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Perceptual Countermeasures:
Simulator Validation Study

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Monash University Accident Research Centre

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Abstract

Perceptual countermeasures to speeding involve paint and/or gravel road markings aiming to slow vehicles down by influencing the speedperception ofdrivers. This study set out to validate the TAC mid-range driving simulator at MUARC as an appropriate toolfor the development and evaluation of these treatments off the road. The drivingperformance of a sample of drivers in an instrumented test vehicle on-road was compared with that of a similar group in the driving simulator at sites with and without transverse rumble line treatments. Performance measures included speed profiles, braking, deceleration and lateralposition and differences were examined statistically between treated and control sites on the road and in the simulator. The results showed that speed and braking responses were cowelatedfor most sites and that lateralplacement results were similarfor curves. In addition. while there were consistent speed reductions in both test environments, they were more pronounced in the simulator than on the road. A second simulator trial showed that rumble effects enhanced the visualperceptual effects of these treatments, althoughfurther research is warranted to test this more rigorously. Importantly, though, the validation study confirmed that the simulator is a suitable test environmentfor evaluating perceptual countermeasures, especially when testingfor speed reductions, and to a lesser degree braking, as the principal dependent measures. Lateral placement is a valid measure of curve drivingperformance.

Keywords

SAFETY, ACCIDENT, PERCEPTION, INJURY, COUNTERMEASURE, COST-BENEFIT, BEHAVIOUR, SPEEDING

NOTES:

(1) This report is produced jointly hy FORS and RTA and **is** disseminated in the interests **of** information exchange.
(2) The views expressed are those of the author(s) and do not necessarily represent those of the Commonwealth Government **or** RTA.

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The study team are also grateful to ARRB Transport Research Limited for their generous assistance with the research undertaken on the road, especially to John Dods and Brendan Gleeson for their willingness and cooperation in supplying the instrumented vehicle and assistance with data collection and analysis.

We are also grateful to the City of Heidelberg and the city engineer Simon Lanza for his help with the road trials and treatments as required.

The Transport Accident Commission generously provided us access to their driving simulators for this research which was most appreciated.

We are also especially thankful to the subjects who volunteered to undertake the trials so willingly under somewhat trying conditions at times.

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EXECUTIVE SUMMARY

Driving simulators have much to offer experimental research programs as they have the potential to provide a safe and controlled environment for testing driving performance without having to expose participants to the hazards of real world driving. However, they can also be disadvantaged if the participant's behaviour is not normal while using the simulator, that is, if the simulator fails to elicit the same stresses and responses usually elicited while driving.

While validating off-road tests of driving performance would seem to be essential for any simulated driving test, it is rarely undertaken in practice. For the most part, experimental driving research assumes that the laboratory test results are relevant in terms of road behaviour. One might expect that an off-road test that has high face validity is testing on-road driving performance but this is always an assumption without first conducting a rigorous validation test.

A study was undertaken on behalf of the Federal Office of Road Safety and the New South Wales Roads and Traffic Authority to demonstrate whether the Transport Accident Commission's Driving Simulator at the Monash University Accident Research Centre was a valid environment for testing perceptual countermeasures. In addition, it aimed to examine the effectiveness of transverse line treatments at reducing travel speed. The study was intended as a precursor to a full experimental program aimed at evaluating a range of low cost road treatments as a counter-measure to excessive speeding.

Study Method

The study set out to compare driving responses obtained on the road with those obtained in the driving simulator. The City of Banyule (formerly the City of Heidelberg) has used transverse line treatments extensively in the approach zones to intersections, roundabouts and curves to reduce accidents on suburban roads and streets. These treatment locations offered an ideal natural road experiment as similar untreated control locations were also available. The transverse lines are made from 1cm thick anti-skid material and thus provide both a visual and a rumble effect during the approach and negotiation of them.

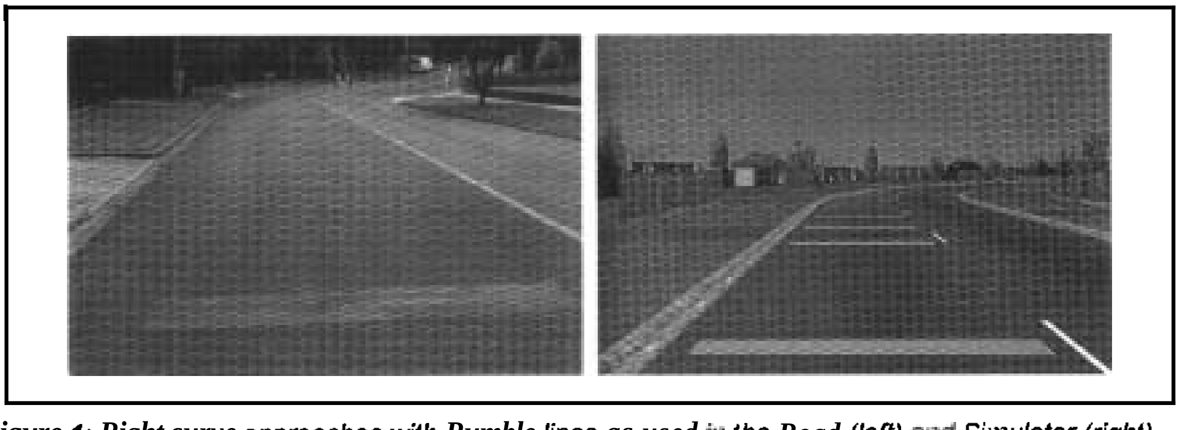

***Figure 1**: Right curve approaches with Rumble lines as used in the Road (left) and Simulator (right) components of the validation experiment.*

Road Trials. **An** instrumented vehicle was provided by ARRB Transport Research Limited and **24** participants were recruited to drive this vehicle over a test route containing a selection of treated and untreated road sections. Primary responses collected included speed, deceleration, braking and lateral position, although yaw and lateral acceleration measures were also available.

The test route took approximately ¾ hour to drive after becoming acclimatised with the test vehicle. Primary interest, however, was only with the driver's responses for up to 100 meters "before" and "during" each treatment and control site. Data were collected on-board during the trial and analysed across **4** sections preceding the treatment and intersection or curve.

Simulator Trials. **A** similar number of treated and untreated sites were then programmed on the suburban road database of the TAC Driving Simulator, taking care to match both the road and treatment characteristics of each of the road sites. While it was not possible to match precisely the full on-road trial test route, a selection of normal suburban roads and road environments that would have been encountered on the road were used to connect each treatment and control site in the simulator. Primary interest again was in the participant's driving performance in the 100 metres before and during each treatment and control site.

A different sample of **24** participants then "drove" the simulator route containing these treatment and control sites and their responses were collected for a similar range of performance measures. These data were analysed in the same way so that the road responses were to demonstrate whether the treatment effects found on the road were similarly elicited in the driving simulator.

Validation Findings

Validation can be established at a number of different levels. The least demanding level simply calls for similar patterns of responses in both driving environments. A more demanding test of validity requires statistical significance between the patterns of response on the road and in the driving simulator. **A** correlation of the differences observed between the treatment and control responses on-road and in the simulator constitutes a severe test of validity of the simulator.

A correlation analysis was undertaken on these data using **a** canonical correlation co-efficient. Unlike a usual test of correlation, a canonical correlation allows for a test of "no difference" rather than the usual converse and is eminently suitable for tests of validation. The findings are shown in Table 1.

Speed. The speed measure produced the strongest correlation and had the most similar pattern of results between test environments. However, it was less reliable at roundabouts than other test locations. This was probably the result of a lack of reality in the simulated roundabout and the subsequent discomfort it generated among the participants.

Braking. Braking, too, was significant at three of the four locations but was **less** sensitive in the simulator than on the road generally. This seemed to suggest that the braking motion in the simulator was not well representative of what happens on the road at these sites and probably indicates that the braking mechanism in the simulator would benefit from further development.

Table I: Results of the validation between on-road and simulator trials

Performance Measure	**Site Configuration**	**Te : of Validation**	
		Correlation ($p<.05$)	Pattern
1. **Speed**	**stop sign** **roundabout** **left-curve** **right-curve**	$p<.05$ **not significant** $p<.05$ $p<.05$	**similar** **different pattern in simulator** **greater reductions in simulator** **similar**
2. **Braking**	**stop sign** **roundabout** **left-curve** **right-cuNe**	**not significant** $p<.05$ $p<.05$ $p<.05$	**different pattern in simulator** **more braking on the road** **more braking on the road** **more braking on the road**
3. **Deceleration**	**stop sign** **roundabout** **left-curve** **right-curve**	$p<.05$ **not significant** $p<.05$ **not significant**	**opposite pattern in simulator** **different pattern in simulator** **similar but less in simulator** **different pattern in simulator**
4. **Lateral position**	**left-curve** **right-curve**	**not significant** **not significant**	**similar but more erratic on road** **similar but more erratic on road**

Deceleration While deceleration is related to foot braking, it is also affected by reductions in engine power and the subsequent deceleration influence. A significant negative correlation was observed between the road and simulator deceleration at the stop sign and a weak positive correlation for the left-hand curve, suggesting that it was a less reliable measure in the simulator at these sites.

Lateral Placement Lateral placement was only relevant for curve negotiation. While neither the left- or right-hand curves were statistically correlated, their trends were quite similar, albeit less steady on the road. This was a function of the lack of a constant centreline and the variation this produced in the on-road results compared to those collected with a constant centreline in the simulator. Importantly, in both test environments, participants moved further away from the centreline at the treated sites, confirming that this measure was valid in the simulator trials.

Transverse Line Effectiveness

While this study was principally concerned with establishing the validity of testing perceptual countermeasures in a simulated environment, it was also possible to demonstrate the usefulness of transverse line treatments in reducing speed and whether they have purely a perceptual or an alerting influence on driver's speed choice.

Speed Reduction. The results showed that in either test environment, this low cost road treatment was quite effective at reducing travel speed, both ahead of and in the approach to a potentially hazardous intersection or curve location. Average speed reductions of **2%** on the road and **8%** in the simulator were observed for the treated sites. Moreover, the speed and braking patterns on the road were slower and more gentle with, than without, the treatment.

Rumble Effects. **An** additional trial was also conducted in the simulator where the rumble effect of these lines was removed to see what effect this would have on the results. Another group of **24** participants was recruited and tested using the same simulator test route but with no rumble effects apparent on driving over the treated lines. These results were then compared with the previous simulator findings with the rumble effect present.

The only measure which differentiated between the two sets of results was travel speed. While both treatments resulted in slower travel speeds generally, the line and rumble treatment was markedly slower than the line only treatment. This was particularly so for curves and less apparent for the stop and roundabout intersection. While there were signs of a slightly slower speed **on** the approach to these treatments where the perceptual effect would be expected to be more effective, these differences were not statistically robust. This finding is worthy of further examination in future research efforts.

Operator Discomfort

One disconcerting aspect of the simulator trials was the relatively high number of participants who were unable to complete their trial through sickness or reported a degree of discomfort after completion. Modifying the practice sequence prior to experimentation did reduce the incidence of discomfort substantially. However, most of the difficulty seemed to arise from the roundabout intersection and from other excessive steering movements. While there was no evidence that this discomfort influenced the validation of the simulator, it is important to ensure that future trials be aware of the potential problem and reduce the need for excessive steering wheel movements.

Conclusion

Three major conclusions could be derived from the findings of this study.

1. The results of this study confirmed that the TAC Driving Simulator held at the Monash University Accident Research Centre was a suitable test environment for evaluating perceptual countermeasures.

2. Transverse lines on suburban roads appear to have a positive affect on speed, often commencing some **2** or **3** seconds before the lines are actually reached. This occurred on the simulator as well as the real road. When an approaching hazard is not visually outstanding such as curves, transverse lines will create a slower approach speed, no matter what material the driver expects the lines to be made with.

3. If the transverse lines have an auditory and vibration effects as well as their visual effect, they are likely to have an even larger effect than **a** visual effect alone.

Chapter 1 Introduction

An earlier literature review of perceptual countermeasures (PCMs) by Fildes and Jarvis (1994) revealed a range of road treatments likely to affect a driver's perception of speed on the road that have been tried overseas. These included transverse lines, herringbone and checked patterned edgelines, TNO centreline and edgeline treatments, edgeline comb and hatching treatments, various median strip treatments, curve enhancing lines and raised pavement markers. While some of these treatments have been evaluated in terms of their crash reduction and/or behavioural change, the majority of them have not. Moreover, a systematic study of their relative effectiveness has not been carried out to date, including consideration of whether these treatments are necessarily optimal in reducing travel speed on the road.

A program of research commissioned by the Roads and Traffic Authority of New South Wales and the Federal Office of Road Safety set out to address these issues. While on-road experimentation has the advantage of testing driver behaviour in the real-world, it is often costly and cannot always control for extraneous influences from the many factors associated with driving. Laboratory simulation is an alternative approach, often used for comparative testing. However, it is limited by its ability to generate a truly realistic driving environment. In previous perceptual research, it has been demonstrated that this may not necessarily be of concern as it is the performance of the human perceptual system that is under test, rather than driving skills of the operator.

However, before proceeding with a full scale simulator experimental program, it is first necessary to demonstrate that laboratory testing is capable of simulating real world driving experiences for the treatments under test. In short, a validation study is required to show the degree of realism captured by the driving simulator to perceptual countermeasures.

1.1 PROJECT OBJECTIVES

To address these preliminary concerns, a validation study was undertaken to test the validity of the Transport Accident Commission of Victoria (TAC) driving simulator at Monash University to elicit real world perceptual responses to these treatments. The study set out to compare driving responses obtained in an instrumented vehicle on the road with responses in the simulator to transverse line PCMs and control treatments. In the event that correlation was established between these two sets of responses, a systematic program of evaluation research could then be considered.

This report only describes the validation study procedure and results as part of an ongoing research program into perceptual countermeasures against excessive speeding.

1.2 VALIDATION PROGRAM

The Monash University Accident Research Centre is fortunate to be the home of two new vehicle simulators (one fixed and the other portable) owned by the Transport Accident Commission of Victoria (TAC). These units cost around A$3 million and represent the very latest technology in visual road simulation world-wide. Although they are only fixed-based, they are capable of providing realistic off-road driving conditions. Indeed, driving simulation with this degree of sophistication has not been available before in Australia and represents a major break through for off-road driving behaviour studies in this country.

Computer generated vehicle-based simulators have been used and promoted recently as the ideal environment for undertaking tasks similar to what is proposed here. The Daimler-Benz driving simulator in Berlin, Germany, for instance, has a history of similar research and development as reported in the attached document by Schill and Kading from that organisation. It is expected that the new TAC simulators will also be well suited to this task, given the level of sophistication available with these units.

1.2.1 Image Simulation

The ability of these units to simulate real world conditions is not only dependent upon the degree of sophistication of the simulator but also the subtleties associated with the task to be simulated. While the TAC simulator is the latest and most sophisticated unit available in this part of the world, its validation for this task has not yet been demonstrated; in particular, its ability to replicate the visual effects of these treatments accurately with a 30Hz generator.

The first step, therefore, was to examine the potential for generating suitable images for presentation. With a 30Hz generator, the TAC simulator generates a new image every 1/30th of a second. At 60km/h, a vehicle travels **16.67** metres every second and more than one-half a metre in 1/30th of a second. As many of these treatments are transverse lines of about that dimension, it was important to show whether they could be simulated to a sufficient degree of realism for testing on this device.

A few treatments that were considered most likely to be problematic were programmed and trialed on the simulator using existing road scene scenarios. This relatively simple procedure was undertaken to demonstrate the practicalities and limitations of the system. A few participants drove these treatments and their perceptual and performance responses were measured. The findings showed that indeed these transverse line treatments could be generated with sufficient realism at urban travel speeds to continue with the validation study. These findings were reported earlier in an interim report and have not been included here.

1.2.2 Validity Testing

The next phase of the study was to undertake on-road and simulator tests using similar driving presentations and stimulus materials and compare these results.

ON-ROAD TRIALS: A test circuit containing several existing road treatments was located in the Melbourne suburbs and participants were recruited to drive the circuit in an instrumented vehicle provided by ARRB Transport Research Limited. The circuit also contained similar untreated roads (control sites) for comparing driving performance with and without treatment. Primary driving responses included travel speed, lateral position and acceleration/deceleration profiles. In addition, a few secondary measures such as yaw and steering wheel movements were also collected. Details of the road trials are found in Chapter **2** of this report.

SIMULATOR TRIALS: **A** similar number of participants was recruited to "drive" the simulator using simular stimuli. **A** test circuit was established from the suburban database of the simulator which comprised a selection of straight roads, cross intersections with and without signals and roundabouts. Similar treatments to those on the road circuit were developed and applied to the simulator road database to match the real world treatments as closely as possible. Again, control roads were adopted in the simulator for comparison comprising the same roadways without treatments. Dependent variables were the same as the primary measures adopted on the road. Details of the simulator trials are found in Chapter 3.

ESTABLISHING VALIDATION: Validation of the simulator can be established at two different levels. The least demanding level of validation simply calls for similar patterns of response between on-road and simulator trials. For instance, if a behavioural change is observed on the road on approach to a particular treatment site, validation is said to have been established if a similar pattern is also observed in the simulator.

However, a more rigorous validation test requires statistical association to be established such between both data sets. While a decision to use the simulator may not be dependent ultimately upon the establishment of a strong significant finding, nevertheless, it is worthwhile to attempt such a test of validation to help in assessing the real world significance of any subsequent research effort. The extent of simulator validation found in this study is outlined in Chapter **4.**

1.2.3 Perceptual or Alerting Mechanism

As noted earlier, the main aim of the study was to validate the simulator as a legitimate environment for testing perceptual countermeasures on the road. However, the experimental program adopted here also permitted the testing of another aspect of the effectiveness of perceptual countermeasures, namely whether they achieve speed reductions through purely visual perception or whether there is also an alerting aspect to these treatments. Denton (1971; 1973) argued that PCMs operate by influencing the perceptual array presented to the driver thereby leading to a more conservative behavioural response. Fildes, Fletcher and Corrigan (1987) and Fildes, Leening and Corrigan (1989) similarly argued that the road and road setting can have a marked influence on driving through visual perceptual modification. In tests of a series of transverse line treatments on roads in rural Victoria, however, Jarvis (1989) claimed that the speed reductions measured at these locations (compared to similar control sites) could also be explained in terms of their "alerting influences" on the driver.

It is true that many of these treatments create a rumble effect as cars pass over them because they commonly comprise thick cross-sections of either paint or plastic materials that cause the car to "bump" through the undercarriage as the wheels pass over them. However, as drivers generally visually negotiate the road around 3 seconds ahead of their current position (Shinar 1977) and at times up to **8** seconds ahead of their current position (McLean & Hoffman, 1973), the perceptual effects of these treatments on driving should be apparent well ahead of them. Of course, another type of alerting mechanism is simply their presence, what is sometimes called a novelty effect. However, as most of the drivers who pass over these sites are locals who would be expected to adapt to their presence, these effects usually disappear with time. Jarvis (1989) did report long lasting speed reductions which could not be fully explained through such novelty effects.

Thus, a third experiment was conducted in the simulator to test the rumble effects (alerting influences) of the transverse line treatments, compared to the purely visual perception effects. The results of this experiment are reported in Chapter **5.**

1.2.4 Further Research

The final Chapter of the report discusses the overall findings of the validation study and the degree to which the study objectives have been met. It also describes the need for further research into perceptual countermeasures and outlines a plan for the continued development of perceptual countermeasures following the findings of the validation study.

Chapter 2 Experiment 1 - On-Road Driving with PCMs.

Transverse lines have been used in local streets and suburban roads in and around Heidelberg, Victoria since 1991 as a crash countermeasure. They are used on the approach to curves, stop signs and roundabouts at high accident locations. The rationale used by the Traffic Engineers who introduced these treatments was to reduce accidents primarily through the anti-skid nature of the surface of the bars, and only secondarily from slowing vehicles down (Lanza, 1995). This has led to some instances of less than ideal placement of the bars for perceptual effects, that is, not at ever decreasing pitch on the approach to the hazardous location as suggested by Denton. However, this was able to be corrected at some locations by the addition of extra lines. **A** sample road site is shown in Figure 2.1 below.

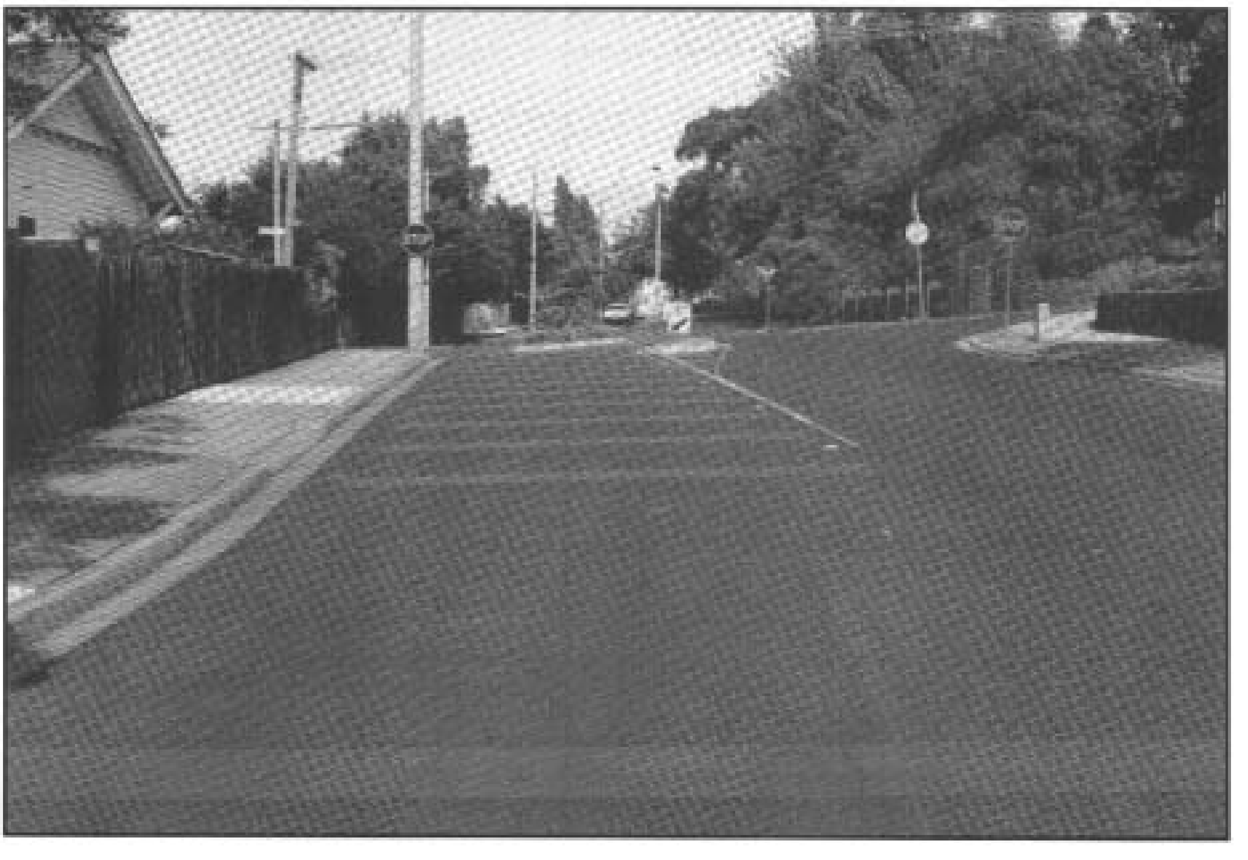

Figure 2.1 Typical site showing transverse lines leading up to a stop sign

The anti-skid bars consisted of layers **of** plastic material, one-lane long, 300mm wide and 10mm thick, heated and pressed onto the bitumen road surface. They were generally coloured red-orange and comprised of a material known to be anti-skid. They had a observable rumble effect as cars travelled over them which caused some concerns to a few residents whose homes were located opposite to the treatment. Generally, the treatment preceded the hazardous location but often also continued through the curve or intersection.

This was because of their anti-skid nature. For perceptual purposes, however, they were still suitable, even with less than ideal placement, for they did precede the hazard. It would be expected that on-road speed reductions would improve with more attention to bar spacing.

Indeed, there was some evidence available on the speed reduction effects of these treatments from a "*before-and-after*" analysis carried out by the local council (City of Heidelberg, 1994). They reported mean and 85th percentile speeds decreased by between 2km/h and 4km/h after the strips were laid. The details of how these measurements were taken and at what time after installation are sketchy and lack statistical analysis, as it was more directed towards the degree of acceptance of the treatments by the local residents. Indeed, acceptance by the residents was high at 76%. Interestingly, half of them believed they did reduce travel speed and half did not while three-quarters believed that they certainly did reduce accidents, especially single vehicle crashes where the left the roadway.

A test route for the road trials was layed out, incorporating treatments at left- and right-hand curves, cross intersections (with stop and give-way signs) and a roundabout. Geometrically similar non-treated sites were also included on the test route as controls. The test route also included a practice section at the *start* where drivers could familiarise themselves with the vehicle and one or two treatments. The test route took approximately 45 minutes to drive and was around 10km long.

