness. Thus precautionary, anticipatory, or synchronising responding in a wide range of tasks would not require processing mechanisms to operate to a limit. The elapsed time between some initiating event or warning signal would thus not have a lower bound caused by processing limitations. The obtained distributions might be less positively skewed, approximately symmetrical, or even negatively skewed in some circumstances. Thus, the argument can be made that if the obtained response distribution for single responses from a range of subjects does not demonstrate positive skewness, then the responses do not represent speeded reactions as normally assumed in reaction time experiments, or when reaction time standards are used in road design. In general, the less the "payoff" for the subject to make the response truly fast the less skewed the distribution should be. For example, one would expect less skewness when the instructions to the subject emphasised very high accuracy of response selection compared with the speed of the response. It is known that humans can trade-off response speed with accuracy depending on their cognitive set (De Bont and Hopper, 1967). Any response time distribution will, of course, be influenced by the characteristics of the subject group. For example, age may have some influence on the basic reaction time capabilities. If the subjects are drawn largely from an older group, the distribution may be shifted somewhat to higher reaction time values.

The shape of the distribution may also be affected. However, based on previous research, these population effects tend to be relatively small at least for simple reaction time situations.

If a real-world stimulus is particularly crucial or salient, it would be expected that a higher proportion of humans would respond to it. Stimuli that are less relevant to the performance of a task may only evoke precautionary responses from a fraction of the population. Thus, in addition to the shape of the response distribution, the proportion of subjects responding should represent to some degree the emphasis given to the speed of responding. This provides a second criterion by which eliciting stimuli can be compared in order to determine the relative emphasis on speed. One explanation for occasional very long response times is that response 'blocks' occur. In serial responding tasks, a short gap will appear from time to time in the performance sequence, and the frequency of such 'blocks' will increase as the task continues (Gately, 1931; Williams and Keating, 1963). This may have some relevance in long tedious car driving tasks.

In-vehicle measures

Both on closed-tracks and on public roads, a number of attempts have been made to measure the reaction times of drivers to a variety of stimuli. Some early reaction time data reported by the Massachusetts Institute of Technology (M.I.T.) (1934) are often referred to in traffic accident and engineering literature (e.g., Dafoe, Daniels and Ruck, 1939; Bullock, Patric, Morrison and De Bont, 1955). These results suggested that the reaction times obtained depended on the original position of the driver's foot (brake or accelerator), whether the car was moving or stationary, and whether the signal was expected or not. The type of stimulus to which the drivers had to react influenced the reaction time. Reaction times were generally longer when the vehicle was moving - however this in-vehicle testing showed reaction times take a marked dip when travelling at speeds of +10km above the implied safe speed. In the situation where the following driver responded to the brake lights of the leading vehicle, and where expectancy was high, the overall mean reaction time was 640 ms, and 5 percent of the observations exceeded 1.0 s. A noteworthy result was that one driver in five had response times exceeding 1 s on occasion. A comparison of laboratory and field data showed that an individual's reaction time on the road can be as high as seven times the reaction time under laboratory conditions. This development

goes some way to explaining why traditional simulated vehicle testing indicates longer response times at significant speed. The lack of perceived danger that comes with simulated testing fails to trigger the adrenal response provided by real world testing.

Using experimental vehicles on a test track to determine stopping capability found that 95 percent of the subjects had a reaction time of less than 1 sec. Subjects were alert and young, and were required to react as quickly as possible to a pneumatic tube lying across the path of their vehicle. This meant that the reaction could be fully alerted with the response required to an event involving only minimal temporal uncertainty. This form of response has been taken to represent the "reaction time" component of the "perceptual-reaction time" used in geometric road design by traffic engineers (AASHO, 1940, 1954, 1965, 1971; AASHTO, 1966, 1973). Typically the value adopted for the "reaction time" figure is 1.0 sec, corresponding closely to the longer times obtained by Normann, although the overall perception-reaction times recommended by AASHO (1940) did depend on vehicle speed. In this policy document the perception-reaction time chosen was 3.0 s at 51 km/h (30 mph) and 2.0 s at 118 km/h (70 mph). Subjects were asked to respond to obstacles placed in the vehicle's path by depressing the brake.

