# Signs of trouble to come? A behavioural assessment of the effectiveness of road warning signs

# **Final Report**

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# **General introduction**

This report is the final report under a FORS grant to use a driving simulator to measure the effectiveness of some standard Australian road warning signs.

The present grant was sought in order to make the best use of a STISIM<sup>®</sup> driving simulator and an eye-movement tracker to be bought using funds provided by the ARC, The University of New South Wales, Sydney University and Macquarie University. This project has resulted in the first large-scale driving simulator at a New South Wales research institution. Currently the final full-scale simulator bought under the grant is being installed in a purpose built laboratory at UNSW. This simulator incorporates a 135° field of vision projected onto screens to produce a life-size driving scene. The simulator is currently being interfaced with a Hyundai Excel car body that will allow subjects to use genuine car controls in the simulation. In addition, a head-mounted eye tracker commissioned this year has recently arrived from the USA. This will allow the collection of additional eye-movement data critical to driver behaviour. The portability of the eye tracker will permit the comparison of performance on the simulator with that of subjects viewing genuine driving scenes in a moving vehicle.

Earlier in the year while awaiting the arrival of the final simulator we purchased a STISIM<sup>®</sup> Model 400, which is a simplified version of the new simulator. This model was chosen after an extensive evaluation carried out in conjunction with a project financed by the NSW RTA. The Model 400 (the simplified version used in the present research) consists of a

single processor and a driving scene represented on a single monitor. The car is controlled by a steering wheel mounted in front of the monitor, and by accelerator and brake pedals mounted on the floor below the steering wheel. The major differences between the model used in the present research and the new model being installed at present is that the new system allows for greater control over the visual presentation of the on-road stimuli such as other traffic, buildings and signage. However the original Model 400 allowed sufficient flexibility for us to manipulate some warning signs and measure their impact upon driver behaviour. The results of these studies are presented in this report.

It should be noted that both the original model and the new model simulators use STISIM's Scenario Definition Language. The programming skills and scenarios already developed will transfer to the upgraded system

We are now in a strong position to further develop this research with a more sophisticated simulator and we will be looking for further funding opportunities with other colleagues to capitalise on UNSW's expertise in this area, backed up with some of the most sophisticated driving simulator and eye tracking technology available today in Australia.

The two studies carried out under the present grant are presented below. The first related to the adaptation of driving behaviour to curve and turn warning signs and the second to the effects of mood and stress on driver behaviour.

# Study 1—Adaptation to warning signs

### Introduction

The general question to be investigated was, under what conditions do drivers ignore warning signs? Does compliance in drivers obey the same principles that have been determined through the examination of warnings in general. This question arises because research of a very general nature into compliance with warnings of many sorts has shown that warnings are not complied with except in very limited circumstances.

There is much evidence that in a situation where a person's prior knowledge, or knowledge gained through inspection of that situation, is such as to indicate that there is nothing about the situation that would require a warning, the person will take no notice of any warning and may, indeed, not even see any warning that may be present.

Thus, research suggests that warnings requiring or prohibiting specific behaviour are not effective for a person who has omitted or performed that behaviour themselves in the past without incident, or who has seen others omitting or performing that behaviour without incident. A warning can only affect behaviour in the desired direction where the receiver of the warning has no information from past experience and where the warning message is reinforced by what can be plainly seen. In the absence of such conditions the only alternative appears to be obvious and enforced institutional sanctions, such as fines for disobeying traffic lights or other road warnings.

There is a large literature on the effects of warnings on behaviour and much of that literature demonstrates that many warnings are surprisingly ineffective. A volume of 55 papers (Laughery *et al.* 1994) has been published on the topic, beginning with one entitled, "What is a warning and when will it work?" (Ayers *et al.* 1989). This paper brings up many relevant points:

- a. "....people who are not looking for a particular type of information (be it instructions or warnings) are unlikely to notice and use that information if they encounter it."
- b. "If the information is to change a person's behaviour, it must add something substantial to what the person already knew (i.e. be available from past experience or the present context). The information perceived as new must then motivate the person to change."
- c. "People accept some risk in all activities...and are unlikely to heed a warning unless the perceived risks of noncompliance are excessive. ...
  Compliance appears to depend primarily on perceived likelihood of injury...,rather than on expected severity of injury..."
- d. "A person who feels that the situation is already under control does not feel any need to comply with the recommendations of a warning."