2.1 METHOD

2.1.1 Design

The road experiment utilised a repeated measures design, comprising 6 site variables namely a stop sign, a roundabout, two left curves and two right curves. For each test site, a similar control site was also identified comprising the same site variables.

Dependant variables or driving response measures were chosen from what was available in the instrumented vehicle and the driving simulator. The primary dependant variables comprised speed of the vehicle, longitudinal deceleration, lateral placement of the car with respect to the centreline, and foot brake application. Secondary dependant variables included lateral acceleration, steering wheel angle, and **YAW** (the rotation of the car on its axis). Some of these measures are only relevant for the curves and not the intersections, notably, lateral position, lateral acceleration, steering wheel angle, and **YAW.**

The test route on the road was accessed in two different directions to control for order effects, where half the male and female participants drove in each direction. In route one, three treatment sites (T2, T4 and T6) were reached before their corresponding control sites, and three control sites (C1, C3 and C5) occur before their corresponding treatment sites. For the alternative route, the opposite occurred, i.e., C2, C4 and C6 occur before their corresponding treatment sites, and T1, T3 and T5 before their corresponding control sites.

For route one, a right and a left curve (sites 4 and 6) had their treatment sites before their control sites, while the other right and left curves (sites 3 and 5) had their control sites before their treatment sites. Route two has the vice versa with sites 4 and 6 having their control sites before their treatment sites and sites 3 and 5 having their treatment sites before their controls.

At two of the test sites, C3 and C6, there existed an advisory speed sign, advising drivers to drive around the curve at 40 km/h. The bottom part of these signs, which contained the numbering **40,** was covered while the top part, containing an arrow curving in the direction of the curve, was left exposed. This was to stop participants from adopting the recommended speed for the sole reason of the advisory speed sign suggesting it.

2.1.2 Apparatus

INSTRUMENTED CAR: The instrumented vehicle was supplied by **ARRB** Transport Research Limited. **A** normal white Holden Apollo with front wheel drive was used, with the only difference in appearance coming from some wires coming out of the bonnet into the back door window on the passenger side of the car, a 10 cm^3 box hanging down under the steering wheel stem, two cameras 10 cm by 5 cm^2 mounted on the very back of the boot on the drivers side, and electrical boxes and a portable computer in the back seat.

Brake activity was measured by recording the electrical current which would have travelled to the brake lights of a trailer if one was attached. Speed and distance were measured via the speedometer of the car. Longitudinal deceleration measurements came via an accelerometer (Sundstrand Data Control's QA-700 Q-Flex@servo accelerometer). Lateral position was measured from two cameras mounted on the boot of the car filming the road behind the car. Each camera was at a different angle in order not to miss the centreline no matter how far the car was away from it. The distance behind the front wheel where these cameras aligned with the road was 4.5 metres. Yaw and lateral acceleration measurements came from a Piezoelectric Vibrating Gyroscope (Gyrostar™), mounted in the centre of the car on the floor. Lastly, steering wheel angle was measured from a cable around the steering wheel stem on the steering wheel column, running to a transducer (Celesco transducer) mounted below the steering wheel.

RUMBLE STRZPS: The rumble strips which were used in the study were red, 60 cm in width, and were generally the lane width wide (although some were less than this - see photos). They are approximately **3m** high, and have an anti-skid surface made from Degadur Methyl Methacrylate (City of Heidelberg, 1994). A picture of these can be seen in the photo pages, and length dimensions (across the lane) in table 2.1.

EXPEZUMENTAL SZTES: There were six pairs of sites chosen. All sites were from Melbourne, Australia, in the council municipality of the City of Banyule, comprising the suburbs of Heidelberg, Ivanhoe, View Bank, Rosanna and Macleod.* The six treatment sites were chosen from the twenty installed in 1991 as reported by the City of Heidelberg (1994). The twenty sites used were originally chosen because these were areas where single vehicle accidents were occurring. The six sites chosen from these for the present study were chosen on a semi-random basis, takmg into account whether a suitable control site could be found.

The corresponding treatment and control sites were matched to the extent possible for on-road and off-road details. Effort was taken to match sites for the distance of straight uninterrupted road before a curve or intersection; they were also matched for the surrounding environment, such as the presence of houses around the site, while maintaining similar road

* **In** 1991, what was then called the City of Heidelberg in the report by the City **of** Heidelberg (1994), is **now part** of what is called the City **of** Banyule.

characteristics, All control and treatment curve sites had a radius of curvature (as measured and calculated by the specifications in Fildes, Leening, and Corrigan, **1989,** page **60)** within **30%** of each other.

These figures, along with the road widths of the sites can be seen in Table **2.1.** Descriptions of each site are shown in Tables 2.2 below (detail layout specifications of each treatment site, including distances between rumble strips are also included in the appendix to this report). Photographs of each site configuration are also included (Photos **1** to **8).**

Table 2.1: ***Radius of Curvature. Guided and total lane widths of the sites used.*** ***Note: Guided lane width refers to the width of the transverse lines, which are sometimes also accompanied by separate edge-lines (see photos).***

	Radius of Curvature	Angle of Curve	Total Lane Width	Guided Lane Width (Rumble Bar Length)
RIGHT CURVES				
T3	125m	140°	3m	3m
C3	125m	149°	3.8m	N/A
T4	100m	150°	4.4m	3.1m
C4	75m	146°	3.1m	N/A
LEFT CURVES				
T5	130m	133°	4.4m	3.1m
C5	125m	149°	3.8m	N/A
T6	100m	150°	4.4m	3.1m
C6	130m	150°	3.3m	N/A

Table 2.2: ***Site Descriptions for the Stop Sign. Roundabout and Curves.***

STOP SIGN	Distance from first rumble line - stop sign/stop line	Number of rumble lines
T1	43m	15

ROUNDABOUT	Distance from first rumble line (from the start of give-way line)	Number of rumble lines from first rumble line - start of roundabout	Number of rumble lines on the roundabout
T2	29.7m	6	14

CURVE	Distance from first rumble line - start of curve	Distance between start of curve and end of rumble area	Number of rumble lines from first to start of curve	Number of rumble lines on the curve
T3 (right)	6m	53.5m	4	19
T4 (right)	31m	42m	5	21
T5 (left)	26.5m	60m	5	27
T6 (left)	51.5m	40m	6	19

Photo 1: **Treatment Site** 1: Stop Sign **at Hawdon st. (corner** of Brown **st.). Heidelberg**
(approach from **North)**

Photo 2: **Control Site 1: Stop sign at Castle st. (corner** of **Hawdon st.). Heidelberg.**
(approach from **East)**

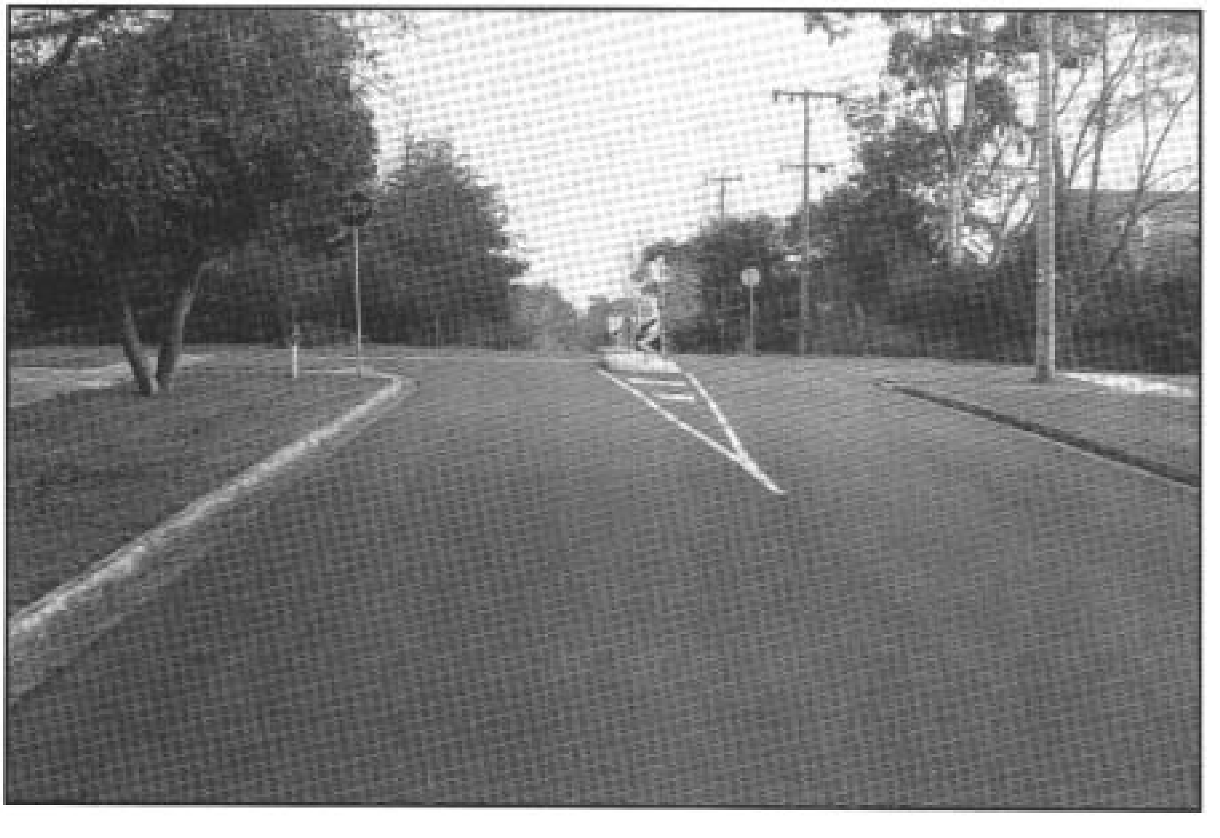

Photo 3: Treatment **Site 2:** Roundabout at Carwarp st. (corner of Erskin rd), Macleod (approach from North)

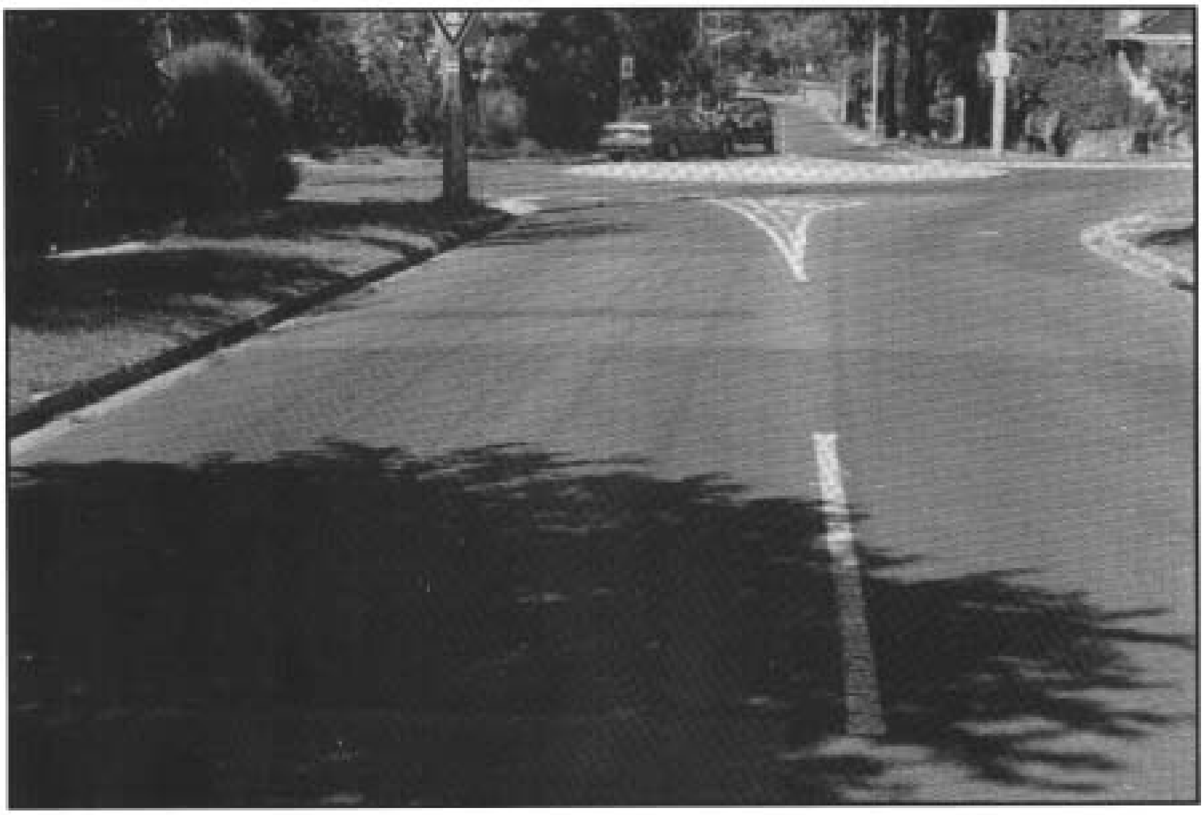

Photo 4: Control Site 2: Roundabout at Caue st. (corner of Brown st.), Heidelbere. (approach from North)

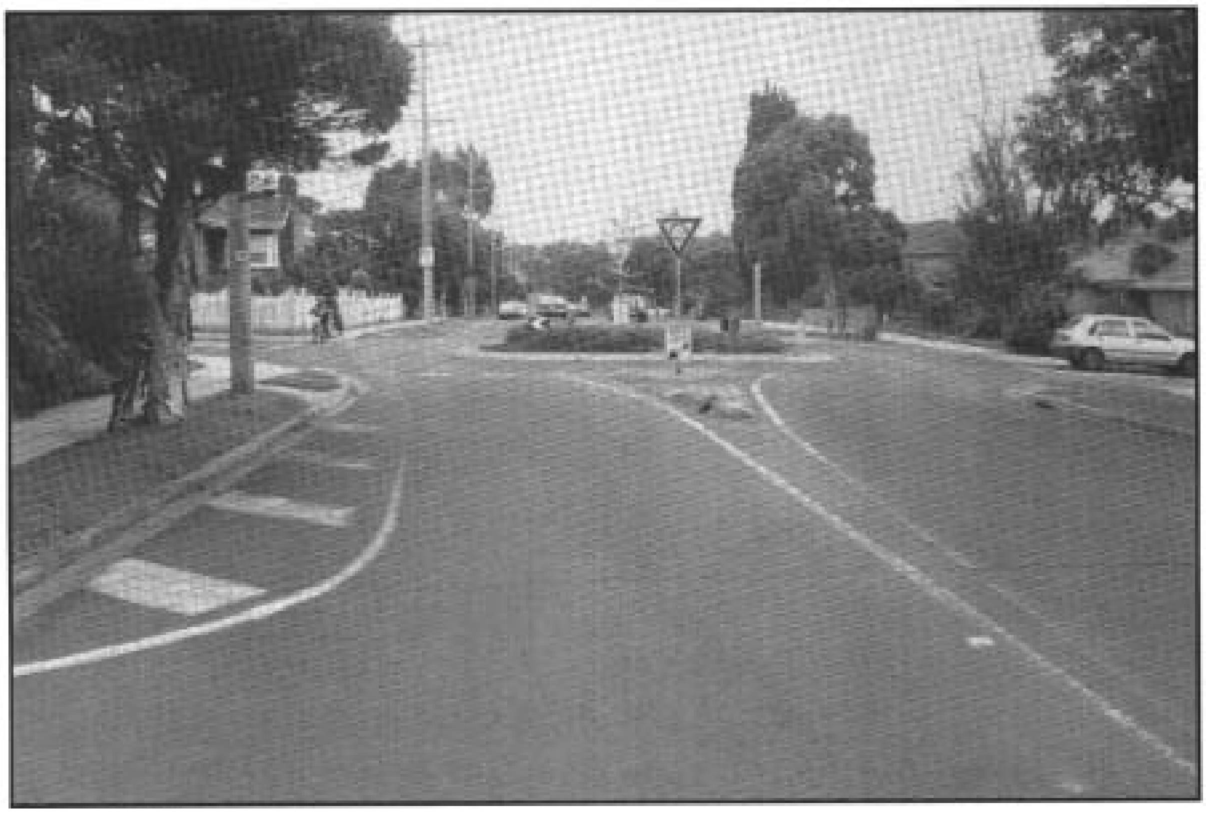

Photo 5: Treatment Site 4: Right curve on Finlayson st.. Rosaana.
(approach from South)

Photo 6: Control Site 4: **Riaht** curve on Lvon rd.. View **Bank.**
(approach from South)

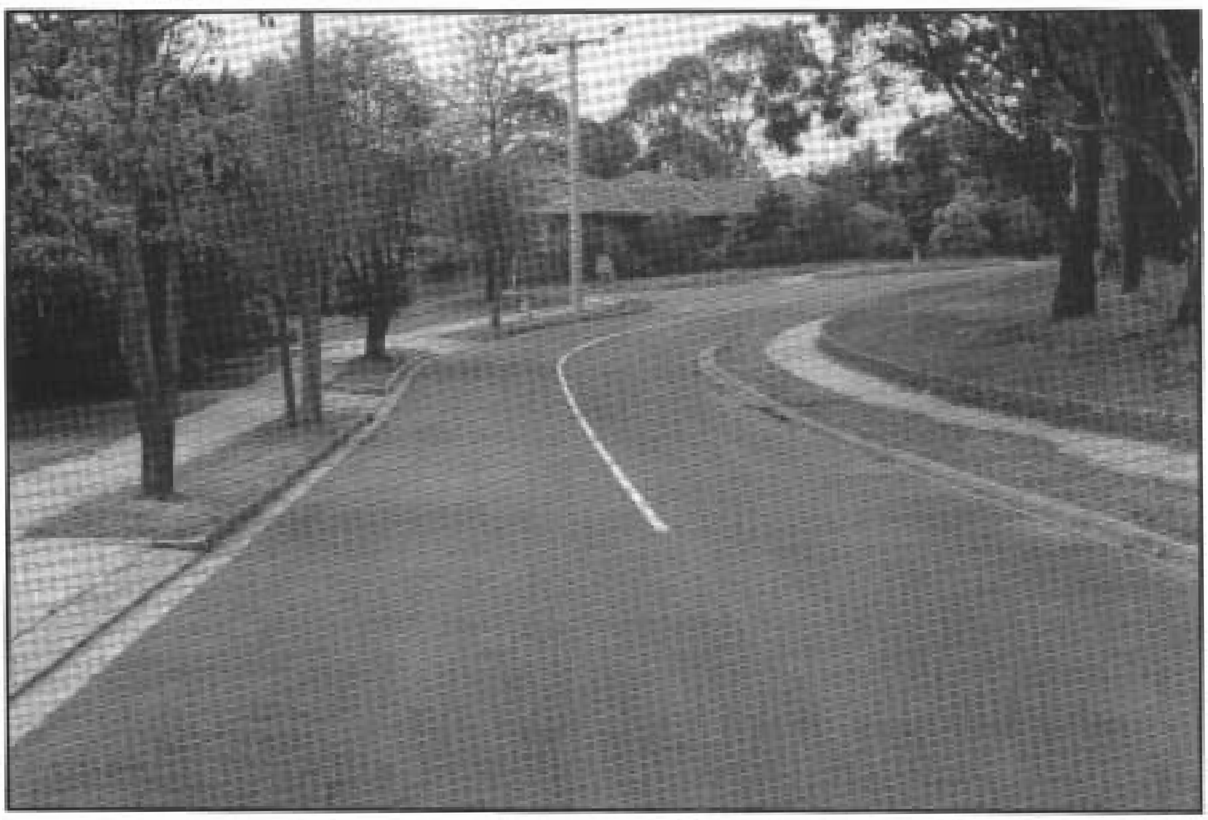

Photo 7: Treatment Site ***6:*** Left curve on Finlayson st., **Rosanna.**
(approach from North)

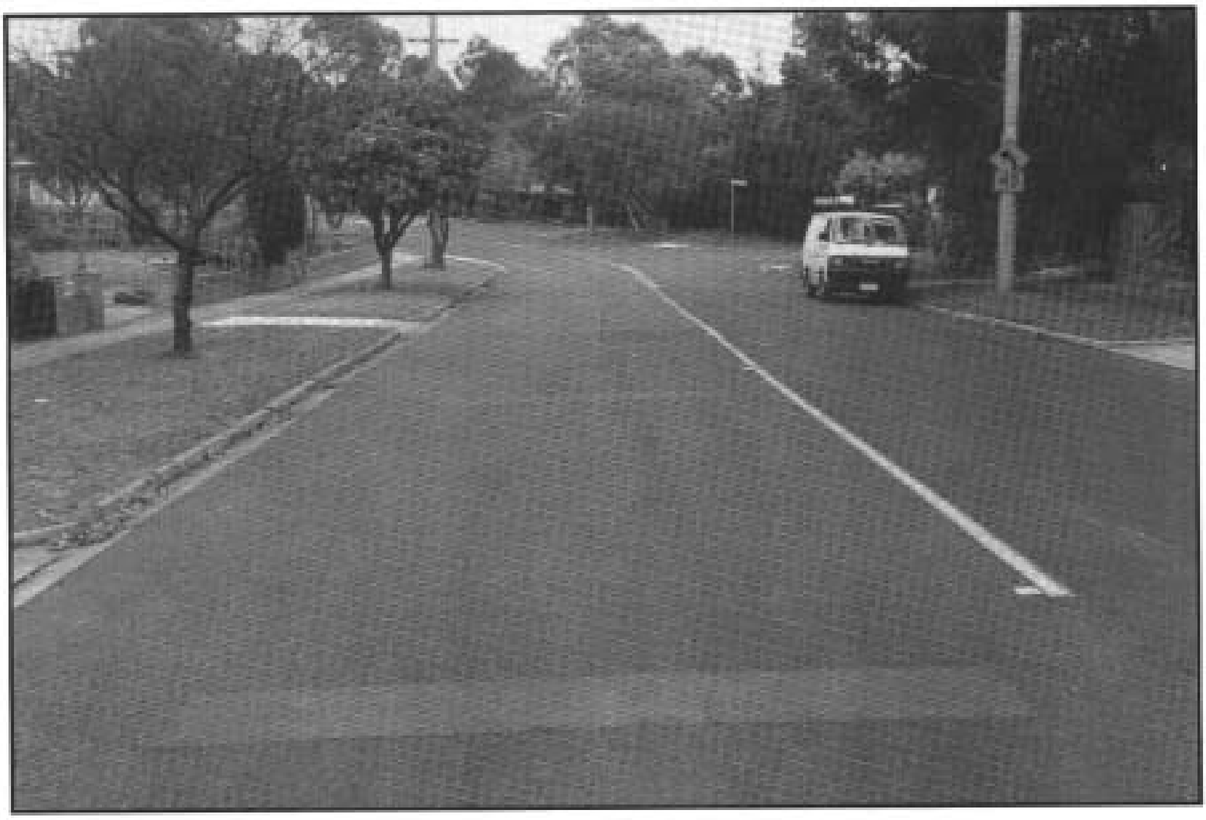

Photo 8: Control Site ***6:*** Left curve on Banyule **rd..** View Bank.
(approach from West-North-West)

2.1.3 Procedure

There were 24 participants in the road experiment comprising equal numbers of males and females, with an average age of **29.8** years and a range of **22** to 52 years. All participants were paid $10 for their test time. Each participant was driven individually to the Heidelberg test area by car which took approximately 35 minutes. At start point at Banksia Park, the participant was given the instructions (seen in Appendix) to read and at the same time was played a tape recording in the car's stereo of the same material spoken in the experimenter's voice. The instructions told participants to drive as they normally would in these conditions.

An observer was seated in the front passenger seat of the car to provide travel directions and act as an emergency driver. Route direction instructions were pre-determined and were provided at fixed locations including where to turn, which lane to travel in on multi-lane roads and where to exit from roundabouts. **An** ARRB Transport Research technician was seated in the back seat of the car directly behind the driver to maintain the data logging equipment and monitored its performance through a note book computer.

Participants practiced driving the car for 6km (approximately 11 minutes) before they started the test route to familiarise them with the car's handling and the experimental setup. The practice drive included one rumble strip treatment on a left-hand curve to ensure that the first treatment site would not be a totally novel experience for the participant. Towards the end of this time the participant was asked if he or she was comfortable at driving the car (if they were not, a longer practice was available, although this proved unnecessary).

The test drive then commenced which took between **40** and 50 minutes, depending on the driver and the traffic circumstances along the route. **As** the car approached a test site, the experimenter signalled to the technician by activating a light switch out of sight from the participant. Signals were given at the start and stop lines of each site. When the route was completed, the participant drove back to the starting point where he or she was picked up and delivered back to the University.

Five participants responses were subsequently eliminated from the experiment because of unnatural impairments that occurred during the experiment at either the control and/or the treatment sites. These included abnormal traffic or traffic manoeuvres (such as having to slow down or swerve from the normal travel path) or pedestrian behaviour that unduly affected the performance of the participant. In all cases, elimination decisions were made without any reference to their data.