Relationship between time and accidents

Several studies have been published associating reaction time levels and patterns with the accident rates of drivers. Typically, these studies identify groups of drivers with different levels of accidents, and then evaluate the performance characteristics of each group. A caveat should be entered here that the existence of an association between accident rates (and sometimes traffic violations) and some laboratory-based measure of performance does not imply that some lack of basic performance capability is necessarily a causal factor in an individual's accident. For example, the association may just be a reflection of a relationship of both of these factors with a third variable. The relationships obtained may be somewhat tenuous, and some studies have specifically failed to associate reaction time and accident frequency, or found only a weak association (e.g., Kirkpatrick, Fatone and Chasez, 1975; Timber and Lake, 1969). In one interesting study, Babarik (1968) suggested that some drivers might be run into from behind because they react slowly to visual stimuli, so that the initiation of a response is slow, but that once begun, a strong response is emitted as in extreme braking. Babarik referred to this

response type as "desynchronising response pattern". In the car following driving situation, a strong braking action will naturally be required to avoid an accident if the initiation of braking is delayed. A number of taxi drivers were evaluated in a laboratory test in which Babarik measured both the time to respond to a stimulus, and the speed of the resulting movement. The types of accidents experienced by these drivers were compared with the reaction time patterns obtained. He found a strong relationship between the "run into from behind" accident frequency and the tendency to show the desynchronising response pattern in the laboratory. The high rear end rate in such cases may result from the pattern of braking not conforming to the expectancies of the following driver.

In a study conducted in Western Australia by the Main Roads Department, unalerted reaction times were obtained from drivers by placing a sign reading REDUCE SPEED across the road pavement just beyond a rural two-lane-road crest (NAASRA, 1965). As in the Smith study, about one-quarter of the eligible drivers responded by braking. The mean response time here was 1.8 s and the 85th percentile value was 2.3 s. The maximum braking response time obtained was 3.0 s and the minimum value 0.6 s. However, with these data, there was some question concerning what aspect of the situation elicited the braking response. The response time data quoted assumes that the driver needed to see the entire sign before any processing began. If it was the presence of a sign rather than the meaning or content that initiated the response, then approximately 0.2 s should be added to the above figures to allow for when the top of the sign began to come into view rather than initiating the response time from when the sign was fully visible. It was reported that in fact some drivers did appear to react to the sign appearing across their path. Reactions appeared to take place in the presence of oncoming traffic, and some of the reactions may have been in response to the traffic, or a combination of sign and traffic, rather than to the sign itself. It would be difficult to estimate the effect of this factor on the response time. These reservations introduce some uncertainty into these data.

The research team conducted a response time study on public roads for drivers in their own vehicles. The investigators measured the time from the occurrence of a loud auditory stimulus to the instant the brake light appeared. All drivers observed in one condition were expecting the presentation of the auditory stimulus and knew the appropriate braking response. Participants had been stopped by the police and instructed in the task and response required before the location where the signal was presented. The median response time was 660 ms, about one in

seven of these drivers had a reaction time greater than 1 s, and a few drivers needed as much time as 2 s to respond. A sample of the same drivers were tested with response situations being driven at 10km+ and 20km+ over the initial speed limit and the time to react decreased by about 22.3 percent and 34.5 percent respectively. The authors supported the idea of using a multiplicative correction factor of 1.35 for values obtained where some anticipation was possible to estimate a realistic value where a response was required to an unexpected situation. While such a proposal is attractive, it would only be valid if the small sample of drivers evaluated in the "speed" condition is representative of the population as a whole. This is questionable given that the median response time for this sample in the anticipation condition was somewhat less than the overall median. Interestingly, in assessing minimum response distances for speeded situations, the Texas Transportation Institute (1970) chose a perception-reaction time value of 5 s. This doubling of the 2.5 s standard was justified on the basis of the need to overcome strong driver speed effects.