A practical example of the application of these principles is the wearing of protective equipment in industry. Workers who do not understand the dangers associated with long periods of loud noise, for example, will instead emphasise to themselves the inconvenience of having to wear hearing protection. One way of improving compliance is to use penalties. That is, the use of the required safety apparel can be made a condition of employment such that workers will be penalised, perhaps by dismissal, if they do not comply. This is a common method of increasing the rate of compliance, but it is by no means totally effective.

Another way of increasing compliance is by means of intensive discussion groups in which workers discuss work hazards, work methods and safety behaviour and agree to comply with particular safety-related work routines, possibly including the use of specific safety equipment. Signs can then be used which will have the effect of reminding workers that they have agreed to comply with particular safety directives.

In the context of road use behaviour, road side traffic warning signs have long been the primary source of information provided to drivers informing them of potential hazards. Despite the advent of in-car information systems developed in the US and Europe under the auspices of the US intelligent vehicle highway system (IVHS), and the Dedicated Road Infrastructure for Vehicle Safety in Europe programme (DRIVE) (see Ayland & Bright, 1991), road sign fixed warning signs will remain the primary hazard warning system for the forseeable future.

It is important therefore to consider carefully the design and placement of hazard warning signs. For example, under what circumstances do such

signs give what is seen as essentially new and useful information, as the Ayers et al (1988) report would suggest is required?

The first study described below examines this question by asking how behaviour changes when the signage conditions change in a situation where drivers experience a series of identical curves at random intervals in a driving task, some with signs and some without. Driving behaviour was examined when a 'curve' sign was introduced on a number of curves, and then later when a sharper 'turn' sign was introduced. The converse was also examined using a different group of subjects, namely when the turn sign was used first and then, later, the more gentle curve sign was introduced.

### Method

Subjects were asked to drive the simulator through a course involving a series of 20 curves over a distance of 24 000m. The course began with a straight section of 3000m followed by curves at 1000m intervals. Curves were all of 86 degrees and 150m in length. The curves were randomly assigned as left or right in direction so as there were an even number of left and right hand curves. The curves became visible at a distance of 250m.

Of the 20 curves, 15 were without signs. The 4<sup>th</sup>, 9<sup>th</sup>, 12<sup>th</sup>, 17<sup>th</sup> and 20<sup>th</sup> curves had signs. These signs were either a curve sign or turn sign placed 20m before the curve and visible from 250m distance. In condition 1 the first four signs were the curve sign and the final sign was the turn sign. In Condition 2, using different subjects, the first four signs were the turn sign and the final sign was the turn sign and the final sign was the turn sign.

The curve and turn signs were those found in the NSW Road Users Handbook (Figure 1.)



Figure 1. The two signs investigated: (a) Curve Sign, (b) Turn sign

Traffic conditions were moderate to light to nil traffic at random throughout the scenario. All participants were instructed to drive as they normally would on a road, in a real vehicle (as opposed to when playing a video game). All participants were given a 4000 metre practice drive on the simulator.

Subjects

A total of 30 first year psychology students, all with previous driving experience, took part in the study. They were randomly assigned to one of the two driving scenario conditions using the STISIM driving simulator.

#### Procedure

The subject was seated in front of the simulator and given instructions on how to drive it. They were then given a five kilometre practice session where there was no other traffic. This allowed all subjects to adapt to the differences between real driving and "virtual" driving on the simulator. Subjects spent about five minutes in this practice session, which included several curves for the subjects to negotiate as well as stop signs and signal lights so that subjects could test the brakes.