2.2 DATA ANALYSIS

The data for experiment 1 was collected at a rate of 30Hz for each dependent variable at each of the 12 sites for each participant. **As** time was not constant between control and treatment sites nor between participants at the same site, this data was transformed so that each participant received an average for each dependent variable ***for each one metre of travel.*** In addition, two derived variables were constructed namely longitudinal deceleration and lateral placement which included a measure of the rate of change within each metre of distance travelled. This was calculated as the absolute difference between the largest value of a particular variable within a one metre distance and the smallest value also within that one metre distance. These two new variables will hereafter be referred to as longitudinal deceleration change and lateral placement change (respectively).

On examination of the steering wheel angle and **YAW** data, it was apparent that the road characteristics of the actual curve at the treatment and control sites were not similar enough in terms of curvature and radius to include data collected in the actual curve itself in the analysis. Moreover, as perceptual treatments should theoretically affect speed choice on the approach to the curve rather than on the actual curve itself, it was decided only to use the approach data to the curves and roundabout. Given the emphasis on performance in the approach to the curves, it was decided that the right curve site **3** was not appropriate for the analysis because the treatment site had only six metres of rumble lines in the approach zone. Six metres was not sufficient for a driver to react to adequately and was not a suitable distance for comparing pre-rumble with rumble effects.

2.2.1 Primary Variables

The amount of data collected from the number of dependent measures was considerable and somewhat overwhelming (the full range of measures were included because they were available and provided a degree of insurance and redundancy). **As** the variables of speed, braking, deceleration and lateral position were the ones of primary interest, it was decided to only use these in subsequent analysis (data on lateral acceleration, **YAW,** and steering wheel angle were not analysed in this report but are available for subsequent use).

2.2.2 Data Management

Real world experimentation always presents difficulty in controlling for the effects of extraneous factors. For instance, examination of the speed and longitudinal deceleration data plots suggested that for the left curve (site **5),** the initial speeds for the treatment and control sites were not similar enough to include this site in the final analysis. This was most likely due to the fact that at the treatment site, a roundabout preceded the curve and participants still seemed to be accelerating to some degree in the approach zone. The difference in speeds between treatment and control for the first 23 metres measured (some **22** metres behind where the rumble strips started at the treatment site) was 6.26km/h or more than 3 times that of the other sites). **A** prime assumption for the validity of the comparison of treatment and control sites was that the initial speeds measured would be the same. Thus, in the final analysis, only 5 of the 6 sites were included, namely a stop sign, a roundabout, two right-hand curves, and one left-hand curve.

For the stop sign and roundabout sites, the longitudinal variables of speed, longitudinal deceleration and deceleration change, and brake behaviour were appropriate for analysis. For the curve sites except for site 4, lateral placement and lateral placement change were also included. (Site 4 could not include lateral placement because of an inadequately faint centreline in the second measurement sector. However, Site 4 was able to include lateral placement change in the analysis, although these results need to be treated with caution).

The data for every metre was further transformed into 4 sectors, with each participant receiving a mean value for each dependent variable for each sector. **As** can be seen in Figure 2.2, the third and fourth sectors were made up from the **first** and second half (respectively) of the rumble areas (and the control site equivalent areas) on the approaches to the stop sign, roundabout and the two remaining curves. The end of the fourth sector was the stop line, roundabout giveway line, or the beginning of the curve respectively.

Figure 2.2: The lay-out of the four distance sections used for each site.

The distances for these sectors differed across sites, depending on the actual length of the rumble area and are shown in Table **2.3** below. The length of the first two sectors used for each site were approximately equal in length to the rumble area sections. For the stop sign approach (Site **1**) and left curve approach (site ***6)***, the first two sectors were **45** metres before the rumble lines at the treatment site with an equivalent area for the control site (site ***6*** could not be longer than this because of restrictions with lateral placement indicator on the rear of the vehicle). For the roundabout approach (site 2) and right curve approach (site **4),** the first two sectors comprised ***30*** metres prior to the rumble area.

Table 2.3: Distances for the sectors used in experiment I data analysis.

Sector	Stop Sign (Site 1)	Roundabout (Site 2)	Right Curve (Site 4)	Left Curve (Site 6)
1 (non-rumble)	23m	15	15m	23m
2 (non-rumble)	22m	15m	15m	22m
3 (rumble)	22m	15m	16m	26m
4 (rumble)	21m	14m	15m	25m

2.2.3 Analysis Procedure

The main analysis involved a two-way repeated measures univariate Analysis of Variance **(ANOVA)** for each of the dependent variables used for each particular site. This was carried out using SPSS (Statistical Package for the Social Sciences) for Windows repeated measures program. This runs repeated measures with a MANOVA (multivariate ANOVA) command but uses a mixed-model approach. The first factor was type of site (treatment or control) and the second factor was the distance sectors, containing ***four*** levels.

For each variate, two **sets** of ***planned*** orthogonal main effect contrasts (for the two factors) and interactions were used. Out of these, only the ***site main effect*** and the ***interaction*** contrasts are of interest in terms of interpretation of the effect of the perceptual treatment. The ***site main effect*** contrast was simply the difference between the treatment and control site averaged across the **4** distance sectors. The ***distance sector main*** effect contrasts tested the difference between the first sector and the remaining sectors, the difference between the second sector and the third and fourth sector, and the difference between the third and fourth sectors, all averaged across the two types of site. The ***interaction*** contrasts enabled the analysis to test whether any differences between the treatment and control sites which occurred did so starting in the first half of the rumble approach area, in the second half of the rumble approach, or in the first half of the rumble area. The contrasts are listed in Table **2.4.**

Analysis	Contrast **Coefficients**
Distance sector main effects	3 -1 -1 -1
(1 2 3 4)	0 2 -1 -1
	0 0 1 -1
Site **by** Distance interactions	3 -1 -1 -1 -3 1 1 1
(C1 C2 C3 C4 T1 T2 T3 T4)	0 2 -1 -1 0 -2 1 1
	0 0 1 -1 0 0 -1 1

Reporting of these statistics below will, unless otherwise specified, always occur in the order of the Site Main Effect first, followed by the three Interaction contrasts in the order specified in Table **2.4.** The Distance Main Effect contrasts will not be described.

The fact that all contrasts were orthogonal and planned (on an ***a priori*** basis), meant that no adjustment of the alpha level was needed on the individual variate level to control for type one error rates as a decision wise error rate could be used. However, since more than one dependent variable was used for each site, each contrast for a particular variate was ***not*** orthogonal to the same contrast on another variate, meaning that a family-wise error rate was needed to control for type one error rate across all the variates. Thus, the alpha level of 0.05 was adjusted using the Bonferroni decision rule of dividing α by the number of variates used at that site, namely 4 for sites 1 and 2 ($P \leq$ **0.0125** for significance), *6* for site *6* ($P \leq 0.0083$ for significance), and **5** for site **4** (due to the lack of lateral placement data analysis noted above) ($P \leq 0.01$ for significance).

However, as argued by Miller (1981), the decision of what constitutes a natural family is not in agreement between all statisticians or researchers, and is not governed by any stringent criteria which can necessarily be applied to all situations all of the time. He argues that the trade-off between the benefits of the tight control of type one error rates and unnecessary loss of sensitivity ultimately must he left up to the particular experimenter in the particular situation The purpose for which the results of an experiment are to be used is one important consideration. The two extremes cases are the search type experiment concerned with discovering leads to be pursued further, and the definitive experiment where the conclusions are drawn and reported. The former would warrant according to Miller **(1981)** a less-conservative decision of what constitutes a family compared to the latter.

The current experiment lies in between these extremes, but more towards the former. It was therefore decided to adopt an appropriate family in-between the two extremes as well.

Borrowing from Keppel (1991), three decision types were used instead of the usual two where:

- a *significant* result was one which was significant using the Bonferroni adjusted family-wise error rate;
- a *non-significant* result was one which was non-significant using the decision-wise error rate; and
- a decision of *judgement* ***reserved*** applied for those results which were significant using the decision-wise error rate but non-significant using the Bonferroni adjusted family-wise error rate.

2.3 RESULTS

2.3.1: Statistical Critical Values

Site 1 - STOP SIGN APPROACH: The stop sign approach was analysed using the four dependent variables of speed, brake action, longitudinal deceleration, and longitudinal deceleration change. The distance factor used comprises four distance sections, namely two non-rumble sections (23m for section 1 and 22m for 2), and two rumble areas (22m for section **3** and 21m for 4). Data from 19 participants were included in the sample for this site, producing for the planned orthogonal contrasts a critical F value of $F_{0.05;1,18}$ = 4.414 (or $p \leq 0.05$) for the decision-wise error rate and $F_{0.05/4;1,18}$ = 7.698 (or $p \leq 0.0125$) for the Bonferroni adjusted family-wise error rate (adjusting for the 4 variates used).

Site 2 - ROUNDABOUT APPROACH: **As** with the stop sign approach, the roundabout approach was analysed using the four dependent variables of speed, brake action, longitudinal deceleration, and longitudinal deceleration change. It also uses four levels for the distance factor, two non-rumble sections at **15** metres each and two rumble areas at 15m and 14m respectively. Due to eliminated participants, 19 remained in the sample for this site, producing for the planned orthogonal contrasts a critical F value of $F_{0.05;1,18}$ = 4.414 (or $p \leq 0.05$) for the decision-wise error rate and $F_{0.05/4;1,18}$ = 7.698 (or $p \leq 0.0125$) for the Bonferroni adjusted family-wise error rate.

Site 4 - RIGHT CURVE: Five dependant variables were used for the right curve as for the first two sites plus lateral placement change (lateral placement data was not processed due to missing data). There were four distance sections, the two pre-rumble sections at 15 metres each, and two rumble areas of 16m for section 3 and 15m for section 4. One participant was eliminated at this site, bringing the total to 23 and producing a decision-wise error rate of $F_{0.05;1,22}$ = 4.301 (or $p \leq 0.05$) and a Bonferroni adjusted family-wise error rate of $F_{0.05/5;1,22}$ = 7.95 (or $p \leq 0.01$).

Site 6 - LEFT CURVE: All six dependant variables were used for this site. The four distance sections were made up of the two non-rumble sections (23m and 22m), and two rumble sections of 26m for section 3 and 25m for section 4. Twenty participants remained for this site, producing a Hays decision-wise error rate of $F_{0.05;1,19}$ = 4.38 (or $p \leq 0.05$) and **a** Bonferroni family-wise error rate of $F_{0.05/6;1,19}$ = 8.68 (orp ≤ 0.0083).

2.3.2 Speed Results

The speed results obtained for the stop and roundabout intersections and the left and right curves are shown in Figures **2.1** to **2.4** opposite and described below.

***Figure 2.1 - STOP SIGN APPROACH* : As** suggested in Figure **2.1,** when averaged across the **4** distance sectors, the treatment site speed was significantly slower **(37.02** *kmh)* than the control site speed **(40.06** km/h) **($F_{1,18}$ = 15.39, *p* < 0.001).** There was also a significant interaction in that the treatment speed was slower than the control speed during the last three distance sectors but not during the first distance sector **($F_{1,18}$ = 31.21, *p* < 0.001).** The change in speed between the treatment and the control site in the last three sectors was approximately **5km/h.** The other two interactions were not significant **($F_{1,18}$ = 1.47, *p* = 0.241** and $F_{1,18}$ = 2.37, ***p* = 0.141** resp.).

Figure* 2.2 - *ROUNDABOUT APPROACH : There was no overall difference in speed between roundabout treatment **(41.04 km/h)** and control site **(41.13 km/h)** in the approach zone when averaged across the four distance sectors **($F_{1,18}$ = 0.36, *p* = 0.558).** However, each of the sectors had significant interactions. Speed at the treatment site changed from being faster than the control speed during the first section, to being slower than control speed averaged over the last three sections **($F_{1,18}$ = 30.39, *p* < 0.001),** and from faster at the second section to slower than control speed in the rumble area **($F_{1,18}$ = 12.91, p = 0.002).** The treatment site speed was also significantly slower than the control site during the second half of the rumble area than it was during the first half **($F_{1,18}$ = 11.56, *p* = 0.003). As** can be seen in Figure **2.2,** this third interaction is the cause of the first two interactions above.

Figure 2.3 - RIGHT CURVE: There was no overall difference between the mean treatment site speed **(52.85 km/h)** and mean control site speed **(51.68** *kmh)* ($F_{1,22}$ = 0.80, ***p* = 0.381).** The treatment site was significantly faster than the control site during the first section than it was during the final three sections **($F_{1,22}$ = 22.69, *p* < 0.001),** and a decision reserved result is given to the apparent relative faster treatment speed in the second half than in the first half of the rumble area **($F_{1,22}$ = 6.75, *p* = 0.016,** judgement reserved). There was no interaction with the second section and the final two **($F_{1,22}$ = 0.89, p = 0.357).**

Figure 2.4 - LEFT CURVE : There was no significant overall difference between the treatment site speed **(59.2** *kmh)* and the control site speed **(60.40 km/h) ($F_{1,19}$ = 1.90, *p* = 0.185)**. However, the treatment speed was significantly slower than the control speed during the last three sections compared to the first section **($F_{1,19}$ = 48.89, *p* < 0.001), as** well as during the last two sections compared to the second section **($F_{1,19}$ = 52.01, *p*** < 0.001). The last section on the left curve approach also has relatively slower treatment site speed than the first half of the rumble area **($F_{1,19}$ = 12.53, *p* = 0.002).**

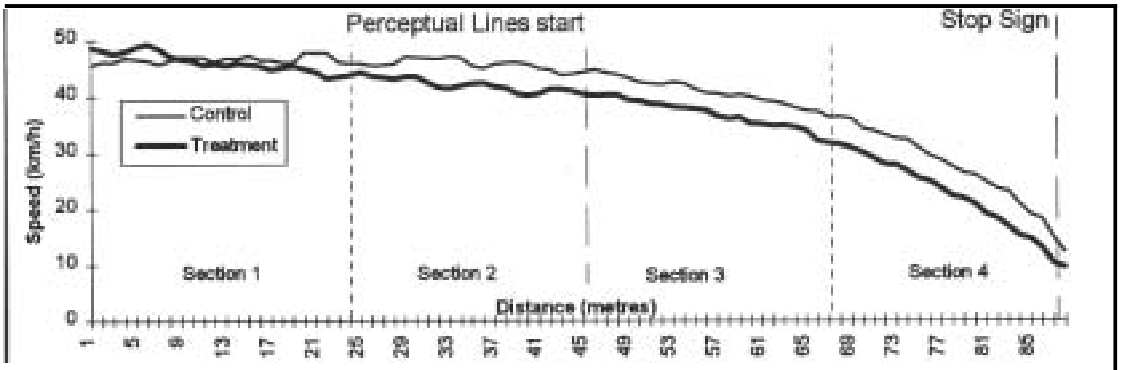

Figure 2.1: Speed at the Stop Sign Approaches

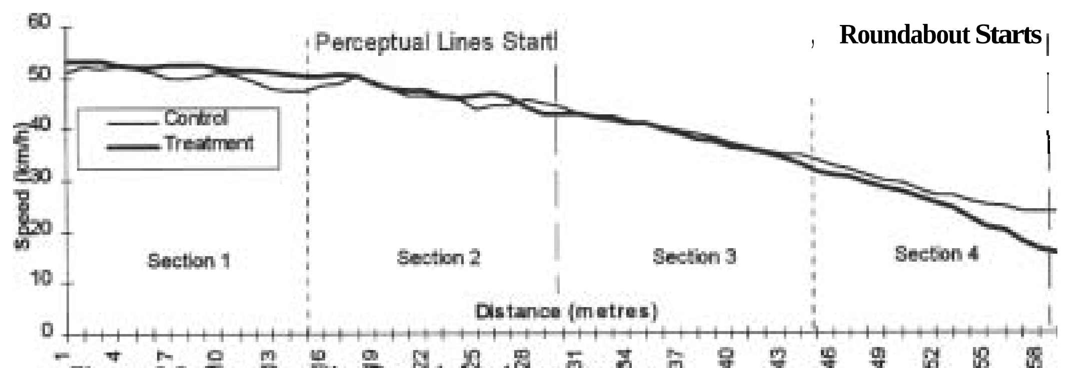

Figure 2.2: Speed on the Roundabout Approaches

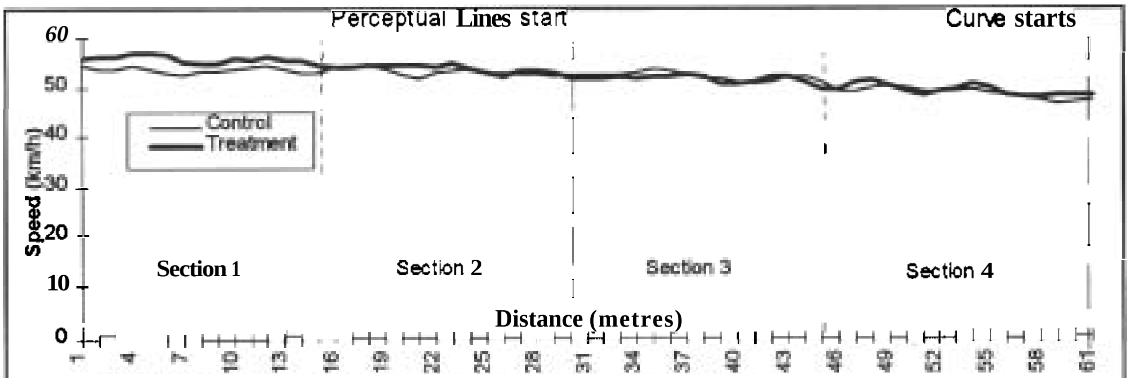

Figure 2.3 Speed on approach to the Right Curves (Site 4)

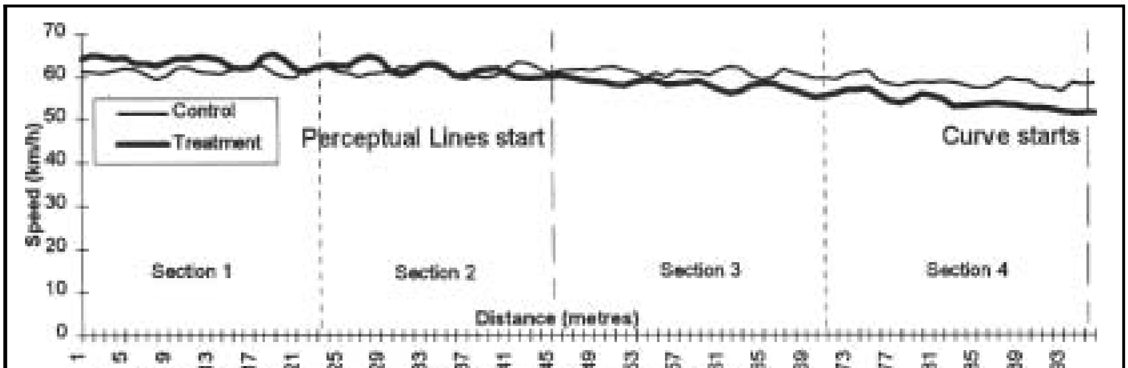

Figure 2.4: Speed on approach to the Left Curves (Site 6)

2.3.3 Brake Activity

The results for the level of brake activity (i.e., when the brake was either on or *off)* are shown in Figures **2.5** to **2.8** opposite and described below.

Figure 2.5* - *STOP SIGN APPROACH* :** There was no significant difference between the amount of braking during the approach to the treatment and control **stop** signs ($F_{1,18}$ = 0.00, ***p*= 0.956).** The was also no suggestion of a significant interactions between the treatment and control braking over the four sectors ($F_{1,18}$ = 0.31, *p* = **0.585,** $F_{1,18}$ = 0.13, *p* = **0.723** and $F_{1,18}$ = **1.72,p* = **0.206** resp.). Thus, the presence of the treatment did not influence the amount of braking at this site.

***Figure 2.6* - *ROUNDABOUT APPROACH* :** Participants applied the brake for a significantly greater proportion of the approach to the treatment than the control roundabout (89% cf. **78%,** $F_{1,18}$ = **9.62,** *p* =0.006). There was no difference in the amount of brakiig observed between sectors **2** and **3** because participants continually braked throughout these sectors. Thus, it was not meaningful here to analyse the average across each of the four distance sections as with little variance, even the smallest change is statistically significant.

Figure* 2.7 - *RIGHT CURVE* :** There was no overall difference in the amount of braking between the treatment site and the control site on the approach to the second right curve ($F_{1,22}$ = 0.05, *p* = **0.829).** However, more braking did occur at the treatment site relative to the control in the first sector than in the final three ($F_{1,22}$ = **9.37,** p = 0.006). There was also less braking in sections 3 and 4 at the treatment site where there would have been rumble effects than the control site but more braking during section **2** (i.e., a significant interaction was observed, $F_{1,22}$ = **21.76,** ***p < 0.001). There was no difference between the final two sections ($F_{1,22}$ = 1.96, ***p*** = 0.176).

Figure 2.8* - *LEFT CURVE* :** There was also significantly more braking overall at the treatment than the control site for the left-hand curve ($F_{1,19}$ = 55.01, *p* < 0.001). However, this excessive braking was greater in the first sector than the final three ($F_{1,19}$ = **22.21,** *p* < 0.001), in the second sector compared to the final two (rumble) sections ($F_{1,19}$ = **29.82,** *p* < 0.001) and in the third sector compared to the final one ($F_{1,19}$ = **10.58,** ***p = 0.004).

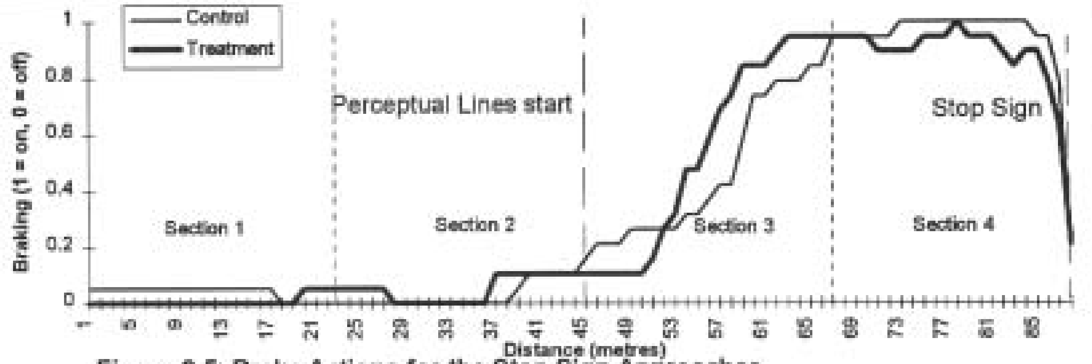

Figure 2.5: Brake Actions for the Stop Sign Approaches

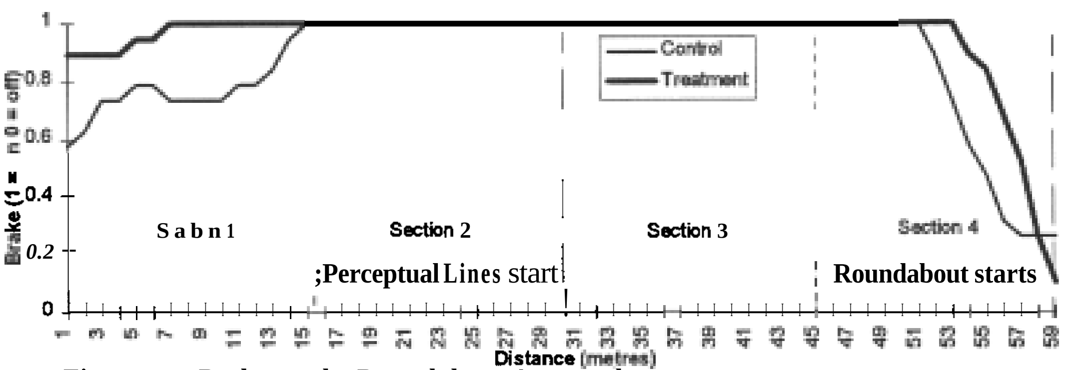

Figure 2.6: Brake on the Roundabout Approaches

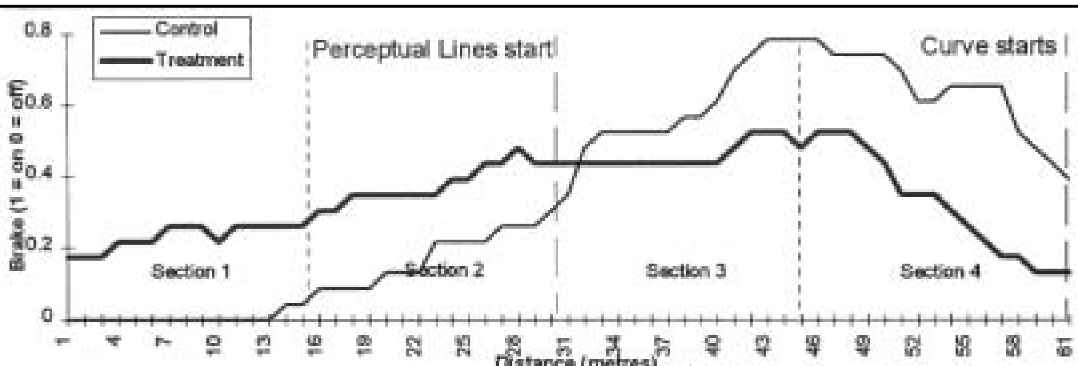

Figure 2.7: Brake on approach to the Right Curves (Site 4)

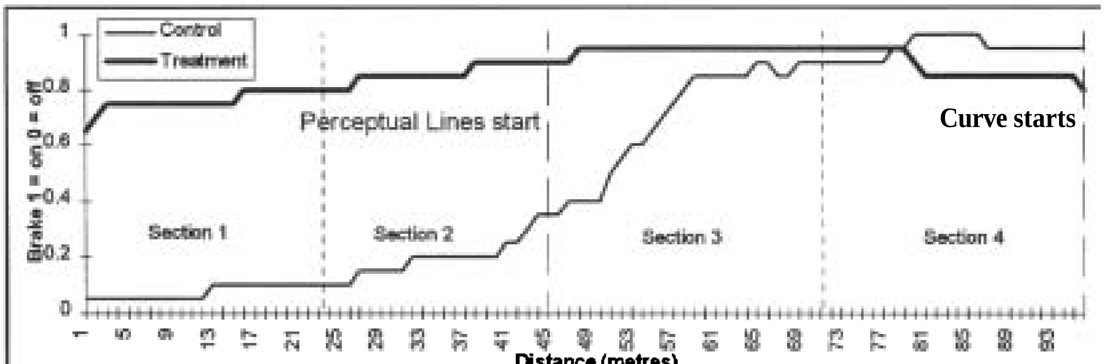

Figure 2.8: Brake on approach to Left Curves (Site 6)

2.3.4 Deceleration

The deceleration findings for the stop and roundabout intersections and the left- and right-hand curves are shown in Figures **2.9** to **2.12** opposite and described below,

Figure 2.9* - *STOP SIGN APPROACH **:** There was significantly greater deceleration in the approach to stop sign at the treated site than its control **($F_{1,18}$ = 9.69, p = 0.006).** This was especially more pronounced during the first distance section compared to the other three sections combined **($F_{1,18}$ = 6.33, p = 0.022).** The other two sector interactions were *not* significant ($F_{1,18}$ = 1.23, p = **0.282** and $F_{1,18}$ = 1.10, p = **0.308** resp.).