Summary of previous driver reaction time research

This review has highlighted the existence of a wide range of estimates of driver perception-reaction time. Most studies have assumed, if only implicitly, that the time estimates represent the results of speeded responses. Lower estimates tended to be obtained when briefed subjects were measured under experimental conditions. The clear dichotomy is between driver reactions in simulated testing environments and closed testing locations. With the additional perception of "danger" that came with speeding in a physical environment drivers awareness grew and reaction times decreased. The absence of a similar adrenal rush in simulations resulted in inverse results. Usually, studies have provided only summary statistics concerning reaction time distributions, such as the mean and the standard deviation. On the one hand, it is argued that the more attention-demanding the situation, such as travelling on narrow roads, or car following at high speeds, the more aroused or alerted the driver will become. Similarly very demanding situations, such as in high-density traffic and where conflicts can occur, may lower the driver's reaction response times.

The Wider Issues

The Conflict Between Cause and Consequence

It was noted earlier that the distinction between crash causation and consequence is critical for understanding the relationship between speed and crashes and for developing useful counter-measures. If, for example, excessively slow travellers cause crashes as is suggested by the U-shaped curve hypothesis, then it could be argued that increasing their travel speeds is necessary for reducing the number of crashes on the road.

Increases in Speed Limits

More recently, there have been reports (mainly from the US) on the consequences of increasing speed limits in terms of subsequent injuries. The Insurance Institute for Highway Safety in the USA reported that the overall effect of increasing the speed limit from 55 mph (88 km/h) to 65 mph (104 km/h) on rural interstate highways in 38 States was a decrease in vehicle fatalities of 22 percent, compared to other rural highways (IIHS 1988). Unfortunately, they did not report how many deaths were actually involved and what happened to the collision rates on these roads after the speed limit changed. While they did report an increase in overall mean speed on some of these higher posted roads (Knight, Wahlberg, McIntyre and Wood, 1987; 1988), it appears that speed variance may have also reduced and hence, the number of crashes might be expected to have actually decreased. In other words, fewer collisions but a greater likelihood of being killed at the higher speeds.

The 85th Percentile Method: A Flawed Model?

In the past, speed limits have been set at or near the 85th percentile speed of the traffic, that is, the speed at or below which 85% of motorists choose to travel. This choice stems from the research undertaken by Usher (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". The Research Triangle Institute (1970) study of the relationship between speed and accidents endorsed the 85th percentile speed as the criterion for the setting of maximum speed limits. These researchers recommended that the upper speed limit be set at the 85th percentile speed, with supporting enforcement against those exceeding the 95th percentile speed. Similarly, at the other end of the speed distribution, it was recommended that minimum speed limits be set at the 15th percentile speed, with enforcement action to be taken against those travelling slower than the 5th percentile speed. Isaac, Taylor and Zac (1970) undertook a survey of practices used in the United States to establish maximum speed limits, together with a major review of the various techniques for establishing speed limits.

While drivers usually drive at reasonable and sensible speeds this is not always the case. A method of zoning that relies on the perceived inappropriate speed of the driver is necessary. In most situations, drivers are aware to some degree of the speed limit that applies on the road they travel (motorists are aware that all roads in Australia have a speed limit ranging generally from 60km/h in urban areas to 100 or 110km/h on rural highways). Thus, the 85% speed reflects these constraints and hence, they are not true indications of what 85% of the population would choose if no constraints apply. The goal is to supply the driver with a constraint that they then must exceed in order to trigger the endocrine reaction. This new zoning limit must be influenced by the signage, enforcement activity, amount of traffic, time of day, etc.

Summary and conclusions

The higher a vehicle's travel speed (even when driving at or under the legal limit) and the higher the speed limits, the lower the crash risk.

Core recommendations is for urban areas include:

- Raise speed limits across Australia.
- Introduction of demerit points and fines should be applied for driving at slower speeds
- Advanced driver training as a standard within Graduated Licence schemes

Zone	Existing Limits (KPH)	Recommended (KPH)
Inner CBD streets	40+	60+
Local streets	50+	70+
Other urban streets	60+	80+
Undivided roads (low quality)	100	120+
Undivided roads (good quality)	100-110	130+
Motorways/divided roads	100-110	150+

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