Subjects were then given instructions for the main driving task. All subjects were instructed that the task that they were about to perform was a simulation, not a game. For this reason, subjects were asked to drive as much as possible the way they usually drive in a real car. Subjects were reminded that road rules would apply as they do in the real world.

The subjects then performed the main driving task in the condition to which they had been allocated. The task took approximately 40 minutes to complete. When the study was over they were then debriefed by the experimenter who explained the purpose of the study in more detail.

## Results

The simulator was programmed to collect data every 10 metres on a series of variables. The relevant ones for this study were as follows:

- Elapsed Time (sec)
- Metres travelled
- Velocity (m/sec)

From this data information regarding a number of relevant variables was extracted for analysis for each curve, as follows:

- Velocity (m/sec) at the point when the sign appeared (ie. 20m before the curve) or at the point at where the sign would have appeared had there been one.
- Velocity 10 metres after the sign appeared, or 10m after the point where the sign would have appeared had there been one.
- Velocity adjacent to the sign, or adjacent to the point where the sign would have appeared had there been one.
- Velocity at the beginning of the curve.
- Velocity at the middle point of the curve.

Comparisons were carried out between the mean speeds at which the two groups of subjects were travelling (a) 10m after the sign appeared, (b) when they were adjacent to the sign, (c) when they were at the beginning of the curve and (d) when they were in the middle of the curve. There were no differences between the two groups for any of these comparisons.

The first question to be asked is, do subjects slow down (a) immediately after a sign appears. (b) ten m after the sign appears, (c) adjacent to the sign itself (d) at the beginning of the curve or (e) in the middle of the curve more when a sign is present than when it is absent?

First, it is necessary to ascertain that the drivers do indeed slow down when a sign is present. For each of these situations the speed at the relevant place was noted and the next recorded speed was subtracted. This was done for Curves 4, 9, 12 and 17, these being the curves on which the first sign was shown. These figures were then averaged. Table 1 shows a test of whether each of these is greater than zero.

#### **Table 1 Deceleration data**

	Test Value = 0					
	t	df	Sig. (2-tailed)	Mean Difference		
Av decel sign appears to 10m later	1.220	29	.232	.3070		
Av decel 10m to adjacent sign	5.781	29	.000	12.1940		
Av decel adj sign to beg. of curve	2.981	29	.006	4.1703		
Av decel beg. to mid curve	-3.185	29	.003	-4.6853		

**One-Sample Test** 

These results indicate significant decelerations between two pairs of points, namely from the position 10m after the sign appears to the position adjacent to the sign, and then from there to the beginning of the curve. There appears to be a significant acceleration from the beginning to the middle of the curve.

Considering these two situations where there was deceleration when the sign was present, the question arises as to whether this deceleration was greater when the sign was there than on the curves when no sign was present. The corresponding data from the curves where there were no signs were averaged and compared to the data from the first four curves where there was a sign (Table 2).

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Table 2. Comparison of deceleration, with and without signs, from the point 10m after the sign appears to the point adjacent to the sign, and then from the point adjacent to the sign to the beginning of the curve.

		Paired D				
		Mean	Std. Deviation	t.	df	Sig (2-tailed)
Pair 1	Decel from 10m to adjacent "sign" position without sign VS Av decel 10m to adjacent sign with sign	6.7E-02	2.2320	.164	29	.871
Pair 2	Decel from adjacent "sign" to beg. of curve without sign VS Av decel adj sign to beg. of curve with sign	4415	2.0366	-1.19	29	.245

Paired Samples Test

These data suggest that the signs were not effective in causing greater decelerations at either of the two positions examined.

The next question is whether there was any greater deceleration when the sign changed at Curve 20. The relevant means are shown in Table 3. There were no significant differences between these means.

Table 3. Means for deceleration from the point 10m after the sign appears to the point adjacent to the sign, for the first sign (average over 4 occurrences) to the second, changed, sign on the 20th curve.