Figure 2.10 - ROUNDABOUT APPROACH **:** There were significantly higher decelerations overall at the treatment site compared to the untreated control for the roundabout intersection ($F_{1,18}$ = 71.47, $p < 0.001$). Deceleration was significantly larger during the second half of the rumble area compared to the first half ($F_{1,18}$ = **8.56,** p = 0.009), although there were no other significant interactions ($F_{1,18}$ = 0.02, p = **0.896** and $F_{1,18}$ = 0.36, p = **0.556** resp.).

Figure 2.11 - RIGHT CURVE **:** No differences were found in deceleration rates overall between the treated and control sites for the right-hand curves **($F_{1,22}$ = 0.84, p = 0.370).** There was, however, significantly more deceleration at the treatment site relative to its control during the first section than the final three **($F_{1,22}$ = 34.96, p $<$ 0.001)** and the second sector compared to the final two **($F_{1,22}$ = 23.35, p $<$ 0.001).** Interestingly, there was less deceleration in the second half of the rumble area at the treatment site relative to the control than there was in the first half of the rumble area **($F_{1,22}$ = 8.23, p = 0.009).**

Figure 2.12 - LEFT CURVE **:** Contrary to the right-hand result, there was a greater amount of deceleration overall at the treatment site than the control for left-hand curves **($F_{1,19}$ = 46.12, $p < 0.001$).** While there was an apparently larger relative treatment deceleration in the first section compared to the final three sections combined ($F_{1,19}$ = 4.91, p = 0.039), this was only at a reserved judgement level. There was however a more significantly amount of deceleration at the treatment site relative to its control in the second sector than the final two (rumble) sections ($F_{1,19}$ = 11.34, p = 0.003), and in the first half of the rumble area compared to the second half **($F_{1,19}$ = 8.97, p = 0.007).**

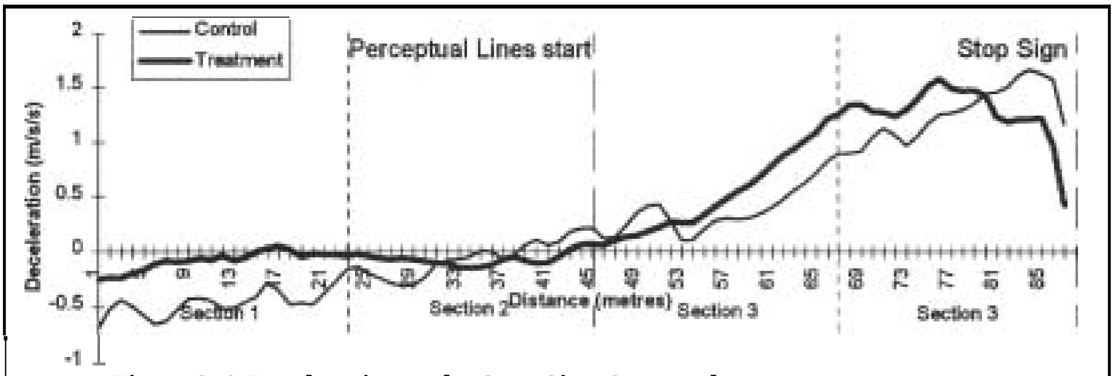

Figure 2.9 Deceleration at the Stop Sign Approaches

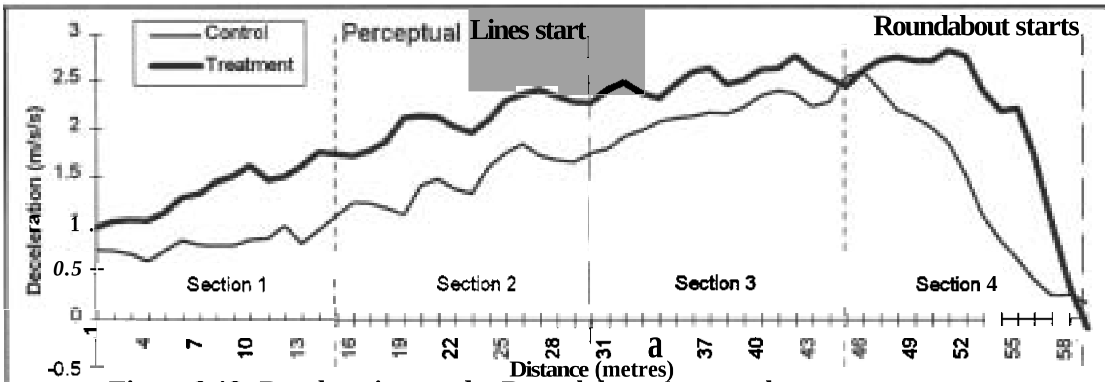

Figure 2.10: Deceleration on the Roundabout Approaches

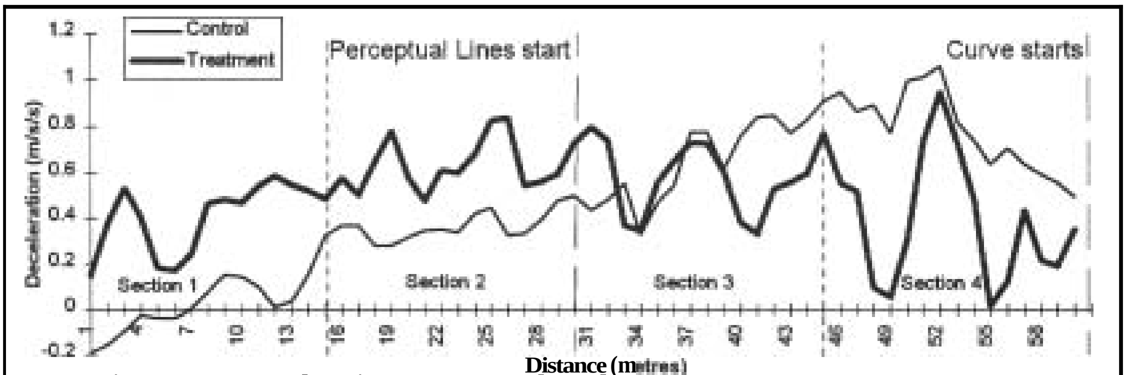

Figure 2.11: Deceleration on approach to the Right Curves (Site 4)

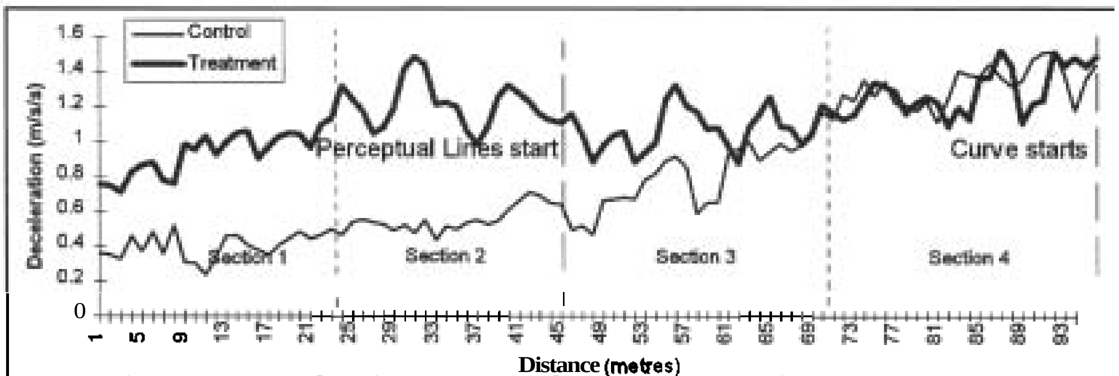

Figure 2.12: Deceleration on approach to Left Curves (Site 6)

2.3.5 Deceleration Change Per Metre

As noted earlier, it was also possible to analyse the deceleration results in terms of the amount of deceleration change per metre between the treated and untreated control sites at each of the four location types. These results are illustrated in Figures 2.13 to 2.16 opposite and described below.

Figure 2.13 - STOP SIGN APPROACH **:** There was more deceleration change per metre overall at the treatment stop sign approach than at the control site ($F_{1,18}$ = 200.67, $p < 0.001$). In addition, there was also more deceleration change at the treatment site in the rumble area (sectors 3 and 4) than in the previous sector 2 ($F_{1,18}$ = 93.84, $p < 0.001$). There was also more deceleration change at the treatment site in the final three sectors compared to the first ($F_{1,18}$ = 85.25, $p < 0.001$) and in the third compared to the fourth sector ($F_{1,18}$ = 61.68, $p < 0.001$).

Figure 2.14 - ROUNDABOUT APPROACH **:** There was more deceleration change per metre overall at the treatment site than at its control on the approach to the roundabout ($F_{1,18}$ = 12.93, $p = 0.002$). The deceleration change in the rumble area (sectors 3 and 4) was again higher than in sector 2 for the treatment site compared to the control ($F_{1,18}$ = 62.14, $p < 0.001$) and similarly in first sector compared to the other three ($F_{1,18}$ = 25.90, $p < 0.001$). Moreover, the greater treatment site deceleration change for each metre was greater in the fourth sector than it was in the third ($F_{1,18}$ = 11.21, $p < 0.004$).

Figure 2.15 - RZGHT CURVE : The overall deceleration change per metre was greater at the treatment approach to the right-hand curve than the untreated one ($F_{1,22}$ = 80.44, $p < 0.001$). Significantly more deceleration change per metre occurred for the treatment site during the final three sectors than in the first ($F_{1,22}$ = 45.04, $p < 0.001$), during the second sector than the final two ($F_{1,22}$ = 10.52, $p = 0.004$) and for the final sector over the third ($F_{1,22}$ = 85.86, $p < 0.001$).

Figure 2.16 - LEFT CURVE **:** There was also significantly more deceleration change per metre at the treatment site than the control site overall ($F_{1,19}$ = 112.66, $p < 0.001$) with greater deceleration change at the treatment site relative to the control during the final three sections than the first section ($F_{1,19}$ = 44.55, $p < 0.001$) and for the final two sections than the second section ($F_{1,19}$ = 39.32, $p < 0.001$). There was, however, no interaction between the final two sections at **this** location ($F_{1,19}$ = 1.08, $p = 0.311$).

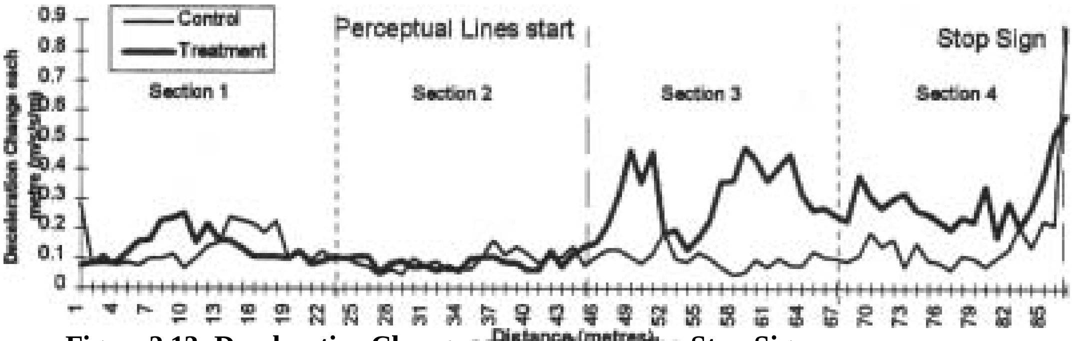

Figure 2.13: Deceleration Change each metre on the Stop Sign Approaches

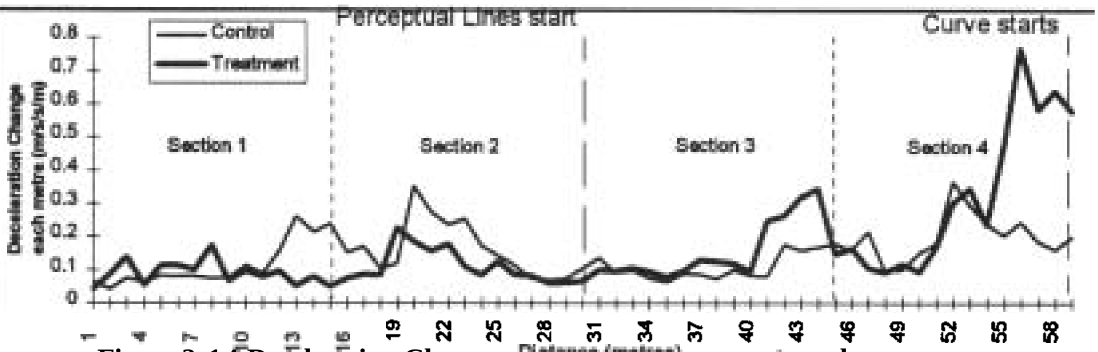

Figure 2.14 Deceleration Change each metre on approach to the Roundabouts (Site 2)

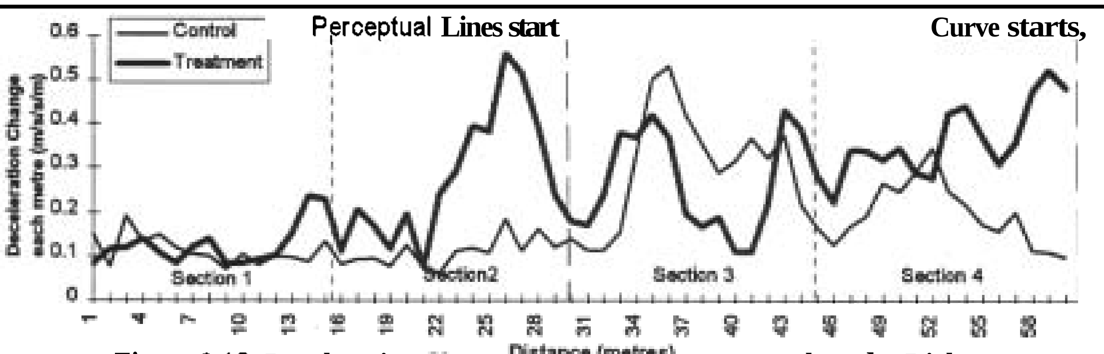

Figure 2.15: Deceleration Change each metre on approach to the Right Curves (Site 4)

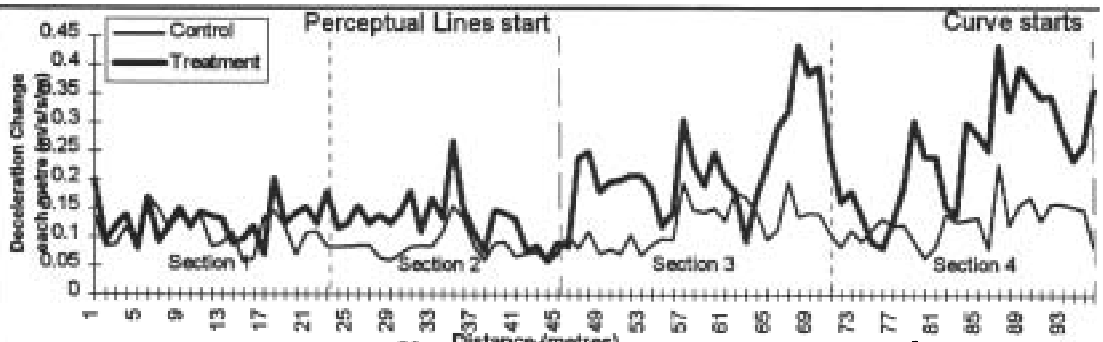

Figure 2.16: Deceleration Change each metre on approach to the Left Curves (Site 6)

2.3.6 Lateral Placement

The final analysis examined the lateral placement differences between the treated and control sites at left- and right-hand curves and these findings are shown in Figures **2.17** and **2.18** opposite and described below.

Figure 2.17 - RIGHT CURVE **:** Lateral placement findings for right-hand curves needed to be interpolated for missing data at the control site due to gaps and the faintness of the centreline and were not analysed statistically. However, there was a hint that lateral placement was further from the centreline in the approach to the curve for the treated site than it was for the control. This finding should be treated with extreme caution given the lack of statistics.

Figure 2.18 - LEFT CURVE: The distance from the centreline at the treatment site was significantly greater than at the control (**$F_{1,19}$ = 7.21, p** = 0.016). However, there were no interaction effects observed here ($F_{1,19}$ **= 1.75, p = 0.204,** $F_{1,19}$ **= 0.77, p = 0.393** and $F_{1,19}$ = 0.06, p = 0.804 resp.).

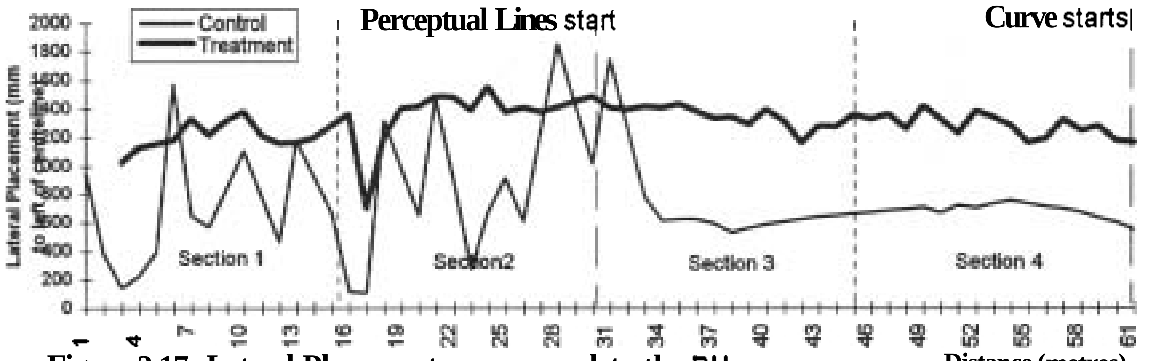

Figure 2.17: Lateral Placement on approach to the RH curve (Site 4) (with interpolation for missing data)

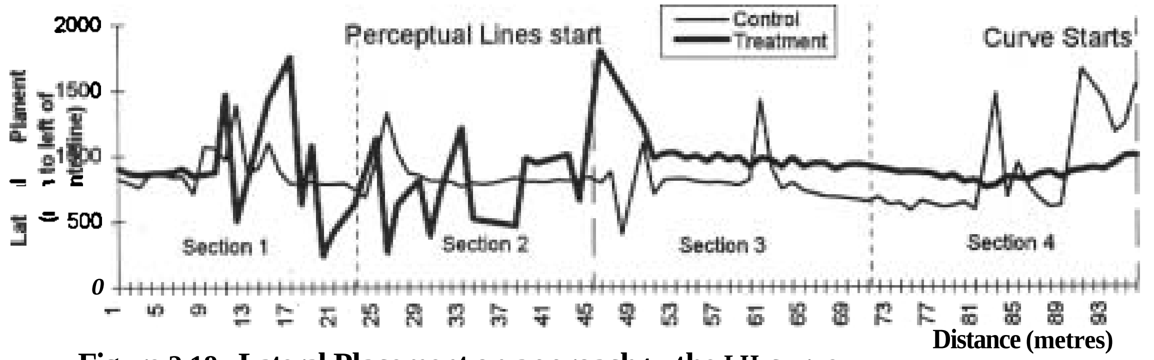

Figure 2.18: Lateral Placement on approach to the LH curve (Site 6) (with interpolation for missing data)

2.4 DISCUSSION

The road trials were conducted primarily for comparison with a similar set of trials in the driving simulator to validate the simulator as a legitimate test environment for perceptual countermeasures. However, the results of the road trial analysis, themselves, reveal important differences observed in driving performance on the road for transverse lines placed on the approach zone to stop and roundabout intersections as well as on left-hand and right-hand curves in suburban roads. These differences are discussed in terms of the principal measures taken during the road trials. The validation analysis is reported in Chapter **4.**

2.4.1 Speed

Approach speeds to the stop sign intersection were slower for the those where transverse lines were present than when not. Most of this difference occurred 15 metres prior to commencement of the lines as well as in the line zone itself. This suggests that the transverse lines are causing drivers to slow down more than they normally would and therefore likely to have a positive safety effect. There were also speed differences observed in the approach zone to the left- and right-hand curves. For the right-hand curve speed differences were **only** apparent immediately before commencement of the treatment and were not robust in the treated zone leading into the curve itself. The left-hand curve, however, did have significantly slower speeds in the treatment zone and did get progressively slower across all four sections, compared to the control site speeds,

The fact that there was no speed difference at the roundabout intersection until the final 15 metres before the give-way line is curious as a similar pattern of behaviour to that observed for the stop sign intersection was expected. There were significant differences in travel speed in the treated zone however, even if not preceding it, which is consistent with similar findings from the stop sign. It would appear that in this trial, transverse lines in the approach to the roundabout had less perceptual effect than at the stop sign. This is further investigated in Chapter 5. It could be a function of the minimal length of the treated section at the roundabout as the stop sign has approximately **40%** more treatment. Alternatively, it could be because the transverse lines on the ***approach*** to the roundabout did not produce the rumble noise and vibrations as they did at the stop sign treatment site, (although the lines did produce the “rumble” when driving through the actual roundabout).

It was interesting that there were very few differences observed in travel speed **15** to **30** metres before the lines at any of the locations (right-hand curves in fact had higher speeds for the treated sites that the untreated ones) This represents a preview time of between 1 and **2** seconds ahead of the treatment. It would be expected to influence driver behaviour as other evidence suggests that drivers’ preview distance is around 1.5 seconds under normal driving conditions and this is where you would expect perceptual effects to have maximum effect. However, preview distance has not been firmly established in the approach to intersections and it could be that at these distances, drivers are more attentive to the intersection itself than the road immediately in front of them.

In summary then, it does appear that on the whole, speed is reduced by the placement of rumble lines on suburban roads, if only in the lead up ***to*** the traffic control device. This finding needs to be tempered though as most of these treatments were not optimal in terms of what is normally recommended, both in terms of amount and placement. **As** drivers in the road trial **were** new to this area and these treatments, it would also be interesting to see if these effects were apparent for local residents who travel these roads regularly.

2.4.2 Brake Activity

Braking was only recorded as whether the brake was on or off as the instrumented vehicle was not setup to record braking pressure or any other surrogate braking measure. It would be more useful for future on-road experimentation to record other aspects of braking activity as they could be more sensitive measures of braking performance. However, examining the amount of braking results was still of interest in helping to understand the ways in which perceptual countermeasures affect driving performance.

The two intersections did not display marked differences in braking behaviour between treated and untreated sites. The roundabout approach showed statistically more treatment site braking, but this was tempered by the lack of variance as all subjects at both sites braking for approximately **35** metres during the approach and hence any slight difference would be statistically significant. Thus, this result needs to be taken with a great deal of caution.

For the curve approaches, however, braking was different at the treated sites than their controls. There was more braking on the approach to the right-hand curve and less braking in the transverse line zone, compared **to** its control. The left-hand curve had more braking before and up to half-way into the transverse line area compared to its control. It seems, therefore, that drivers braked later at curves without transverse lines than those with and hence the transverse lines appear to have improved braking performance (greater safety margin) in the approach to bends in the road.

The reason why there were differences between the intersection and curve results may be explained by differences in negotiation at these locations. When approaching an intersection, braking is necessary in order to stop and give way to traffic and thus the amount of braking is a given depending on the approach speed of the vehicle. Curves, on the other hand, do not necessarily require the driver to come to a complete stop and there is more potential for the lines to influence the amount of braking required to negotiate the curve. The intersection may be enough warning itself within the short distances measured on their approach **(80** and 61 metres for stop sign and roundabout respectively) for participants to accurately judge when they needed to start braking.

However, this does not mean that drivers did not choose to take more caution on an intersection approach when rumble lines were present (which in fact the speed and deceleration data suggest they did), but rather shows that caution may have been manifested in other ways than using the foot brake, such as allowing the engine to do some of the braking. It is interesting to note that the widespread use **of** transverse lines has been on the approach to intersections rather than in curves which opens the possibility of more general use of these speeding countermeasures.

2.4.3 Deceleration

Greater decelerations overall were observed in the approaches to both the stop and roundabout intersections at the treated sites. This confirms the above that more caution was indeed taken at the treatment intersection approaches as the participants started to slow down earlier than they did when no transverse lines were present. **As** suggested earlier, this was not achieved by using the brake, and so must have occurred through less throttle.

At the stop intersection, the treated site also had greater deceleration during the first section compared to the other three than its control did. By contrast, there were actual accelerations recorded in the first section of the untreated stop intersection site. **This** might suggest that the road conditions **58** metres before the stop sign at the control site were different to those at the treatment site. Alternatively, as both sites were on upwards slopes, acceleration could be expected during the first section, and so it is possible that the treatment site participants were in fact taking greater caution and starting to decelerate from over **25** metres away from where the transverse lines started.

At the approach to the treated roundabout, deceleration was intensified during the second half of the treated area relative to the first. This suggests that apart from approaching the intersection more cautiously over the whole 60 metres, the final deceleration up to the stop line was also greater initially but then dropped off suddenly when transverse lines were present. At the untreated roundabout, there was a more uniform deceleration pattern in the approach to the stop line. This result should not be interpreted in terms of how comfortable the participants felt with or without the raised rumble lines as, in fact, the lines at this location were only paint in the approach zone (they had to be supplemented prior to the on-road trials as they did not exist initially and it was not possible to get the normal plastic sections fitted in time). This last minute deceleration is also reflected in the speed results for the roundabout.

The approach to the treated right-hand curve did not yield greater decelerations over the whole distance. **As** was the case for braking, this may have been due to greater deceleration occurring for the treatment site during the approach to the treated area itself and greater decelerations for the control site during the equivalent treated area (in particular the last half of the equivalent treatment area). Thus, the greater deceleration 30 metres preceding the treated area for the treated site meant that there was less scope for decelerations closer to curve entry.

The left-hand curve, however, did show greater treatment site deceleration overall. The interactions also suggested that greater deceleration occurred for the whole approach as well as the first half of the treatment area. Deceleration at the control site only occurred in the second half of the equivalent line area (that is, immediately preceding the start of the curve). By this time however as argued above, the speeds at the treatment site were significantly lower than the control site, so the matched deceleration immediately preceding the curve means little as a greater speed reduction was already reached at the treatment site.

In summary, the results from both curves show that transverse lines lead to greater initial decelerations and a much smoother curve negotiation pattern overall. While it could be argued that some of this may have occurred because the entry speeds to the treatment curves were slightly faster than at their controls, this cannot be the sole reason behind the curve deceleration results. For the right-hand curve, the control site had a greater deceleration peak immediately preceding the actual curve, suggesting that a similar amount of deceleration was needed to safely negotiate the curve. However, as this only occurred at the last second, it does provide evidence that participants were responding perceptually to the transverse lines in the approach to these curve locations.

2.4.4 Deceleration Change Per Each One Metre

All sites produced more deceleration change each metre overall at their treatment sites than their control sites. At the two intersections, this greater fluctuations in treatment site deceleration only occurred in the treatment zone itself, and for the roundabout approach, mainly in the second half of the treatment zone. For the two curve approaches, the greater deceleration fluctuations started to occur immediately preceding the treatment area as well as during the treatment zone.

This may suggest that the rumble effect is causing some uncertainty about driving over these treatments. However, the roundabout approach where the lines where only painted also produced this effect, so it was probably the actual presence of the lines causing it rather than the presence of the rumble per se (the sudden drop-off of deceleration immediately preceding the give-way line at the treated roundabout probably also contributed to these findings during the second half of the treatment area). It could be that participants were not familiar with rumble lines and were unsure how to react to them. Even though the rumble **lines** could be driven over at any speed, the fact they made a "bump" may have caused some doubt as to what speed they could be driven over. It therefore suggests that the lines might have a direct influence on driving, which was quite possibly a conscious effect, rather than a purely perceptual one. With repeated exposure, however, this effect may be reduced.

2.4.5 Lateral Placement

As the lateral position of the car was not expected to change on straight roads leading up to the stop and roundabout intersections, **this** measure was only of relevance for the left-hand and the right-hand curve locations.

For the left-hand treated curve, drivers did move further away from the centreline than at the control curve by approximately 14cm. Because of the lack of a solid centreline in some parts of the treated and untreated right-hand curves, reliable statistical data could not be generated (although it should be noted that the patterns were generally supportive of the left-hand curve findings). There were though some differences in lateral positioning at right-hand curves with and without the treatment which might be simply due to wider lanes at the treatment sites. It is possible that the 'visual lane' outlined by the ends of the rumble lines guided driving to the curve, and as they do not extend all the way to the actual centreline, they resulted in driving further away from the centreline when they were present. In any event, the effects were not particularly physically large and there was considerable noise or imperfections in these data.

2.4.6 Extent of Treatment

It should also be noted that the small distances involved in most of these treatments (between **30** and **46** metres) are less than optimal in terms of amount and layout that would be expected to have a strong perceptual influence. Previously reported effects of these treatments such as on motorways in Britain (Helliar-Symons, **1981)** were for lines that commenced some 400 metres ahead of the intersection or curve and were of diminishing pitch. None of these conditions were present at the locations used in this study. Nevertheless, these findings do suggest that even brief transverse lines on suburban roads may have a positive effect on driving safety and may be equally relevant (or possibly more so) for curves as they are for intersections.

2.5 CONCLUSIONS

While this experiment was not designed to test whether these lines have a pure perceptual effect or not, the results here show some evidence that transverse lines can have a positive effect on driver behaviour in a suburban environment. Speed behaviour at transverse line locations, compared to untreated equivalent sites was slower earlier and greater overall in the approach to intersections and curves. Braking was affected only at curve approaches, and it would be interesting to see if there would have been differences in the intensity of braking if this could have been measured. There is also evidence from the lateral placement data that the position of the transverse line may guide a drivers road position, also in a positive direction away from the centreline.

Transverse lines appear to influence speed, deceleration and, to a lessor degree, braking behaviour well before they are physically driven over suggesting that they may well be having a perceptual effect. This will be tested further in a later experiment. Driving on the raised transverse lines did influence deceleration fluctuations, possibly due to a degree of uncertainty by drivers to these treatments. The results have implications for preview sight distance approaching intersections and curves in suburban environments:

Chapter 3 Experiment 2 - Simulator Trials with PCMs.

The second experiment set out to replicate the findings from the on-road experiment with those generated in the TAC driving simulator located at the Monash University Accident Research Centre to demonstrate if this unit was valid for use in developing perceptual countermeasures (PCMs). This unit is the most sophisticated one available in Australia at this time for undertaking this research and comes complete with **4** projector silicon graphics image generation capacity, a 180 degree front screen, a flat rear screen, **4** speaker stereo sound generating system, road sensation feedback, and a modern passenger car cabin. A photo of the view from the TAC laboratory simulator is shown in Figure ***3.0*** below.

Figure 3.0 The TAC laboratory-based driving simulator at MUARC at the left curve treatment site.

The TAC simulator images ace generated using a road environment database enhanced with other road features. For this study, it was appropriate to use the suburban database, modified to include the curves and intersections of interest here, and supplemented with the various road treatments and occasional other traffic. It was possible to replicate precisely the treatment and control sites used for the on-road trials when constructing the supplementary test database, although it was not possible to replicate the total road network used in the test route. Indeed, **as** the main interest of the study was to see if the responses elicited on the road could be replicated in the simulator, it **was** not necessary to conduct a full replica of the on-road test in the simulator.

3.1 METHOD

3.1.1 Design

As previously, the simulator experiment was also a factorial repeated measures design, using **4** sites, namely a stop sign, a roundabout, a left curve and a right curve. For each test site, a similar control site was also identified comprising the same site variables.

The main dependant variables again were speed, the level of braking (based on how hard a participant is pressing on the brake pedal) and lateral placement. From these, other dependant variables could be calculated, such as braking activity (on/off), longitudinal deceleration, longitudinal deceleration change per 1m, and lateral placement change per 1m to provide the same range of responses to those collected in the road trials. Additional dependent variables also collected here because they were available were the steering wheel angle and throttle (as a percentage of the amount of pedal depression).

The two experimental simulator routes are outlined in Appendix **C.** Both routes were driven by each participant in a counterbalanced order. While both routes used the same database, the four sites they each contained were manipulated so that the order of presentation of each site **was** equally represented as either a treatment or a control across all participants. A low level of opposing traffic was also included but not during critical test manoeuvres. Unlike the road trials, it was possible here to ensure that each of the treatment sites **was** exactly the same as their respective control site except for the existence of the transverse rumble lines.

3.1.2 Materials

VEHICLE BODY: The vehicle body used for the simulator is a standard Australian Ford Falcon sedan with automatic transmission, full controls and all standard features inside the cabin and externally. It can be "driven" as a normal car except for the side rear-vision mirrors which do not match up precisely with the projected images and therefore are not used.

IMAGE PROJECTZON: The projection system consists of four overhead mounted (Barco 700HQ) video projectors, each projecting onto its own screen. One screen is directly in front of the vehicle, and two screens are on either side at a ***60"*** angle, producing 180° front vision. The fourth screen is directly behind the vehicle, producing a rear-view mirror scene of ***60".*** Visual images are updated at a rate of 30Hz.

AUDIO SYSTEM: The 3D audio system consists of a PC compatible computer, two amplifiers and four speakers located at the comer points of the vehicle, with a sub-woofer mounted at the front of the vehicle. The computer system contains four (Alphatron) sound cards which produce the correctly spaced audio, with the closest eight sounds within the 3D space being played.

MOTION PLATFURM: **A** motion platform is located under the simulator vehicle, providing road feel for accelerating, braking, cornering, and passing over tram tracks and other raised road objects. It provides vertical movements only, meaning the usual horizontal G-force from acceleration and braking in real driving is missing. The motion platform controls the simulator vehicle's movements by three servo motors, one under each of the two front corners of the vehicle, and one in the middle of the back of the car.

COMPUTER SYSTEMS: The computer systems used for the simulator are an Onyx and an Indy, both manufactured by Silicon Graphics Inc. The computer systems have three major links: (i) they are linked to the 3 dimensional (3D) audio system, (ii) to the projection system, and (iii) to the programmable logic controller (PLC) based control system, which in turn controls the motion platform and vehicle cabin. The Simulator uses the Onyx for generating visuals for the video projectors, for controlling the 3D audio system, for handling the vehicle input and output, calculating vehicle dynamics and displaying real time performance feedback, The Indy provides graphical user interface, builds, edits and runs simulator scenarios, generates real-time performance feedback, and provides a scenario replay facility.

SIMULATOR SCENARIOS: Four simulator scenarios were used, two for practice and two for the experiment. The first practice scenario was a rural road environment involving low levels of driving difficulty. This was a wide straight road with no intersections passed, surrounded by a country background of fields and a single farm house. This was used to introduce participants to the simulator in a non-demanding way to help avoid feelings of simulator discomfort. The second practice route was a suburban setting (as were the experimental routes), with streets surrounded by houses, fences and trees, **as** well as a squash centre, school and petrol station, and included a give-way with the rumble bar treatment. No speed signs were encountered. The participant saw cars on this route, but always on the other side of the road or on cross-roads.

The two experimental routes of suburban roads and scenes were exactly the same as each other except for the location of the transverse line treatments and the location of some buildings and the pedestrian crossing (details on the routes used are contained in layout diagrams in Appendix C). These routes also included cars on the opposite side of the road and on cross-roads. Photographs of the **8** test sites are shown in Photos **9** to 16.

SIMULATED ROAD, RUMBLE STRIPS AND SITES **:** The road lanes were **4.7** metres wide. All roads had a vertical gradient of zero. The suburban scenarios had perfectly smooth roads, where-as the rural road had a rough surface providing some bumpiness when driven over. Each transverse line (with rumble effect) was 0.6m x 3.6m, with 0.5m between each end of the bar and both the center lines and gutters.

3.1.3 Procedure

Twenty four participants were recruited from around Monash University, comprising 12 males and 12 females, with an average age of 26.4 years ranging from **22** to **40.** To minimise practice effects, no participant used in the previous road trials was used again in these trials.

The procedure was as similar as possible to the previous on-road experiment. Participants read the experimental instructions (seen in Appendix D) as well as having them played through the vehicle's sound system. They were then given practice "driving" the simulator car to get use to its handling, the lack of motion cues and seemingly light steering, before commencing the test. This drive also included rumble lines on the approach to a give-way intersection so they would not be experiencing them for the first time when their performance was being measured, as previously. Additional practice was available if requested but, again, this was not needed.

Photo 9: Treatment Simulator Stop Sien Auuroach.

Photo 10: Control Simulator Stop Sign Auuroach.

Photo 11: Treatment Simulator Roundabout Approach.

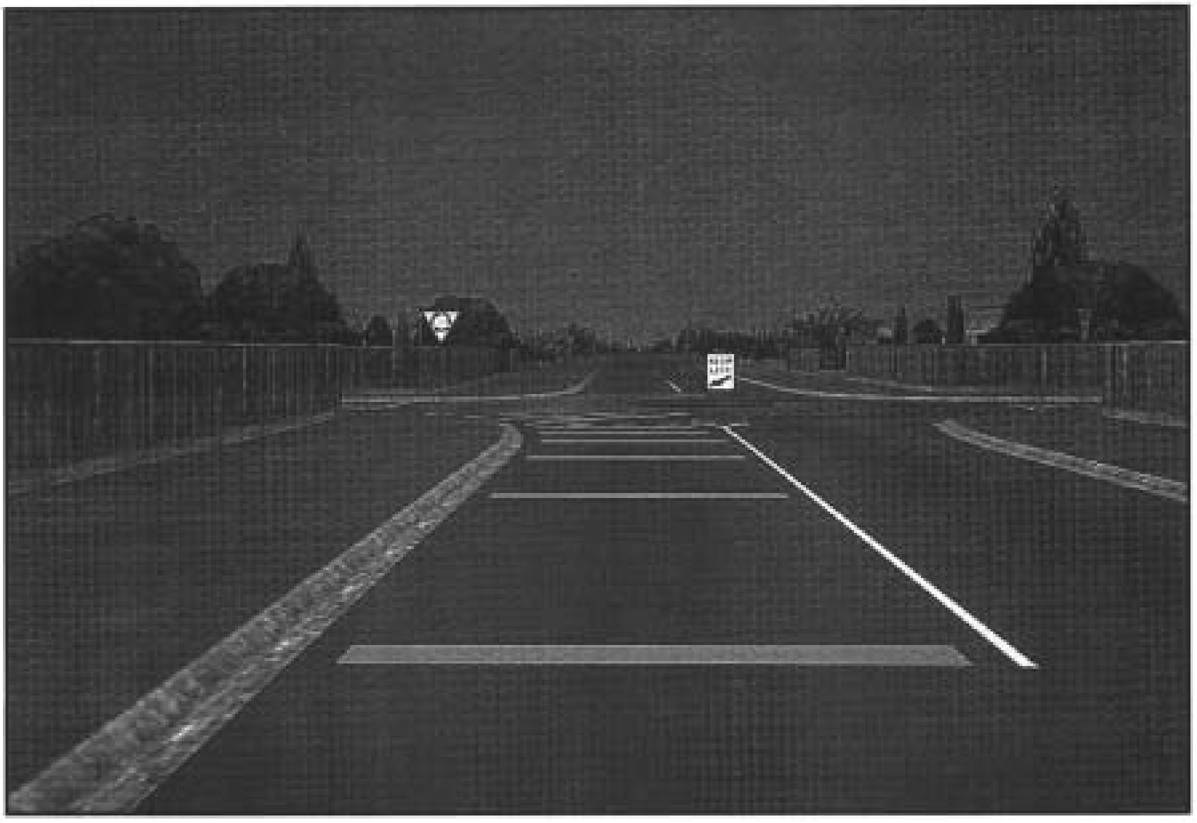

Photo 12: Control Simulator Roundabout Aooroach.

Photo 13: <u>Treatment Simulator Right Curve Approach.</u>

Photo 14: <u>Control Simulator Right Curve Approach.</u>

Photo 15: Treatment Simulator Left Curve **Auuroach.**

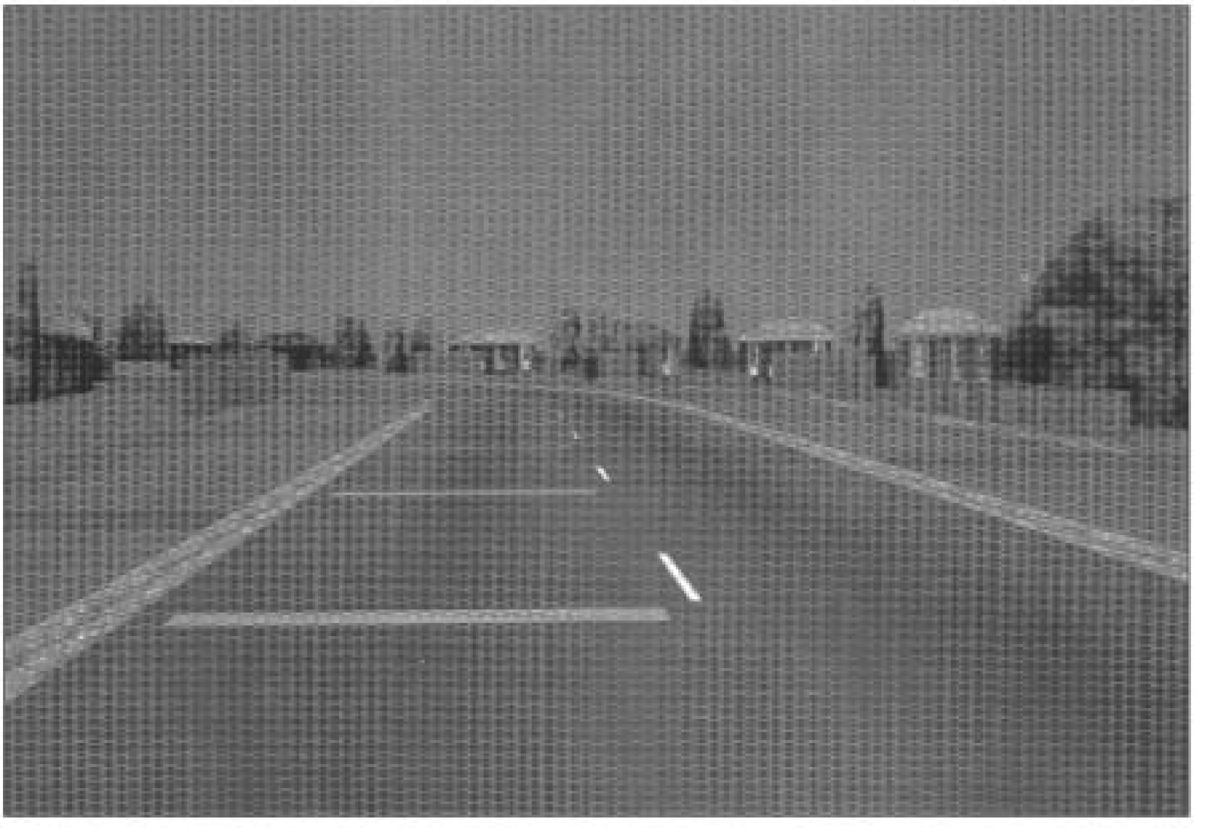

Photo 16: Control Simulator Left Curve Approach.

The participant and experimenter sat in the car in the driver and passenger seats respectively. The seat, windscreen rear-view mirrors and steer wheel column were adjusted by the participant if needed, with the side mirrors remaining pointing towards the floor ***so*** they could not be used.

The participant was asked to start the car **as** they would a normal car and ***set*** off straight but at a low speed. The experimenter explained how no longitudinal movements occurred when accelerating and braking and asked the participant then to brake and watch the speedometer and note this lack of G-force. They were then asked to accelerate quickly and also to note the lack of G-force, then to brake and accelerate again, and then again. A road sign was pointed out, noting that it could not be read clearly until they were reasonably close to it. It was explained that if they crashed, by hitting another car or the pavement, that the program would simply stop without crashing noises. They then drove the car off the road to experience this. This drive typically lasted **2** to **3** minutes.

After putting the simulator into park and turning off the "engine", both the participant and the experimenter got out of the simulator car and walked around to the back of the screens while the next scenario was booted up. This was to decrease the possibility of the participant feeling simulator discomfort, and lasted for about a minute. The second practice scenario was then driven, with the participant driving as they normally would on suburban roads. The experimenter instructed the participant when to turn right and when to pull over for the finish, with the participant making all other driving decisions such **as** to stop at red lights and give-way signs etc.. The second practice session lasted for **3** or **4** minutes and was approximately 3km long. Again this was followed by a break out of the car between scenarios.

Once the participant had completed both practice trials and was comfortable with the task and the simulator, the two experimental scenarios were then given with a break between them. No instructions were given except to drive straight ahead and when to pull over at the end of each route. The experimenter remained in the car throughout all trials and answered any questions posed by the participants. These drives typically lasted around **4** minutes each with a **2** to **3** minute break between sessions. After completing the two experimental sessions, each participant was asked to fill in a questionnaire on aspects of discomfort they may have suffered **as** a result of the trials.

3.1.4 Simulator discomfort

It is well documented that all simulators are capable of producing a degree of discomfort among the participants using them. The extent of simulator discomfort is usually a function of the sophistication of the machine and the severity of the driving manoeuvres attempted. Age of the participant also appears to be important. While it is undesirable to induce discomfort in any experimental setting, of major concern is the degree to which simulator discomfort can bias the experimental results.

To minimise the effects of simulator discomfort, participants were instructed to avoid severe driving manoeuvres such as fast acceleration and rapid steering wheel movements. Unfortunately, not much is known about this phenomenon and ways in which it can be prevented or alleviated. A standard simulator discomfort questionnaire (Kennedy, Lane, Berbaum & Lilienthal, **1996)** was therefore administrated both immediately after the trial and some time later in an attempt to understand the extent of mild discomfort induced by the trials as well as its lasting effects. These results will be reported elsewhere. Suffice to say that approximately 16% of the participants recruited in this experiment were unable to complete the road trials because of simulator discomfort and that many others reported mild discomfort after the experimental trials. Further effort is currently being undertaken to alleviate these effects.

Discomfort bias in the results is always a possibility and its effects are not always clear. However, in this validation study, discomfort bias would only he a problem if the two sets of results did not correlate (correlation would show that driving performance was the same and simulator discomfort would therefore not be relevant for the experiment).

3.2 DATA STRUCTURE AND ANALYSIS

3.2.1 Structure

Data collection again commenced **45** metres before the start of the transverse lines and ended **5** metres after the last line finished (except for the stop sign where datacollection finished at the stop line).

Similar start and stop locations were used for the control sites. Data were collected at 30Hz, as in the on-road experiment. From the speed data, deceleration was calculated for every two sequential 30Hz intervals. The brake activity recorded was in percentage, indicating how much pressure the driver was exerting on the brake pedal. This data was also converted into binary brake activity, similar to that recorded for the on-road experiment. The criteria for brake activation was when the brake pressure was 2% or greater.

The data collected by time was converted to distance data by taking the average of each variable occurring within each 1m interval as was adopted for the on-road experiment. The amount a variable changed within each metre was also calculated for both deceleration and lateral placement data. In addition, the data for every metre was grouped into similar distance categories as that used in the first experiment for the stop sign, roundabout, and the two curve approaches.