Sign Group			Mean	Ň	Std. Deviation
Curve sign first	Pair 1	Av decel 10m to adjacent sign for changed sign (curve 20)	4.5207	15	6.2134
		Av decel 10m to adjacent sign for first sign (curves 4,9,12,17)	3.2973	15	2.5587
	Pair 2	Av decel adjacent sign to beg. of curve for changed sign	5073	15	3.8216
		Av decel adjacent sign to beg. of curve for first sign	.9747	15	2.0889
Turn sign first	Pair 1	Av decel 10m to adjacent sign for changed sign (curve 20)	2.3513	15	4.9635
		Av decel 10m to adjacent sign for first sign (curves 4,9,12,17)	2.7997	15	3.2556
	Pair 2	Av decel adjacent sign to beg. of curve for changed sign	.8413	15	1.5260
		Av decel adjacent sign to beg. of curve for first sign	1.1105	15	1.7968

Paired Samples Statistics



An examination of the successive curves when there was a sign (Figure 2) shows the nature of some of these data.

Figure 2. Graph showing deceleration from 10m after the sign appears to the point adjacent to the sign for the five curves where a sign was present



Figure 3. Graph showing deceleration from the point adjacent to the sign to the beginning of the curve for the five curves where a sign was present

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An examination of the deceleration from a point just after the sign appears to the point adjacent to the signs shows that, for Condition 1 where the curve sign appeared first, subjects appeared to be learning to decelerate less and less over the first four curves with the curve sign, and then decelerating much more when the sign changed to a turn sign (a quadratic curve fitted to this data accounts for 54% of the variance). This pattern was not evident for Condition 2 where the turn sign appeared first. However, as shown in Figure 3, this dichotomy between the two conditions did not carry on to the next phase of the curve, namely from the point adjacent to the sign to the beginning of the curve itself. In this next phase both conditions appear to follow the same pattern of deceleration.

## Discussion

These results are of interest because they have enabled a detailed examination of how drivers decelerate at signs and at curves. There is a large literature on the impact of warning signs and in particular the problems associated with repeated exposure to the same sign. Further, there is field evidence that drivers may become less responsive to repetitious warnings, for instance the train driver in a UK rail accident reportedly ignored a warning bell that had routinely sounded on previous occasions with no negative consequences.

The results shown in Figure 9 suggest that the subjects were reacting only to the change from a familiar sign to a different one, as Helson's (1964) classical adaptation level theory might predict, but since this conclusion is derived from the finding of no difference between two curves it would be necessary to explore this finding in a wider variety of circumstances before any such conclusion can be reached with confidence.

A further issue uncovered in this study is only at this stage anecdotal. It appears from an examination of the subjects' behaviour during the simulation runs that the density of traffic has a profound effect on their behaviour in relation to signs. Since the traffic density in this study was only of a single value it is not possible to examine this conclusion statistically. Clearly further studies which vary traffic density are required to elucidate further the nature of behaviour in relation to traffic signage.

Given the time and resource limitations, a second study was undertaken which did involve greater control over traffic density, but it was decided for the moment to examine other variables related to stress in traffic.

# Study 2-Mood, stress and driver behaviour

### Introduction

There is much evidence to suggest that everyday driving is associated with moderate levels of stress and negative mood states (Matthews, Dorn, Hoyes, Davies, Glendon & Taylor, 1988). These mood states can range from mild emotional reactions to negative events to extreme feelings of distress or even severe driver frustration (also known as "road rage"). In a recent review of driver behaviour and stress, Mathews *et al.* (1998) reported:

"Stress appears to predispose drivers to a heightened risk of motor vehicle accidents. Variables that discriminate between accidentinvolved and non accident-involved drivers include specific sources of stress, such as interpersonal and job problems, as well as overall assessments of recent exposure to stressful life events (Selzer & Vinokur, 1975). Accident likelihood is also connected to personality characteristics that are associated with stress vulnerability, such as personal maladjustment, depression, anxiety, and aggression (see Gulian, Matthews, Glendon, Davies, & Debney, 1989; Seizer & Vinokur, 1975). Stress effects can sometimes be quite large in magnitude. Brenner and Selzer (1969) estimated that drivers who have experienced a recent stressful event are five times more likely to cause fatal accidents than are unstressed drivers." (p 136).