The first two distance sections represent the approach to the transverse line area (and equivalent distance at the control sites), with a combined distance of **45** metres for the stop sign and left curve approaches and 30 metres for the roundabout and right curve approaches. The third and fourth sections represented the first and second halves of travel across the transverse lines (or control site equivalent). The actual distances involved can be seen below in Table 3.1. The four distance categories were consistent with experiment 1.

Table 3.1: *Distancesfor the sectors used in experiment **1** data analysis.*

Sector	Stop Sign Approach	Roundabout Approach	Right-Hand Curve	Left-Hand Curve
1 (non-rumble)	23m	15m	15m	23m
2 (non-rumble)	22m	15m	15m	22m
3 (rumble)	21m	15m	15m	22m
4 (rumble)	21m	15m	15m	22m

3.2.2 Analysis

The analysis was carried out in the same way as was outlined in Chapter 2 for experiment 1, using a two-way repeated measures univariate ANOVA for each dependant variable at each of the four sites. The main analysis involved a two-way repeated measures univariate Analysis of Variance (ANOVA) for each of the dependent variables used for each particular site. This was carried out using SPSS (Statistical Package for the Social Sciences) for Windows repeated measures program. This runs repeated measures with a MANOVA (multivariate ANOVA) command but uses a mixed-model approach. The first factor was type of site (treatment or control) and the second factor was the distance sectors, containing ***four*** levels.

For each variate, two sets of ***planned*** orthogonal main effect contrasts (for the two factors) and interactions were used again. Out of these, only the ***site main effect*** and the ***interaction*** contrasts are of interest in terms of interpretation of the effect of the perceptual treatment. The ***site main effect*** contrast was simply the difference between the treatment and control site averaged across the 4 distance sectors. The ***distance sector main*** effect contrasts tested the difference between the first sector and the remaining sectors, the difference between the second sector and the third and fourth sector, and the difference between the third and fourth sectors, all averaged across the two types of site. The ***interaction*** contrasts enabled the analysis to test whether any differences between the treatment and control sites which occurred did so starting in the first half of the rumble approach area, in the second half of the rumble approach, or in the first half of the rumble area. The contrasts are listed in Table 3.2.

Analysis	**Contrast Coefficients**
Distance sector main effects	3 -1 -1 -1
(1 2 3 4)	0 2 -1 -1
	0 0 1 -1
Site by Distance interactions	3 -1 -1 -1 -3 1 1 1
(C1 C2 C3 C4 T1 T2 T3 T4)	0 2 -1 -1 0 -2 1 1
	0 0 1 -1 0 0 -1 1

3.3 RESULTS

The database comprised performance responses from twenty participants who fully completed the experiment. **As** noted earlier, the results from four additional participants had to be excluded from the final data set as they failed to complete the experiment because of severe simulator discomfort. Because of the amount of data collected, considerable effort was necessary to convert these into a suitable database for analysis.

3.3.1 Statistical Critical Values

The same two statistical decision rules used in experiment 1 were again used here. First, significant results will be those results exceeding the critical F value which has had a Bonferroni adjustment to control the family-wise type 1 error rate at ***0.05*** by adjusting for the number of dependant variables used at each particular site using planned orthogonal contrasts. Secondly, if the Hays decision-wise error rate for orthogonal planned contrasts for each variable at each site is exceeded (but not the Bonferroni adjusted family wise-error rate), then a decision of ***"judgement reserved"*** was adopted. Results not achieving the decision-wise error rate level were considered as non-significant.

STOP SIGN AND ROUNDABOUT APPROACHES **:** These two sites have four dependent variables which are relevant to their analysis: speed, binary brake, deceleration and deceleration change per each 1 metre. The Hays decision-wise error rate for planned orthogonal contrasts therefore is $F_{0.05;\ 1,19}$ **= 4.38.** The Bonferroni adjusted critical F statistic when adjusting for the number of dependant variables is $F_{0.05/4;\ 1,19}$ = **7.61.**

LEFT AND RIGHT CURVES APPROACHES **:** The two curve sites have an addition dependant variable relevant to them on top of those used for the stop sign and roundabout sites, namely lateral placement and lateral placement change per each 1 metre. This results in the same Hays decision-wise error rate as above, namely $F_{0.05;\ 1,19}$ = **4.38.** Bonferroni adjusting for the dependant variables used however results in a critical F value of $F_{0.05/6;\ 1,\ 19}$ = **8.67.**

3.3.2 Speed Findings

The results obtained for the speed measures at each of the test and control sites are shown in Figures **3.1** to **3.4** opposite and are described below.

Figure 3.1* - *STOP SIGN APPROACH: The approach speed to the stop sign was significantly slower at the treatment site **(33.2** *kmk)* than at the control **(36.8 km/h)** ($F_{1,19}$ = **9.87,** p = 0.005). In addition, there was no significant interaction between treatment and control speed at either **of** the two pretreatment sectors **1** and **2** (**$F_{1,19}$** = **0.01,** p = **0.919 &** **$F_{1,19}$** = **0.46,** p = **0.505** resp.). However, there was a suggestion **of** a speed reduction at the treatment site immediately upon entering the transverse line area (sector **3)** compared to sector **4** which included the stopping area ($F_{1,19}$ =6.12, p= **0.023,** judgement reserved).

Figure 3.2* - *ROUNDABOUT APPROACH **:** There was no significant difference in speed between the treated and control sites on the approach to the roundabout ($F_{1,19}$=2.40, **p** = 0.138), nor was there any significant interactions over the four distance sections between the treated and control sites ($F_{1,19}$ = 0.05, *p* = 0.819; $F_{1,19}$ = 1.89, *p* = 0.185 **&** $F_{1,19}$ = 1.71, *p* = **0.206** resp.).

Figure* 3.3 - *RIGHT-HAND CURVE: There was a slight overall reduction in travel speed **(4.3km/h)** on the approach to the treated right-hand curve compared to its control ($F_{1,19}$ = **5.88,** p = **0.026,** judgement reserved) but no significant interactions over the four distance sections for the treatment ($F_{1,19}$ = 3.96, *p* = **0.061;** $F_{1,19}$ = 2.38, *p* = **0.139 &** $F_{1,19}$ = 1.26, *p* = **0.275** resp.).

Figure 3.4* - *LEFT-HAND CURVE: The approach speed for the treated left-hand curve was also significantly slower **(8.9km/h)** than its control site ($F_{1,19}$ = **33.97,** *p* < **0.001).** Moreover, the reductions in travel speed were seemingly even greater for the last three sectors compared to sector one ($F_{1,19}$ = **4.59,p** = **0.045,** judgement reserved). There were no significant interactions, however, between the sites and distance sections **over** the last **three** distance sections ($F_{1,19}$ = 0.60, *p* =0.447 **&** $F_{1,19}$ = 0.45, *p* = **0.509** resp.).

<u>Comparison of Simulator and Road Results:</u>

The pattern **of** responses between the simulator and on-road results was quite similar. There were no significant speed reductions for the treated stop sign and roundabout intersections in either test environment, although there were some minor differences in the types **of** interactions observed. There was a hint **of** a reduction in approach speed for the treated right-hand simulator curve and a stronger reduction at the simulator left-hand curve but no similar reductions at either **of** the equivalent road sites. Similar interactions were observed for the curves in both test settings.

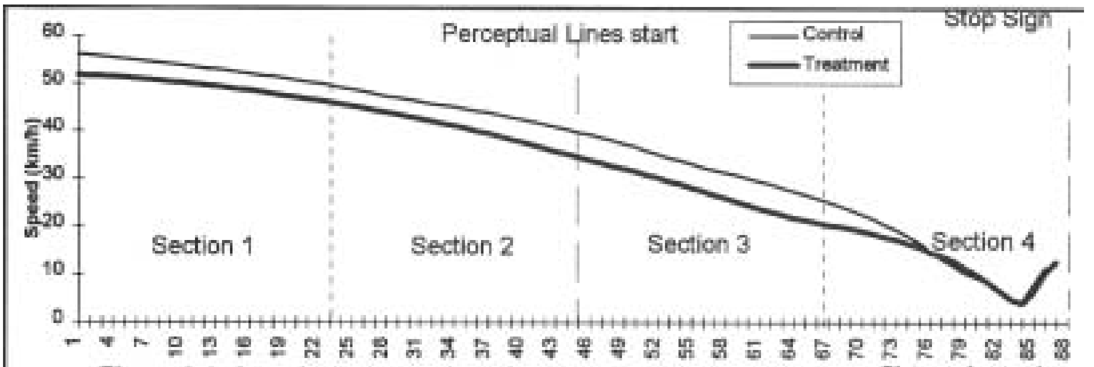

Figure 3.1: Speed on approach to the Stop Signs

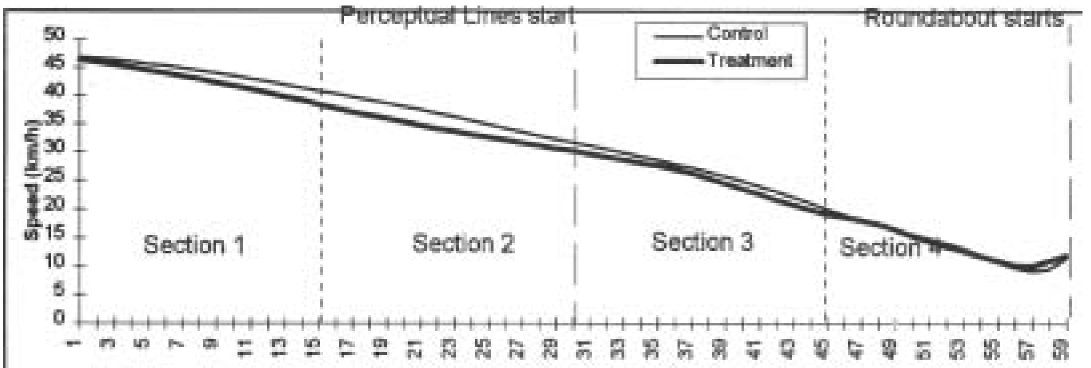

Figure 3.2: Speed on approach to the Roundabouts

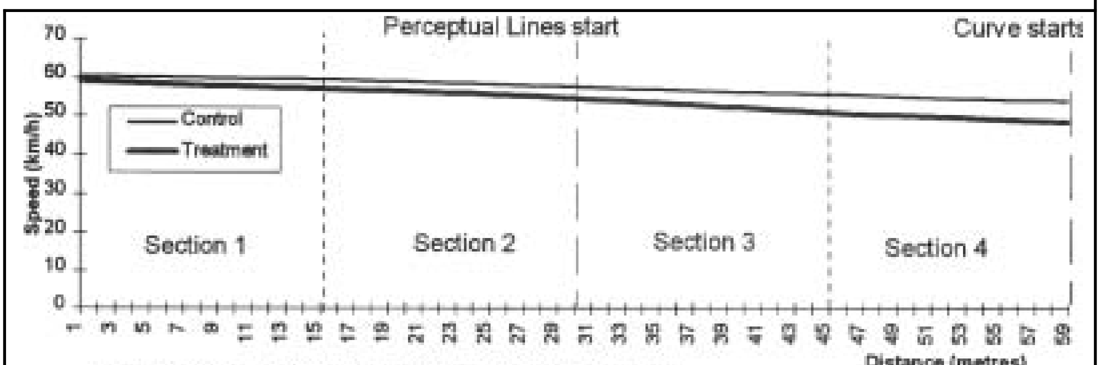

Figure 3.3: Speed on approach to the Right Curves

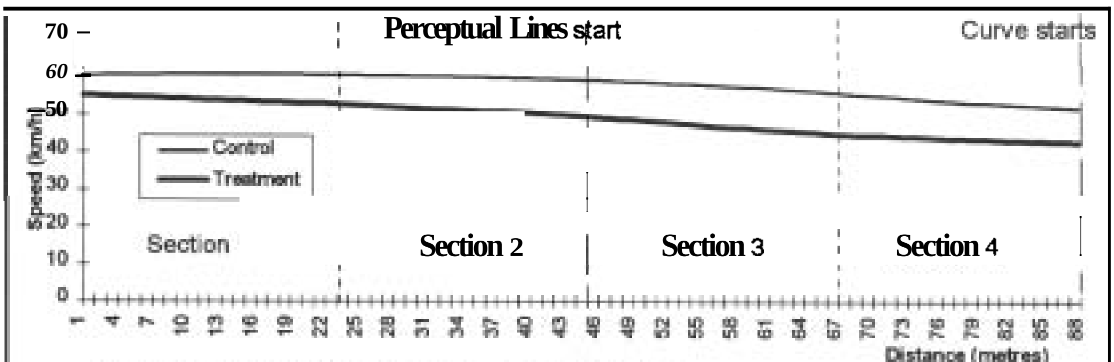

Figure 3.4: Speed on approach to the Left Curves

3.3.3 Braking Responses

There were no significant differences whatsoever in braking responses between the treated and control sites for any **of** the four locations in the simulator. These are plotted in Figures 3.5 to 3.8 opposite and described below for completeness.

Figure 3.5 - STOP SIGN APPROACH: There was no significant difference in braking on the approach to the stop sign at the treated site ($F_{1,19}$ = 2.40, p = 0.138) nor were there any significant interactions in any of the four distance sectors ($F_{1,19}$ = 0.36, p = 0.558, $F_{1,19}$ = 2.68, p = 0.118 & $F_{1,19}$ = 0.17, p = 0.683 resp.).

Figure 3.6 - ROUNDABOUT APPROACH: Similarly, there were no differences observed in the amount of braking between the treated and control sites on the approach to the roundabout, overall ($F_{1,19}$ = 0.44, p = 0.517) or between any of the four distance sectors ($F_{1,19}$ = 1.56, p = 0.226, $F_{1,19}$ = 0.36, p = 0.557 & F,,,, = 0.003, p = 0.995 resp.).

Figure 3.7 - RIGHT-HAND CURVE: Again, no differences were observed on the approach to the right-hand curve ($F_{1,19}$ = 4.02, p = 0.060) or between any **of** the four sectors ($F_{1,19}$ = 1.67, p = 0.211, $F_{1,19}$ = 1.69, p = 0.239 & $F_{1,19}$ = 0.01, p = 0.904 resp.).

Figure 3.8 - LEFT-HAND CURVE: During the first 23 metres of the control left curve approach (sector 1), no participant actually applied the brake at all, hence this could not be analysed statistically because of the lack of variance. There were no differences observed in amount of braking between the treatment and control on the remaining approaches, either overall ($F_{1\ 19}$= 0.09, p = 0.774) or between any of the three sectors (**$F_{1,19}$** = 0.42, p = 0.523, $F_{1,19}$ = 2.60, p = 0.123 & $F_{1,19}$ = 1.97, p = 0.176 resp.).

Comparison of Simulator and Road Results:

The main effects for the braking response were identical between the simulated and on-road trials at the intersection and curved sites (there were no significant differences in braking between the treatment and control sites in either test environment). While there were no interactions observed whatsoever among the simulator responses at any site, there was significantly more braking in the approach zone to both the right- and left-hand curves. However, these differences are relatively minor and the pattern of responses can be considered quite similar.

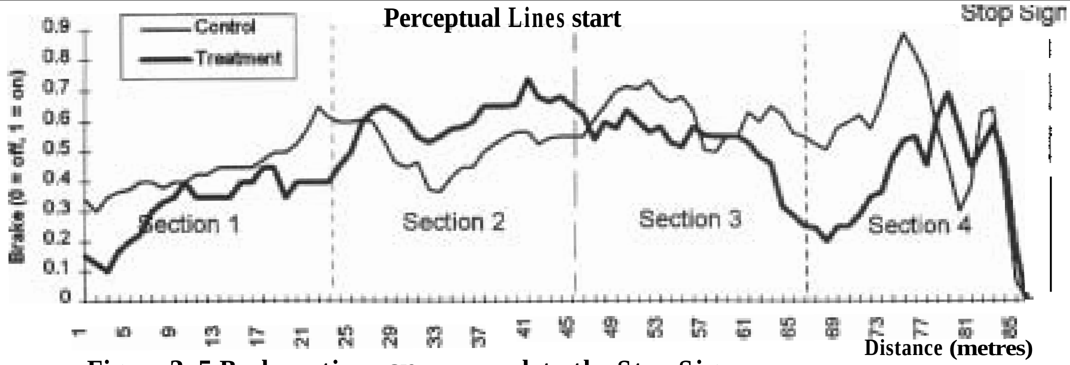

Figure 3.5 Brake actions on approach to the Stop Signs

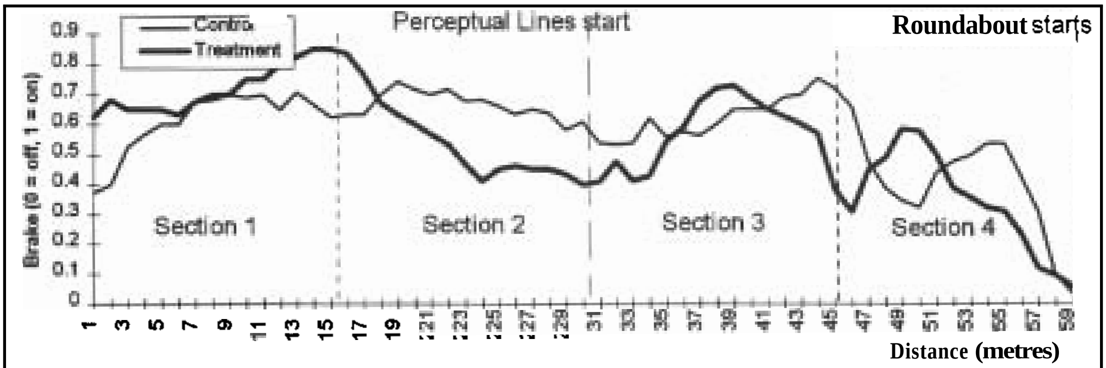

Figure 3.6: Brake actions on approach to the Roundabouts

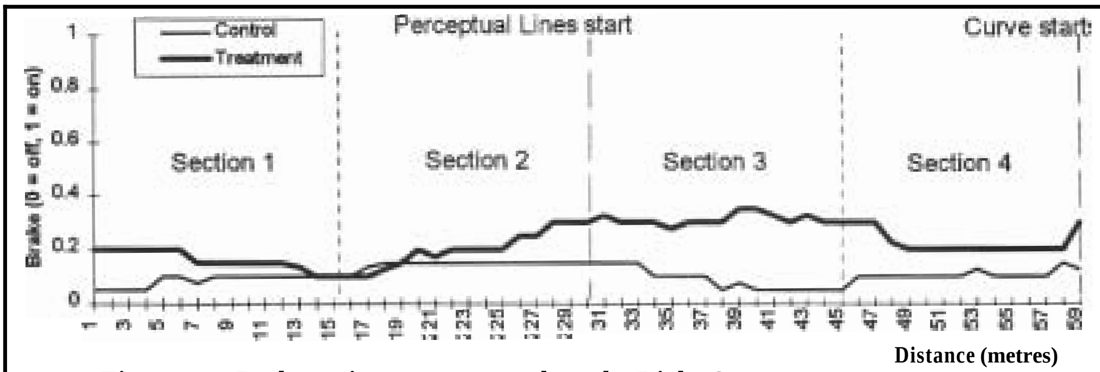

Figure 3.7: Brake actions on approach to the Right Curves

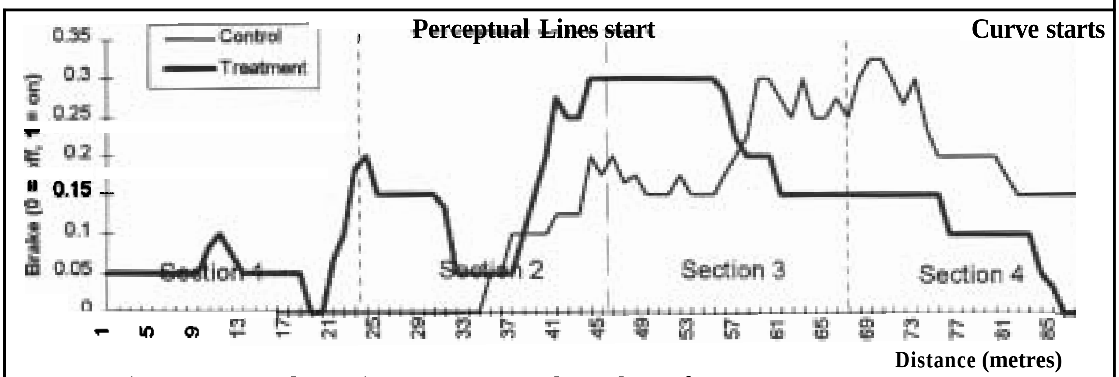

Figure 3.8: Brake actions on approach to the Left Curves

3.3.4 Deceleration Results

Differences in deceleration for each of the different road configurations are shown in Figures 3.9 to 3.12 opposite and are described separately below.

Figure 3.9 - STOP SIGN APPROACH: There was an apparent reduction in the amount of deceleration on the approach to the treated stop sign ($F_{1,19}$ = 5.77, p = 0.027, judgement reserved). However, none of the interactions between the treatment and control sites across any of the 4 sectors were significant ($F_{1,19}$ = 0.00001, p = 0.997, $F_{1,19}$ = 1.35, p = 0.259, & $F_{1,19}$ = 0.27, p = 0.609 resp.).

Figure 3.10 - ROUNDABOUT APPROACH : There was no significant difference in deceleration on the approach to the roundabout for the treated site compared to its control ($F_{1,19}$ = 0.00, p = 0.980). In addition, no significant interactions were found over the 4 distance sections and between the two roundabout sites ($F_{1,19}$ = 2.62, p = 0.122, $F_{1,19}$ = 0.01, p = 0.920 & $F_{1,19}$ = 0.28, p = 0.603 resp.).

Figure 3.11 - RIGHT-HAND CURVE: No significant difference was found between the treatment and control data on the approach to the right-hand curve ($F_{1,19}$ = 2.38, p = 0.139). Moreover, there were no significant interactions between treatment and control over any of the four distance sectors ($F_{1,19}$ = 0.278, p = 0.604, $F_{1,19}$ = 1.16, p = 0.294 & $F_{1,19}$ = 0.18, p = 0.893 resp.).

Figure 3.12 - LEFT-HAND CURVE: Similarly, there was no overall difference in deceleration between the treated and control sites in the approach to the left-hand curve ($F_{1,19}$=1.07, p = 0.314) and no significant sector interactions either ($F_{1,19}$ = 3.74, p = 0.068, $F_{1,19}$ = 3.69, p = 0.70 & $F_{1,19}$ = 3.47, p = 0.78 resp.).

Comparison of Simulator and Road Results:

The simulator responses were generally less sensitive to this measure than those obtained on the road itself. Whereas there were significantly deceleration differences observed on the road at the treated stop sign, roundabout and left-hand curve sites, the only hint of a similar result in the simulator trials was at the stop sign and then not particularly strong. In addition, none of the interactions observed on the road between the section differences and treatment were apparent in the simulator responses.