Matthews *et al.* (1998) also examined how vulnerability to stress affected performance on a driving simulator task. They found that aggression was associated with higher amounts of risk taking, including frequency of overtaking and that mood disturbance and dislike of driving were associated with reduced control skills and greater caution.

The studies described above suggest that stress plays an important role in driver behaviour, but it is not always clear from those studies whether it is stress that causes certain driving behaviours, or whether certain driving conditions cause those behaviours and cause stress as well. It seems possible that we alter the way we drive to suit different driving conditions, but our moods and stress levels may mediate this relation. To investigate this phenomenon we need to examine the driving conditions that are most likely to affect our feelings of stress. Driving simulators give us the opportunity to investigate antecedents of stress as well as the results of stress.

Matthews, Sparkes and Bygrave (1996) investigated the phenomenon of stress in driving simulators using a dual-task method to induce attentional overload in young drivers. However, the results of their study suggested that drivers adapted to the demands placed on them very quickly. This may have been due to the fact that the second task used in this experiment was a grammatical reasoning task that did not directly relate to the task of driving. One aim for the present study was to devise a more ecologically valid manipulation of task demand.

#### **Research on stress and performance**

Much of the research on stress has been conducted in the field of occupational stress, where different aspects of the working environment are examined to see if they elicit stress responses. One of the most popular working environment theories is Karasek's Job Strain model (Karasek, 1979). This model proposes that job strain (also known as occupational stress) is affected by two characteristics of one's working environment: demands and discretion. Demands are the amount of effort and attention required to perform the tasks in one's job. Discretion (also called job control) primarily refers to the amount of decision making freedoms present in any job. Karasek predicts that environments with higher demands are more stressful than jobs with lower demands, and that environments with lower control are more stressful than jobs with higher control.

When high demands are not balanced by a commensurate level of control, Karasek predicts that there will be more stress than might be expected from simply adding the effects of demand and control. Rather, the resultant effect should be observed through an interaction term produced by multiplying the levels of demand and control. Karasek reports that people in these "high strain" jobs score higher on a variety of measures of mental and physical ill-health (including anxiety, sleeping problems and exhaustion).

Most of the studies based on the job strain model have been conducted in the field. Although this approach benefits from increased ecological validity, it can sometimes be at the expense of rigour in the measurement and analysis of the key variables. A few studies, however, have looked at the effects of manipulating levels of demands and control in laboratory simulations where external variables can be controlled, measured or eliminated (e.g. Jimmieson & Terry, 1998).

An example of a laboratory study of Karasek's job strain model is the mail sorting study conducted by Parkes, Styles and Broadbent (1990). These authors asked subjects to read an address on simulated envelopes and press keys that corresponded to a mail code. Subjects performed this task under fast and slow machine-paced conditions as well as a self-paced condition, thus allowing for comparisons between high and low demand as well as between high and low control. The subjects performed best under self-paced (high control) conditions, and this condition was also associated with lower reports of stress. Self-reports of stress was highest in the high demand, low control condition.

#### The present study

In view of the large amount of research conducted using the job strain model it would be appropriate to test it under controlled conditions. The aim of the present study was to conduct a test of Karasek's job strain model by manipulating the factors of demand and control in a driving simulation task. This allows a determination of the extent to which different driving conditions produce different levels of stress, different moods and different driving behaviours. It also permits an examination of whether mood states and stress levels have a consistent effect on driving behaviour regardless of the driving conditions.

Thus there were three hypotheses, based on the work of Karasek (1979), as follows:

- 1. low control will lead to more stress than high control,
- 2. high demand will lead to more stress than low demand, and
- 3. high demand and low control will interact to produce a high stress condition.

## Method

Subjects

A total of 40 first year psychology students, all with previous driving experience, participated in the present study in return for course credit. Of these, 21 were female and 19 were male. Ages ranged from 18 to 27 years, and the mean age was 21.1 years.

#### Design

Subjects were allocated randomly into one of four groups in a 2 x 2 between-groups design. Each group received either High or Low task Demand and either High or Low task Control. Demand manipulations were achieved by varying amount of traffic (number of cars and pedestrians) displayed in the simulation. Control manipulations involved the presence or absence of a speed-sensitive siren. Self-reports of stress and arousal were measured before and after the task, and other dependent variables were measured during or after the task.

#### **Materials: Self Report**

In the present study, as in the Parkes *et al.* (1990) study, stress and arousal were measured with the Stress Arousal Adjective Checklist (SACL), developed by Mackay, Cox, Burrows and Lazzerini (1978) and modified by King, Burrows and Stanley (1983). The SACL consists of a series of a four point scales (0 = "definitely does not", 3 = "definitely does") that describe current mood states. There are ten arousal items and ten stress adjectives, and the scores are combined to form a score out of 30 for arousal and a score out of 30 for stress.

#### Simulator task

The driving simulator task scenario was divided up into rural and urban areas. In rural areas, cross streets occurred infrequently (approximately every 2 kilometres) and the landscape primarily consisted of grass and trees. In urban areas, blocks representing buildings were displayed on either sides of the road, and cross-streets were displayed every 200 metres. There was more traffic in urban areas than rural areas, and most of the cross streets had traffic lights.

For subjects in High Demand conditions, twice as many cars and pedestrians appeared in the scenario as appeared in the scenario for subjects in Low Demand conditions. The task scenario included 6 different speed zones, so that subjects were required to change their speed approximately once every five minutes. For subjects in Low Control groups, a siren was played every time the driver exceeded the speed limit (even if it was by 1km/h). Subjects were instructed that they should slow down when they heard this siren, as it meant that they were driving too fast. This reduced the usual discretion a driver has over speed, as it forced drivers to maintain a speed that was always below the posted limit rather than allowing them to fluctuate above and below the speed limit as drivers usually do. Subjects in Low Control conditions were also told that they were not permitted to stop the vehicle (except at traffic lights, stop signs and for safety reasons) until the end of the task.

Subjects in High Control conditions were not exposed to this siren. These subjects were also told that they could "pull over" at any time if they wanted a break from driving.

The computer program logged data every 10 metres while the subject was performing the task. Data collected included the distance travelled and time taken, the velocity and acceleration of the vehicle, the heading angle error with respect to the centre lines, the lane position with respect to the centre lines, and the number of collisions or accidents encountered. The computer also collected data on the type of accidents that had occurred, the number of times the speed limit was exceeded, and the number of appropriate stops at traffic lights.

#### Procedure

The procedure was as for the first study, except that subjects began by completing the Stress Arousal Adjective Checklist (SACL) in order to provide a baseline level of their stress and arousal. After subjects had completed the task they completed the SACL once again. They were then debriefed by the experimenter, who spent several minutes explaining the study.

#### Results

Analyses were performed on lane position before and after each of four "KEEP LEFT UNLESS OVERTAKING" signs, on driving behaviour in a sample curve from the scenario, and on the number of accidents (including collisions with other vehicles, collisions with pedestrians and off-road accidents), speed exceedances and stops at traffic lights that occurred in the task. Analyses were also conducted on subjects' perceptions of their own driving behaviour and on their self reports of stress and arousal. Partial correlations were performed to investigate the effects of stress and arousal on performance variables, with the influence of the experimental manipulations partialled out.

Four "KEEP LEFT UNLESS OVERTAKING" signs were displayed in the scenario; at 610m, 7760m, 10260m and 17760m. The signs were displayed as black text on a light grey background. The grey signboard was 6.5m wide and 2.5 metres high and its top left corner was 7.5m from the left edge of the road and 7m above the ground. The signs could be seen from 260m away, but they were not clearly legible to most subjects until they were 100m away.