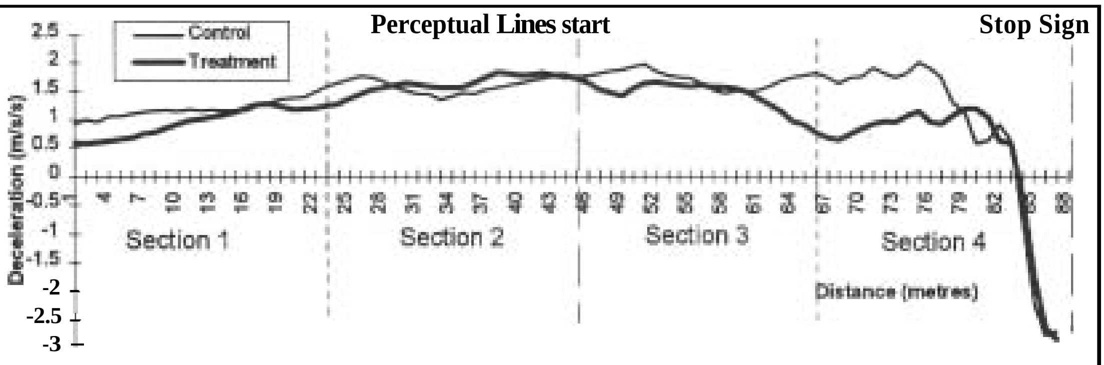

Figure 3.9: Deceleration on approach to the Stop Signs

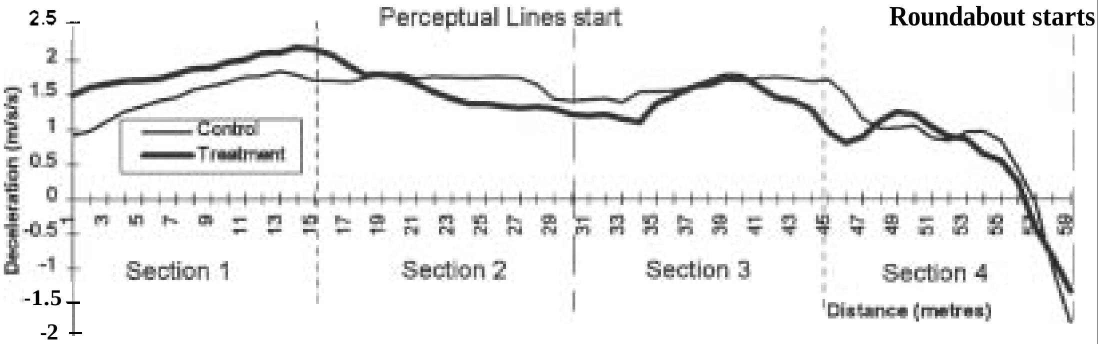

Figure 3.10 Deceleration on approach to the Roundabouts

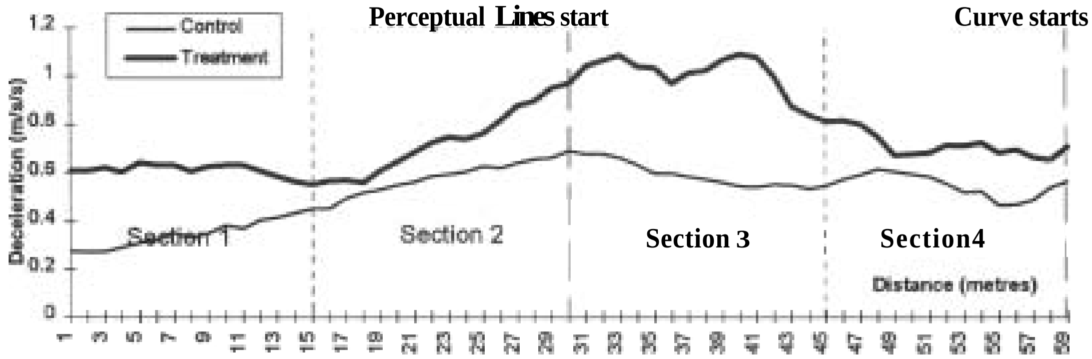

Figure 3.11: Deceleration on approach to the Right Curves

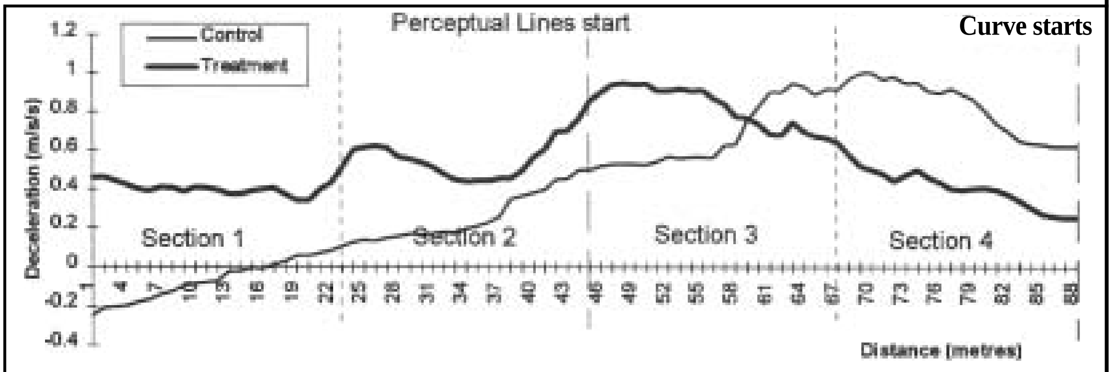

Figure 3.12: Deceleration on approach to the Lett Curves

3.3.5 Deceleration Change

There were practically no significant differences observed in the derived data on deceleration change per metre in the simulator responses which are shown in Figures **3.13** to **3.16** opposite and described below for completeness.

Figure 3.13 - STOP SIGN APPROACH: There were no significant differences in deceleration change on the approach to the stop sign at the treated site ($F_{1,19}$ = **0.06,** ***p*** = **0.804)** and no significant interactions between treatment and control in any of the four distance sectors ($F_{1,19}$ = **0.32,** ***p*** = **0.577,** $F_{1,19}$ = **1.36,** ***p*** = **0.258, &** $F_{1,19}$ = **0.31,** ***p*** = **0.582** respectively).

Figure 3.14 - ROUNDABOUT APPROACH: Similarly, no difference was observed in deceleration change between the treated and control sites on the approach to the roundabout ($F_{1,19}$ = 0.00,***p*** = **0.965).** The only sign of a significant interaction between any of the four distance sectors and treatment level was between the thiid and fourth sector ($F_{1,19}$ = **6.96,*p*** = **0.016,** judgement reserved) where deceleration change was apparently greater in the third sector.

Figure 3.15 - RIGHT-HAND CURVE: Again, no difference was observed in deceleration change between the treatment and control on the right-hand curves ($F_{1,19}$ = **1.69,*p*** = **0.209)** and no interactions either between treatment and control at any of the four sectors ($F_{1,19}$ = 0.10, ***p*** **= 0.752;** $F_{1,19}$ **= 3.40,** ***p*** **= 0.081 &** $F_{1,19}$ **= 0.54,** ***p*** = **0.470** resp.).

Figure 3.16 - LEFT-HAND CURVE: There was no significant difference in deceleration change between the treatment and control left-hand curve responses ($F_{1,19}$ = **0.08,** ***p*** = **0.778).** In addition, no differences were observed in deceleration change between the treatment and control sites for any of the four sectors either ($F_{1,19}$ = **0.48,*p*** = **0.496;** $F_{1,19}$ = **3.23,*p*** = **0.088,** and $F_{1,19}$ = **0.62,** ***p*** = **0.439** resp.).

<u>Comparison o fSimulator and Road Results:</u>

Again, there were considerable differences in the degree of deceleration change per metre between treatment and control sites on the road and in the simulator, suggesting that this measure may have been less sensitive in the simulator trials. There was significantly more deceleration change for all treated sites in the on-road trials and none whatsoever in the simulator. Furthermore, treatment significantly interacted with each of the four sectors for the road trials while the only a hint of a similar finding was between sector **1** and the rest at the roundabout in the simulator responses.

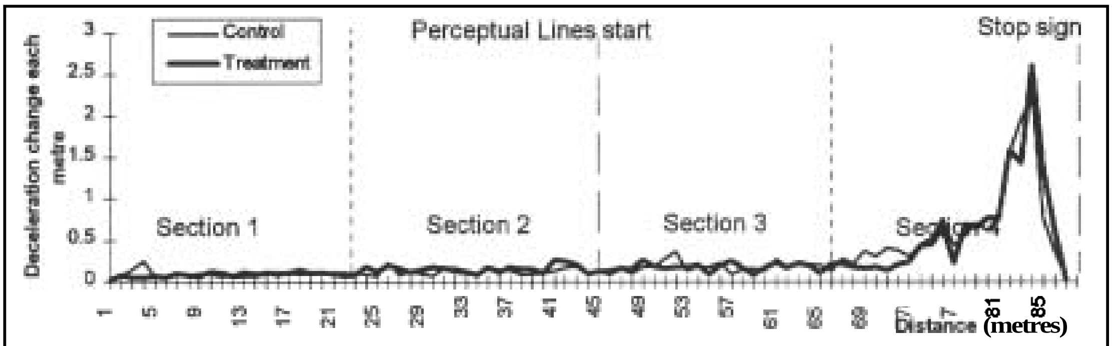

Figure 3.13: Deceleration change on approach to the Stop Signs

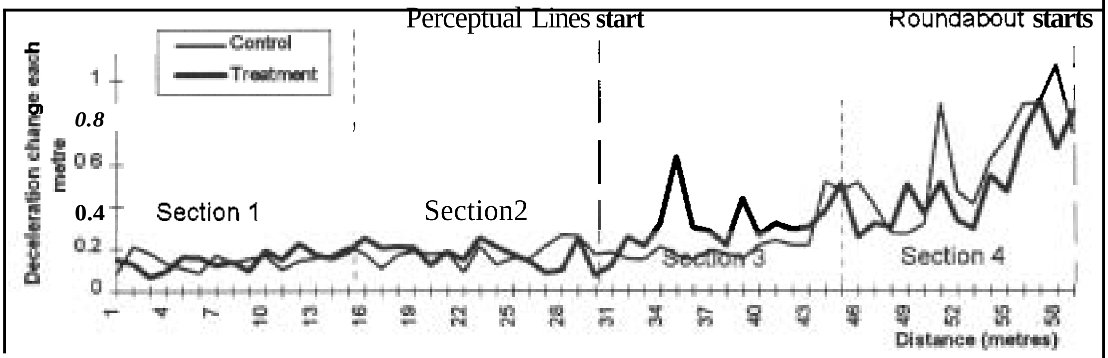

Figure 3.14: Deceleration change on approach to the roundabout

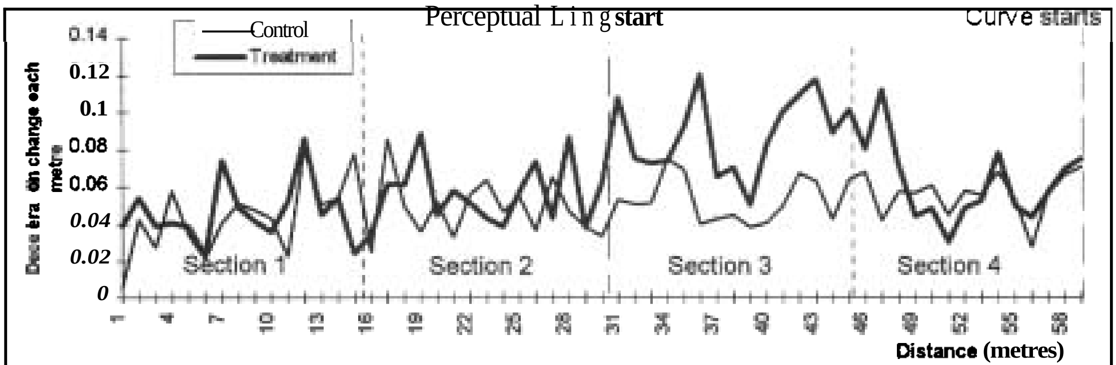

Figure 3.15: Deceleration change on approach to the RH curve

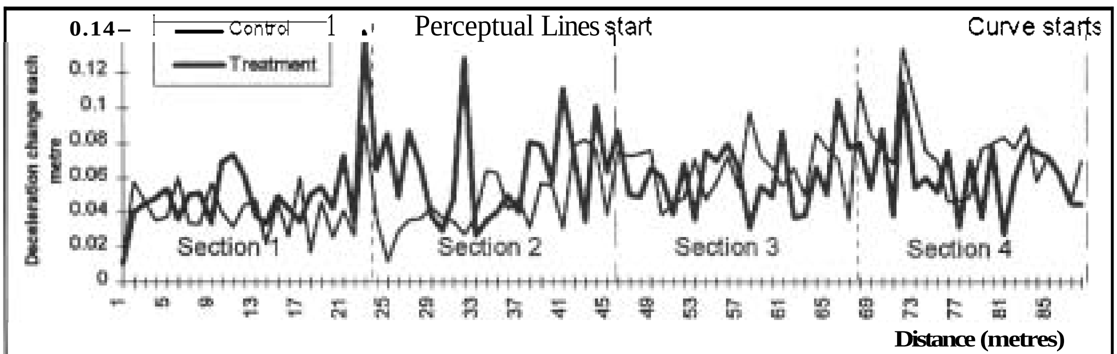

Figure 3.16: Deceleration change on approach to the LH curve

3.3.6 Lateral Placement

Lateral placement was only measured at the two curve configurations as there was no reason to expect transverse lines to cause differences in lateral placement on the straight road approaches to intersections. The lateral placement results are shown in Figures 3.17 and 3.18 and are described below in terms of each curvature finding.

RIGHT-HAND CURVES: Figure 3.17 shows that there was an apparent shift in lateral placement further away from the centreline in the approach to the treated right-hand curve by approximately 16cm ($F_{1,19}=6.21$, $p=0.022$, judgement reserved). The shift was greatest during the first 15 metres compared to the other three distance sectors ($F_{1,19}=8.41$, $p=0.009$). The second sector also appeared to be greater than the remaining two, although not as robust ($F_{1,19}=4.89$, $p=0.039$, judgement reserved).

LEFT-HAND CURVES: In contrast to the right-hand curve findings, Figure 3.18 shows no overall difference in lateral position on the approaches to the treated left-hand curve ($F_{1,19}=0.36$, $p=0.554$) and no sector interactions either ($F_{1,19}$ = 3.41, p = 0.080, $F_{1,19}$ = 0.01, p = 0.906 & $F_{1,19}$ = 3.33, p = 0.084 resp.).

Comparison of Simulator and Road Results:

The lateral placement results between the road and simulator trials were generally similar. On right-hand curves, the treatment caused drivers to position themselves further from the centreline on the road and in the simulator while on left-hand curves, there was no difference between treatment and control in contrast to the road response. It was not possible to examine the interaction effects thoroughly because of difficulties experienced with the interrupted centreline in the road trials.

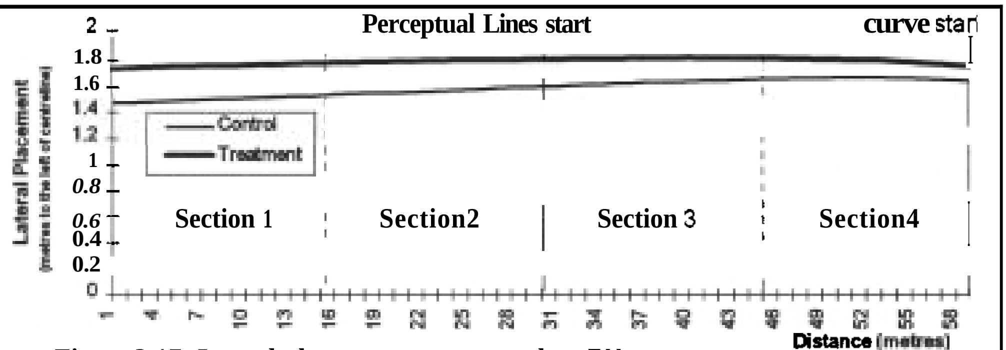

Figure 3.17: Lateral placement on approach to RH curve

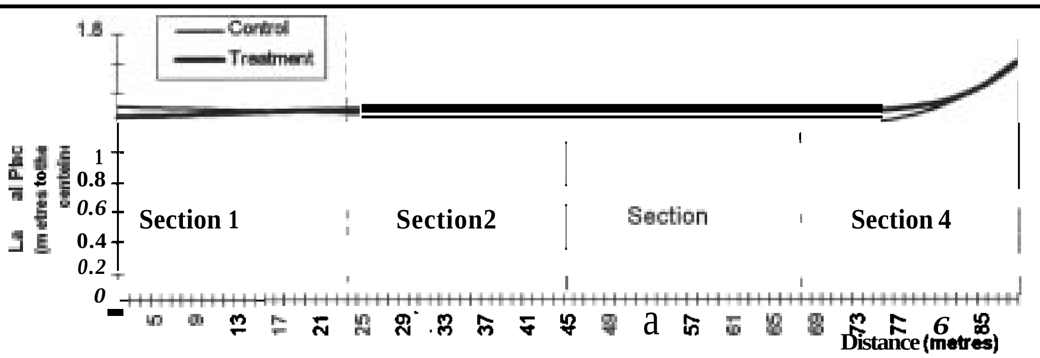

Figure 3.18: Lateral placement on approach to LH curve

3.4 DISCUSSION

These results are primarily of interest in terms of how they compare with data from similar ones from the on-road experiment to demonstrate whether the driving simulator is a valid test environment for perceptual countermeasures. **As** noted in the introduction, validation can be established at at least two levels for the objectives outlined for this study. The simplest level (general validity) is to demonstrate that the pattern of results across the two data ***sets*** is similar. For instance, if a behavioural change is observed on the road on approach to a particular treatment site, validation is said to have been established if a similar pattern is also observed in the simulator. It is a simpler and cheaper option for investigators whose primary interest is in conducting the research, rather than establishing its real world applicability. Indeed, this degree of validation is often considered sufficient to permit a comprehensive research program to be undertaken.

Fildes, Fletcher and Corrigan (**1 987)** and Fildes, Leening and Corrigan (1989), for instance, conducted two such validation experiments in their work on Speed Perception where participants were asked to produce similar subjective responses to moving images of road scenes in a laboratory to what they had produced on the road itself. Validation was said to have been demonstrated when the responses in both settings showed similar trends and patterns (eg; participants judgements of safety became more or less safe in response to changes of road width and environment both on the road and in the laboratory). From these results, they claimed that judgements of a safe speed and a safe headway could be adequately elicited in a laboratory setting and subsequently conducted a series of experiments involving a range of different road and roadside features. No attempt was made to statistically correlate these two data sets, although judging from their results, a statistical correlation could conceivably have been established with a little more research effort.

The statistical correlation between both these data sets is reported fully in the next Chapter of this report. However, it is worthwhile discussing the results found in this and the previous Chapter in terms of their general validity. This will be attempted in terms of the performance measures of prime interest for this study.

3.4.1 Speed

Perceptual countermeasures are intended to influence driver behaviour by principally modifying a driver's speed behaviour without the change in behaviour being necessarily apparent to the individual. Thus, speed differences between test and control locations would be the minimum requirement across the two test environments for face validity to be established.

Indeed, the results on pages **44** and **45** do tend to confirm this. Travel speeds on the approach to the stop sign intersection and the right- and left-hand curves were significantly slower for the **sites** with transverse lines than those without. This varied from 3.6km/h up to almost 9km/h for these sites. There was no significant reduction in travel speed for transverse lines on the approach to the roundabout. **As** most of the speed differences were constant across the **4** sectors, it can be assumed that these treatments are influencing travel speed well ahead of reaching or travelling over the lines.

These results were similar to those obtained during the road trials. There were no significant speed reductions for the treated stop sign and roundabout intersections in either test environment, although there were some minor differences in the types of interactions observed. Thus, it seems that the laboratory simulator is an accurate tool for simulating driver's speed behaviour approaching these intersections. Interestingly, the two curves yielded more significant speed reductions in the simulator than on the road itself, where speed differences only started to occur well after they did in the simulator and so did not occur over all four distance sectors. As the effects were more consistent in the simulator, it suggests that the laboratory environment might enhance speed differences somewhat over those likely to be observed on the road.

This last finding could possibly result from capacity restrictions in the simulator's processing hardware as curves take considerably more computing power to produce than straight roads and the display was not perfect in terms of road curvature. During the trials, it was apparent that the bends tended to be a series of straight road sections, each displaced slightly from the previous sector to create the bend, and while each segment was relatively small, it did not give the appearance of a smooth curve on the inside perspective edge of the road. Whether this represents a real problem for testing perceptual countermeasures is not clear and will be examined further when correlating the results from both experiments in the next chapter. **An** alternative explanation might be that these differences are due to the more exact replication of the treatment-control sites in the simulator, compared to those that existed on the road. If this is ***so,*** then obviously the simulator is a superior environment for testing these effects **as** it offers a higher degree of control of extraneous variation.

Many of the participants reported feeling quite disorientated negotiating the roundabout in the simulator as the steering movements tended to be excessive. This may have led to the non-significant speed result at the roundabout seen in these trials. However, the roundabout in the road trials also failed to generate any significant speed differences between the treatment and control sites which suggests that the lack of an effect here is more widespread. It was noted in the previous chapter that roundabouts have been the main site for these treatments overseas and that perhaps transverse lines may be more effective at other locations. The results from the simulator trials would seem to add support to this hypothesis.

There was also an anomaly discovered between the speed recorded and the speed displayed in the simulator after the experiment was completed. The speed recorded was in fact an accurate representation of the actual **(or** virtual) speed being driven, and this is what was presented in the results section. However, the speed the speedometer in the car showed to the driver was actually faster than what they were doing. **For** example, if the speedometer showed ***60*** km/h, the data recorded would have been around **55** km/h, and the actual speed represented by the passing visual images was also **55** km/h. The difference in the speedometer speed and recorded speed varied depending on what speed the simulator was "travelling" at, being less for slower speeds and more for greater speeds. This problem however has now been fixed and so will not occur in future experiments.

3.4.2 Braking

At all four of the sites in the simulator, there were very few differences between the treatment and control locations in the amount of time spent braking, both over the total distances or in any of the four distance sectors that were examined. This is an interesting difference from the road experiment where there were differences, albeit predominantly at the curves only. This seems to suggest that braking may be less sensitive in the simulator than on the road.

The main reason why this may have been so would seem to be a lack of fidelity in the brakiig activity in the simulator. Many of the participants seem to apply the brakes too hard or too soon in the lead up to the intersection and often almost came to a stop well back from the stop line of the intersection (when this happened, they usually released the brake and allowed the vehicle to roll up to the stop line). Some commented on the lack of motion cues during brakiig **as** they would often feel they were not braking enough because they could not *feel* the car slowing. Also, the braking mechanism in the simulator has a spring and rubber stop mechanism which seems to be less than optimal at eliciting normal brakiig responses. The lack of horizontal motion cues and to a lesser extent, the harder than usual resistance of the brake pedal, often caused a greater braking response than intended. The amount of practice before the trial did not seem sufficient to train the operator in this but could not be extended for fear of inducing additional simulator discomfort. Thus, braking would not seem to be as useful a measure as speed in the simulator when testing for on-road perceptual countermeasure effects.

3.4.3 Deceleration & Change

Deceleration also did not differ significantly between treated and control sites at either the roundabout or the two curves and contrary to the findings obtained on the road. At the stop sign intersection, there was less overall deceleration at the treatment site which did not reach full significance. Given the robust speed differences at this site, this result is not too surprising. There were no significant interactions found between the treatment, control and the four distance sectors at any site.

It should be noted that there was a trend for more deceleration to be occurring earlier at the treatment sites for the approach to the two curves in the simulator results. However, the standard deviation values were often half or more of the average values, thus there was considerable variability in the way each participant chose to slowed down, making significant differences virtually impossible. This again may be related to the fact that participants did not drive the simulator exactly **as** they would a real car, due possibly to the lack of motion cues and perhaps the novelty of the whole situation. It was also the case that deceleration was generated using speed and time differences for each two sequential measurements (at **30** Hz), whereas the road deceleration data was measured directly from an accelerometer. It may be possible that the latter method is **a** more sensitive measure, and so more likely to pick up deceleration differences than the former method.

There were no overall differences in deceleration change per meter at any of the four sites, with the only interaction (at the judgement reserved level) being greater changes in deceleration at the treated roundabout approach during the first half of the treatment area compared to greater changes in the last sector at the control site. By contrast, the on-road results indicated considerable deceleration change between all treated and control sites, again suggesting a lack of sensitivity to this measure in the simulator The one interaction found, however, was especially interesting and indicates that there was at least some response to the transverse lines at the roundabout, perhaps suggesting that the participants were preparing to **stop** earlier. Contributing to these lack of results, as discussed in the results section on braking, is that participants often found it hard to stop correctly at a particular point due to the limited visual, auditory and vertical motion cues.

3.4.4 Lateral Placement

There was strong evidence of a positive treatment effect for the right-hand curve approach where participants positioned their vehicle further away from the centreline than at the control sites. This positioning was at its largest difference at the beginning of measurement and then started to converge up to and within the treatment area. The left curve approach, however, did not produce similar statistically reliable differences in lateral position. The lateral position results from the road experiment, too, while in the predicted direction, were not as robust as these findings, no doubt a function of the lack of a solid centreline for the camera to measure against and possibly a high amount of variance between participants. Nevertheless, it would appear that lateral placement in the simulator is a useful measure of on-road behaviour through curves and this will be examined further in Chapter **4.**

The fact that drivers had greater lateral placement movements for right-hand than left-hand curves is an interesting finding in itself. Wright and Zador **(1981)** and Hall and Zador **(1981)** both reported higher rates of single vehicle accidents on left-hand bends in the USA (right-hand bends in Australia) and similar findings were reported in Australia by Andreasson and Johnston **(1982)** and Sanderson and Fildes **(1984).** Stewart (1977) and McBean **(1982)** found no such bias in the United Kingdom. Fildes **(1986)** subsequently demonstrated a perceptual superiority for left-hand over right-hand curves based on the number of "reversal curves" available for these bends in the road. On this basis, therefore, it could be argued that if drivers had an inferior view on right-hand curves, they may have responded by moving further to the left when that view is enhanced by transverse lines (the ends of the lines and their number provide greater sources of information about curvature than otherwise). This seems to be supported by the data collected in these two experiments.

3.5 OTHER IMPLICATIONS

3.5.1 Rumble Effects

There were a number of additional aspects of these results that warrant discussion. Firstly, the fidelity of the rumble sound could not be fully re-produced with a road marking on the simulator. This meant that the rumble effect associated with transverse lines, while providing a bump, did not produce the same rumble noise as it did on the road. The motion platform did produce some noise when it was activated by the rumble lines, but not totally comparable to the noise on the road.