Figure 4: Lane position by experimental condition

Multivariate Analyses of Variance were conducted on the average lane position that was logged in the 100m leading up to the position of the sign and in the 100m past the sign (Figure 4). The manipulations of Demand and Control did not affect driving behaviour in the 100m before the position of any of the signs, or after the position of the first sign. Control over speed affected driving behaviour after the second sign, with drivers in High Control conditions positioned further to the left than drivers in Low Control conditions (F(8,28)= 4.56, p < .05). Demand over speed affected driving behaviour after the third sign, with drivers in High Demand conditions positioned further to the left than drivers in Low Demand conditions (F(8,28)= 10.89, p < .01). Finally, drivers in High Control conditions were positioned further to the left after the fourth sign than drivers in Low Control conditions (F(8,28)= 5.10, p < .05).

Analyses of Covariance were conducted on the speed, acceleration (at the start of the curve) and angle error with regard to the centre lines for when drivers were negotiating one of the curves displayed in the scenario. The curve was the 6th to appear in the simulation and the 4th curve that had a warning sign. The curve was of 52 degrees and 10m in length. The sign displayed 20 metres before the start of the curve was the left curve diamond-sign, of the type shown in Figure 1a. Below this sign was a yellow rectangle containing numbers indicating that the recommended speed for negotiating this curve was 45 km/h. The speed limit in the area surrounding the curve was 60km/h, and the simulator displayed an urban setting for more than 1km on either side of the curve. This curve was chosen as it was the sharpest curve to appear in the simulation and consequently it was important that the subjects obeyed the safety sign associated with it.

When controlling for the covariate of subjects' experiences with computer

games, demand and control had no significant impact on acceleration or heading angle error, but these variables did affect velocity (speed). Subjects with High Control took the curve much faster than subjects with Low Control (F(1,34) = 8.06, p < .01).



Figure 5: Curve speed by condition

As shown in Figure 5, subjects with Low Demands took the curve much faster than subjects with High Demand (F(1,34)=5.99, p < .05). There was also a significant interaction between demand and control (F(1,34)=9.01, p < .01), which indicated that the main offenders were subjects with low demands and high control, who negotiated the curve at an average of 16.5m/s (approximately 60km/h).

Multiple Regression Analyses indicated that subjects who gave more positive reports of their usual driving ability negotiated the curve at a faster speed than subjects with more modest reports of their ability (t = 4.51, p < .01). However, subjects who gave more positive ratings of the safety of their usual driving behaviour appeared to negotiate the curve at slower speeds than subjects with lower safety ratings (t = -2.83, p < .01).

As shown in Figure 6, subjects with High Demands collided with more pedestrians (F(1, 35)= 9.76, p < .01) and collided with more vehicles (F(1, 35)= 5.41, p < .05) than did subjects with Low Demands. No effect for control was observed for the number of accidents. Off-road accidents were not significantly affected by demands or control.



Figure 6: Accidents by condition

Speed exceedances and stops at traffic lights were influenced by the manipulations (Figures 7 and 8). Despite the traffic to slow them down, subjects in High Demand conditions exceeded the speed limit more frequently than did subjects in Low Demand conditions (F(1,36)= 7.22, p < .05). There was also a significant interaction, which indicated that subjects in High Demand High Control conditions exceeded the speed limit much more than those in other conditions (F(1,36) = 5.23, p < .05). Subjects in High Demand conditions also stopped at fewer traffic lights than did subjects in Low Demand conditions (F(1,36)= 14.63, p < .05), even though the lights changed orange and red at the same time for every subject (relative to their velocity). Subjects in High Control conditions stopped at fewer lights than did subjects in Low Control conditions (F(1,36)=20.21, p < .05). There was also a significant interaction, which in this case indicated that subjects in Low Demand High Control conditions stopped at fewer lights than did subjects in all other conditions (F(1,36)= 16.80, p < .05).



Figure 7: Speed exceedance by condition



Figure 8: Stops at traffic lights by condition

The experimental manipulations did not affect subjects' perceptions of how closely they obeyed the road signs displayed in the scenario. This is an interesting result in the light of the above results, as there were several observed differences between the conditions in driving behaviour with regard to various'signs displayed (ie. KEEP LEFT UNLESS OVERTAKING signs, curve/speed signs, and speed limit signs). However, there was little variance in compliance with road signs: the mean was 4.97 and the standard deviation was 1.12 for a 7 point Likert scale where 1 = "ignored them completely" and 7 = "obeyed them completely". Experimental manipulations also failed to affect subjects' perceptions of how safely they drove in the task, again an interesting result when we consider the observation for collisions and pedestrians hit.

However, an effect was observed for subjects' perceptions of how well they drove in the task. A shown in Figure 9, subjects in Low Control conditions, who regularly experienced a siren to tell them that they were driving too fast, gave more positive ratings of their performance than did subjects in High Control conditions (F(1,36)= 5.03, p < .05).



Figure 9: Perceived driving performance by condition

Self-reports of stress and arousal, as measured by the SACL, were not significantly affected by the experimental manipulations. This appeared to indicate that the Karasek model did not easily transfer to the driving simulator task. However, paired-samples t-tests indicated that there was a significant difference between baseline stress and post-task stress (t(1,39)= 6.19, p < .001) and a significant difference between baseline arousal and post-task arousal (t(1,39)= -2.19, p < .05). This indicated that all subjects were feeling more stressed and less aroused after the task than before.

When controlling for the effects of the manipulations of demand and control as well the baseline levels of stress, the stress experienced during the driving task significantly affected subjects' perceptions of how well they performed the task (r = -.46, p < .01). This indicated that subjects who were more stressed gave more negative ratings of their driving performance. There were no significant correlations with any computer-logged performance measures.

## Discussion

These results suggest that a driving simulator can show how the amount of traffic and the amount of perceived control over one's driving behaviour can influence drivers' behaviour in certain situations. Drivers whose speed was more highly controlled (ie those in the High Control conditions) were more likely to move into the left lane after they passed two of the four "KEEP LEFT UNLESS OVERTAKING" signs. Drivers who experienced conditions of heavy traffic were more likely to move into the left lane after they passed one of these signs.

Drivers who had no traffic to slow them down and did not perceive that there were any particular constraints on their speed did not follow the warning sign on a particularly sharp curve, and negotiated the curve at 15km/h faster than the recommended speed. Drivers in this condition also exceeded the speed limit more frequently than others. Thus the simulator has brought to light the common observation that, even in speed controlled conditions, drivers who see no constraints on their speed such as high traffic volume (or indeed sirens telling them to slow down) will exceed the speed limit by considerable amounts.

Subjects who were exposed to more traffic were more likely to have accidents, were more likely to exceed the speed limit, and were less likely to stop at traffic lights, thus demonstrating what can only be described as a frustration effect. It is possible that the nature of the traffic in the present simulation exacerbated this tendency, as the behaviour of the traffic, particularly in the high-traffic conditions, was seen by the subjects as frustratingly slow.

This second study has highlighted a series of important issues for driving research. First, again we are seeing an impact of signage on driving behaviour, but more than this, we have shown how driver's perceptions of "control" or decision latitude mediate the link between road signs and behaviour. These are rich issues which we wish to explore more fully in

the more sophisticated simulator. A second aspect of this study is worth noting, and that is the high detail in the performance measures that can be obtained using the simulator thus permitting very fine-grained analysis of driving behaviour.

In summary, we have demonstrated the potential of the technology to address some important aspects of modern driving. Even with the basic Model 400 simulator we have managed to obtain some interesting and valuable insights into the relationship between warning signs, mood, traffic density, control and behaviour. These results are the foundation for more substantial investigations in the coming years.

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