The amount of "bumpiness" depended on how fast the simulator car was driving and how close together the lines were. With lines very close together when the car was travelling at a reasonable speed such as going around curves, not every line would be felt as a bump and many had no motion effect at all. This means that the overall bumpiness of the simulator rumble lines was probably not as intense as the lines on the road. When travelling over the rumble lines at normal suburban speeds, the lines produced a subjectively felt bump similar to that produced on the road. However, at very low speeds, the bump increased dramatically and the line thickness appeared to be quite high. **As** a consequence of this, the rumble effect was reduced for lines closer to the intersections and curves, where the driver would be expected to be travelling slower, to produce a more even sense of bumpiness throughout the treatment. One problem with this however was that if the participants slowed down drastically before reaching the lines, as some did, the bump experienced for the initial rumble lines far exceeded the comparable bump on the road.

As the main objective of perceptual countermeasures is to alter the driver's perception of an on-coming hazard before they reach it, these rumble limitations in the simulator may not be a serious problem for future research. However, it should be stressed that many of the proposed treatments include rumble as well as perceptual effects (indeed, a number of them seem to be enhanced by adding rumble effects when travelling over the treatments). When testing these, therefore, the limitations of the rumble effects may need to be taken into consideration.

3.5.2 Simulator Discomfort

As reported earlier, there was a slight problem experienced with discomfort among some of the participants while driving the simulator. Sixteen percent of the total sample of participants did not complete the whole experiment due to feelings of sickness and a number of others reported at least mild levels of discomfort at the conclusion of the test.

The question of whether or not simulator discomfort affected these results can be answered somewhat by the findings of this experiment The pattern of results in the simulator was quite similar to those obtained **on** the road, especially for the speed measures In spite of the participants who completed the experiment reporting some mild discomfort, it does not appear to have influenced their results unduly The phenomenon may partly explain the differences observed in other measures (eg; braking and deceleration), as presumably if the participant is not feeling well, they could easily misjudge braking distance and/or required rates of deceleration. **As** noted previously, further work is currently under way to understand the phenomenon and thus control its effects. Other studies will report on this as additional knowledge is gathered.

Due to the experience gained in the current experiments, future perceptual countermeasures experiments should be able to reduce the levels of simulator discomfort to a minimum. The main cause of discomfort was turning and braking, presumably due to the disparity between the sense of visual reality (gained from the **180**" visual display) and the lack of lateral and longitudinal motion normally experienced when cornering and decelerating. Thus, it was found that the more experienced the driver was with real vehicles, the greater the tendency was to feel disoriented on the simulator and to drop out before finishing the experiment.

In testing future perceptual countermeasures in the simulator, it should be possible to avoid many of the causes behind discomfort through the nature of the road features used as well as through practice. For instance, it was noted by many participants that feelings of discomfort were not really felt before they reached the roundabout. While the roundabout was important for the current study as part of the validation process, it is not likely to be necessary when testing the range of measures contemplated. Sharp comers were seen to result in similar disorientating feelings and these too should be able to be avoided. Simulator discomfort was minimised through the use of practice sessions and ensuring that the participant exits the vehicle and walks around between trials. Thus, even if simulator development is slow to alleviate the problem, it should not hamper further research into perceptual countermeasures.

3.6 CONCLUSIONS

The results from the simulation experiment were encouraging in terms of establishing the general validity **of** the TAC Driving Simulator for perceptual countermeasure experimentation. Speed was reduced on the approach to stop sign intersections and curves with the presence **of** transverse lines, similar to the effects observed on the road itself. Lateral placement findings were also positive. Deceleration, and to a lessor extent braking, were not as impressive for reasons explained. One or two interesting theoretical issues were raised as a result **of** these data which may help further understand the role of perception in driving. While these findings show a degree of validation between the simulator and the road, a more rigorous statistical test is warranted and this **is** the subject of the next chapter.

Chapter 4 Validation of the Simulator

As noted previously, the degree of validation of the driving simulator can be judged at two separate levels. The least demanding level (general validation) simply calls for similar patterns of response between on-road and simulator trials without establishing statistical association. The results reported in the previous Chapter show a high degree of validation at this lower level. In addition, a more demanding, and rigorous validation test demands that statistical significance be established between the two data sets. While it might seem strange for any study to only attempt the first level of validation, it should be pointed out that these two approaches can measure different aspects of validation and are therefore not necessarily conflicting. This **is** discussed further at the end of this Chapter. However, having demonstrated validation using both approaches, the real world relevance of a simulated road environment is firmly established.

Establishing statistical validation between two data sets is a more rigorous scientific test of the validity of two test environments. Analysis of Variance, Logistic Regression and Canonical Correlation (Harris **1985)** are statistical tests available for establishing such an association and their choice is very much dependent upon the characteristics of the particular data ***sets.*** In this case, given that the requirement called for a test of ***"no difference"*** rather than the usual convention, a canonical correlation was chosen as being a more appropriate test. In addition, this procedure allows for a multivariate analysis where progressive performance can be assessed across conditions, sometimes including unequal cells.

4.1 DATA ANALYSIS

Data used for the comparison between the road and simulator trials involved single scores for each metre travelled. Data were collected on vehicle performance characteristics in the approach zone to stop sign and roundabout intersections, as well as at road curves for locations where transverse lines were placed in the approach zone and non-treatment controls. The distances involved for the various sites can be seen in Table 4.1 showing the comparison between the road and simulator trials.

Table 4.1: ***Road and Simulator final measurement distances.***

	Road Stop	Simul. Stop	Road R'about	Simul. R'about	Road Right	Simul. Right	Road Left	Simul. Left
Non-treatment (control)	45m	45m	30m	30m	30m	30m	45m	45m
Treatment (transverse lines in the approach)	43m	42m	29m	30m	31m	30m	51m	44m

A modified canonical correlation analysis was used to compare the road and simulator trials. The distance points (occurring every metre) were substituted for subjects in the analysis process as these were the common element across all conditions. The two experiments (road and simulator trials) were represented as two experimental conditions as these were what needed to be compared (rather than the original conditions of treatment and control). Difference scores between the control and treatment site at each metre were represented as the two dependant variables for each condition (ie. experiment). It should be noted that in the text below, the term ***"participant"*** refers to people who took part in the experiments, whereas ***"subject"*** refers to where participants usually fit into the statistical frame work, being represented as distance points here.

Each dependant variable (control and treatment conditions) needed specific weightings for the linear combinations to be used in the canonical correlation, namely, positive one (equal across participants) for the control and negative one (equal across participants) for the treatment. This could not be achieved using existing statistical programs, so a special program was written and checked using Visual Basic™ in conjunction with Microsoft Excel ***5.0*** and can be seen in Appendix E. This program first calculated **a** correlation matrix between all participants in each condition (as dependant variables) across the distance points (as subjects), using the correlation formula for each matrix entry seen in equation 1.

$$r_{xy} = \frac{Cov_{xy}}{s_x \cdot s_y}$$ ***equation I***

From equation **1,** "Cov_{xy}" is the covariance between participant x and participant y, and "s" is the standard deviation of the same participant x or y (as specified in the subscript). From the correlation matrix, the canonical correlation was calculated using equation ***2.***

$$r_{XaYb} = \frac{\underline{a}' . R_{XY} . \underline{b}}{\sqrt{(\underline{a}' . R_X . \underline{a}).(\underline{b}' . R_Y . \underline{b})}}$$ ***equation 2***

In equation **2,** $\mathbf{R_{XY}}$ is the sub-matrix between road and simulator dependant variables (control and treatment participants), $\mathbf{R_X}$ is the sub-matrix between only the road dependant variables (control and treatment participants), and $\mathbf{R_Y}$ is the sub-matrix between only the simulator dependant variables (control and treatment participants). Also, $\underline{a}$ and $\underline{b}$ are vectors containing only 1s and **-1s** respectively representing the control and treatment site scores respectively, and $\underline{a}'$ and $\underline{b}'$ represent the transpose vectors of $\underline{a}$ and $\underline{b}$.

The resulting canonical correlations are to be compared with the critical value (r_c) taken as the square root of the greatest characteristic root (gcr) critical value $\theta_{\alpha\,(s,\,m,\,n)}$ taken from Harris **(1985)** Table **A.5,** where:

$$n = \frac{N - p - q - 2}{2}$$ ***equation 3***

$$m = \frac{|p - q| - 1}{2}$$ ***equation 4***

$$s = \min(p, q)$$ ***equation 5***

where:

N = **number of distance** points **(ie. as subjects)**
p = number of road participants (ie. as the dependant variables of the **road** condition)
q = number of simulator participants (ie. as **the dependant variables of the simulator condition)**

4.2 RESULTS

4.2.1 Critical Values

The critical canonical correlation for the Stop Sign Intersection approach, using **87** metres (the distance used in the simulator sites) is $r_c = \sqrt{\theta}_{0.05\ (2,\ -0.5,\ 40.5)}$ = **0.315.** The Roundabout approach used ***60*** metres, resulting in $r_c = \sqrt{\theta}_{0.05\ (2,\ -0.5,\ 27)}$ = 0.3997. The Right-Hand Curve with ***60*** metres of approach also has a critical level of $r_c = \sqrt{\theta}_{0.05\ (2,\ -0.5,\ 27)}$ = 0.3997, and the Left-Hand Curve with an 89 metre approach critical value using was $r_c = \sqrt{\theta}_{0.05\ (2,\ -0.5,\ 41.5)}$ = 0.310.

It should be stressed that using canonical correlations, a *significant* result means that there are ***NO DIFFERENCES*** between the two data sets, in contrast with usual statistical findings where no difference would be a non-significant finding. This was important for validation testing and, as mentioned earlier, why this particular statistic is valuable for this purpose.

Both data sets were analysed using the special program written in Visual Basic for this study (see Appendix **E).** The analysis compared the differences between the treatment and control responses at each site across the two test environments in arriving at statistical reliability. These results are re-presented again in this Chapter as single figures (i.e., with the road and simulator findings on a single plot) for each of the four road locations and for each dependent measure and described in terms of the correlation findings.

For ease of interpretation, they are presented again in order of the dependent variables with figures and descriptions opposite each other.

4.2.2 Speed

Figures 4.1 to 4.4 show the speed results for the road and simulator trials for the four road locations and the statistical interpretation of these findings is described below.

Figure 4.1 - STOP SIGN APPROACH **:** There was a significant correlation between the road and simulator stop sign approaches for the difference between the control and treatment speeds each metre ($r_{2, -0.5, 40.5}$ = 0.398). Thus, the two sets of speed results are correlated and not statistically different. The results show that 18% of the variance can be explained by the covariance between the two experiments.

From Figure 4.1, it can be seen that the difference between treatment and control sites for the simulator and road results in the approach to the stop sign intersection were quite similar. One notable albeit minor exception was the slower treatment speed in the simulator at the start of the trial (sector 1) and 45m before the commencement of the transverse lines. The overall speed difference between the treatment and control was very similar (3.64km/h for the simulator and 3.5km/h for the road) and both slower. Standard deviations for the simulator participants (14.3 and 15.2 km/h for treatment and control respectively) were larger than those from the road participants (9.5 and 8.1 km/h resp.).

Figure 4.2 - ROUNDABOUT APPROACH: The correlation between road and simulator trials for the difference in treatment and control speeds on the approach to the roundabout was not significant ($r_{(2, -0.5, 27)}$ = -0.180) thus revealing a significant differences between both sets of data. Speed differences were very small between the treatment and control sites and were similar both for the simulator and the road trials (0.78 cf 0.29 km/h respectively). Overall speeds were initially faster in the simulator than the road but this reversed when the vehicle entered the treatment zone and were much slower at the stop sign (presumably this meant that fewer vehicles entered the intersection without coming to a complete stop first in the simulator than on the road).

Figure 4.3 - RIGHT CURVE The difference between the treated and control results on the road and in the simulator was significantly correlated for the right-hand curve approach ($r_{(2, -0.5, 27)}$ – 0.516), with 27% of the variance being explained by the covariance occurring with the two experiments. Figure 4.3 shows that the speed profiles on the approach to the curve were quite similar, with mean speeds of 52.6km/h (treatment) and 56.4km/h (control) for the simulator compared to 53.3km/h and 52.1km/h for the similar road sites. The overall patterns of response in Figure 4.3 are also very similar between the two sets of data.

Figure 4.4 - LEFT CURVE There was also a significant correlation between road and simulator speed differences on the approach to the left-hand curve ($r_{(2, -0.5, 41.5)}$ = 0.477), with 26% of the variance explained by the covariance occurring with the two experiments. From Figure 4.4, it can be seen that the speed profiles between the simulator and road trials were in the same direction to each other (while there appears to be a larger difference between the treated and control sites **in** the simulator, it was not marked). Overall, the speeds in the simulator were slower (49.0km/h treatment and 57.9km/h control) compared to the respective road speeds (59.6km/h and 60.6 km/h).

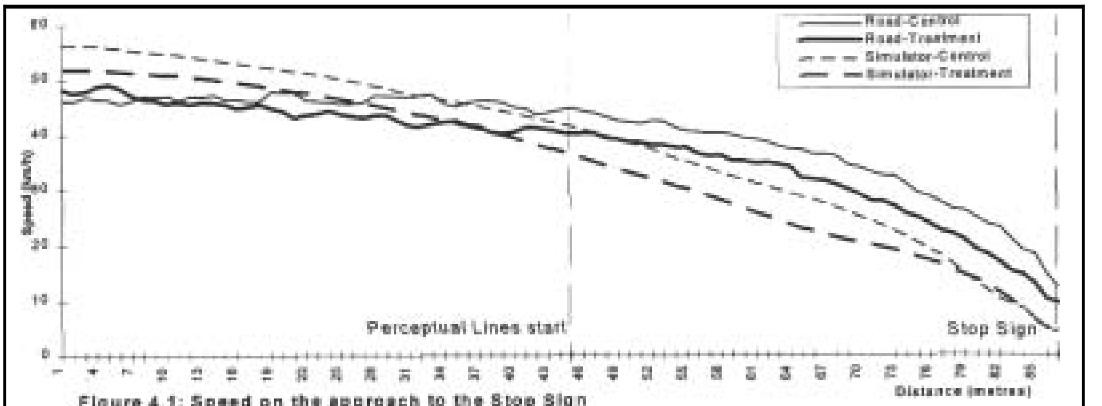

Figure 4.1: Speed on the approach to the Stop Sign

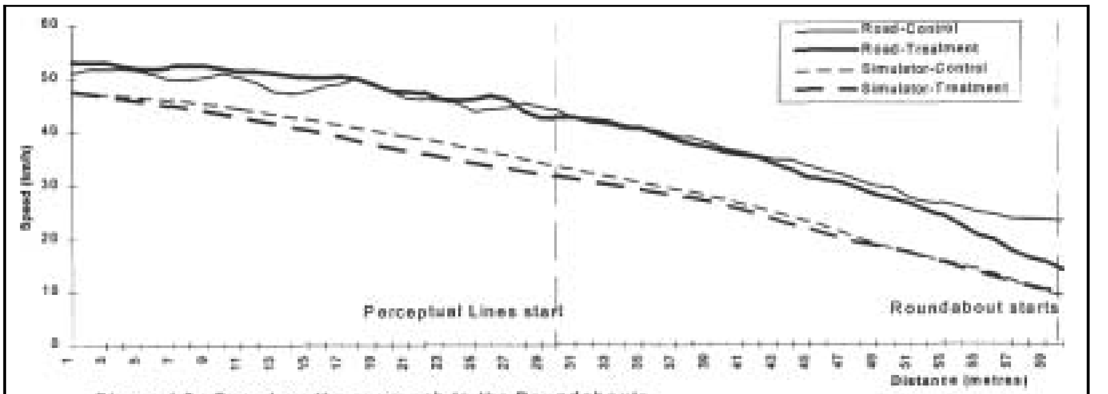

Figure 4.2 : Speed on the approach to the Roundabouts

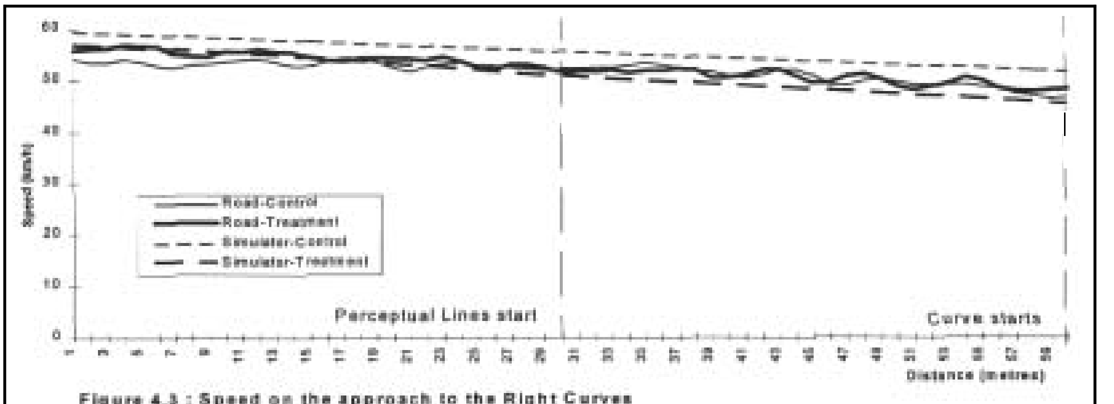

Figure 4.3 : Speed on the approach to the Right Curves

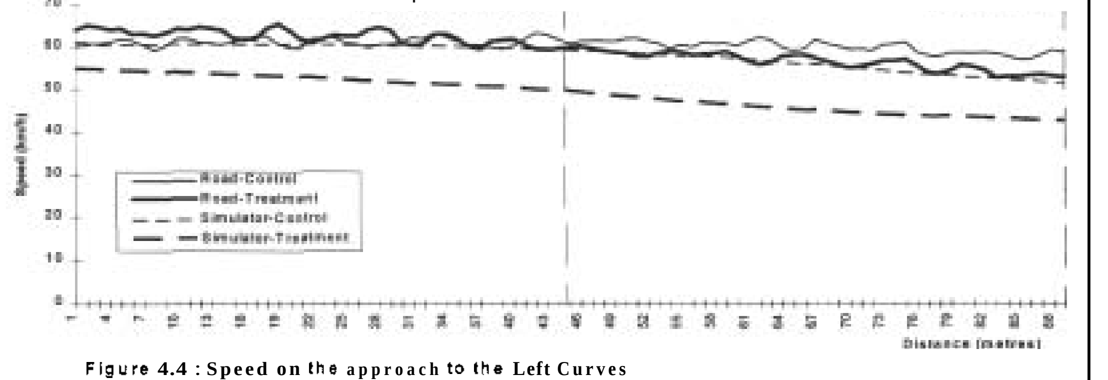

Figure 4.4 : Speed on the approach to the Left Curves

4.2.3 Brake Activity

The correlations for the on-off brake activity are shown in Figures **4.5** to **4.8** opposite and are described below in terms of the dependent variables of interest.

Figure 4.5 - STOP SIGN APPROACH: The correlation of braking at the control and treatment sites between the road and simulator experiments was not significant ($r_{(2, -0.5, 40.5)}$ = 0.016) and the two data sets are statistically different. Braking seems to have started much earlier in the simulator than the road trials for both the control and treatment sites as can be seen in Figure **4.5.** This may have been due to the road trials having both **stop** sign approaches on slight upwards slope, meaning less braking would be required to slow down to a stop. By contrast, the simulator trials contained zero slopes only.

Figure 4.6 - ROUNDABOUT APPROACH: The amount of braking was significantly correlated between the road and simulator for the differences in control and treatment on the approach to the roundabout ($r_{(2, -0.5, 27)}$ = **0.412).** Braking profiles for the roundabouts showed similar patterns up to 10 metres before the start of the rumble lines, but after that, a much greater number of participants in the road trials used the brake than in the simulator trials.

Figure 4.7 - RIGHT CURVE For the right curve approaches, a significant correlation was obtained when comparing the road and simulator trials ($r_{(2, -0.5, 27)}$ = **0.404).** The right curve approaches braking profiles were also similar between the road and simulator participants up until around 10 metres before the rumble lines after which less simulator participants applied the brake compared to the number of road participants.

Figure 4.8 - LEFT CURVE **A** significant correlation also was found for the amount of braking on the left curve approaches between the road and simulator trials ($r_{(2,-0.5, 41.5)}$ =0.619). In the simulator trials, there appeared to be fewer participants braking every metre compared to the number of road participants but this was not statistically robust. **As** these measurements are only binary, it is quite possible that when the brake was being used, the braking pressure was different between the two sets of participants.

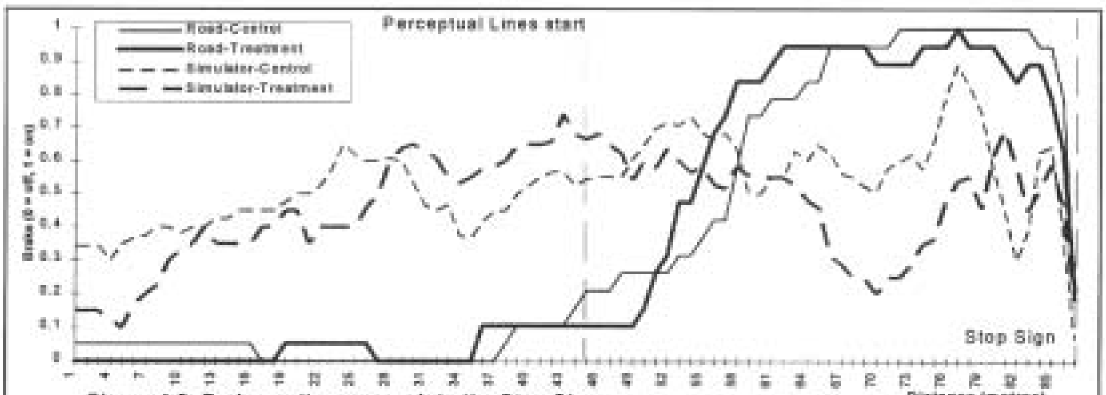

Figure 4.5: Brake on the approach to the Stop Sign

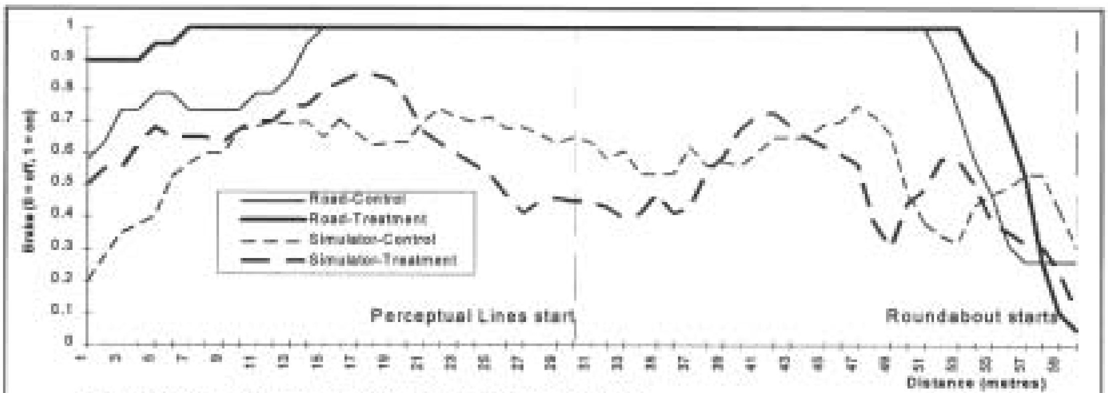

Figure 4.6 : Brake on the approach to the Roundabouts

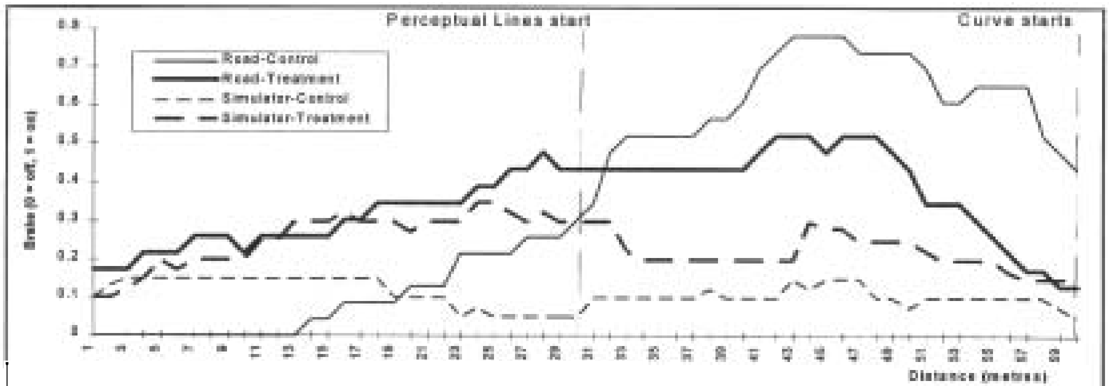

Figure 4.? : Brake on the approach to the Right Curves

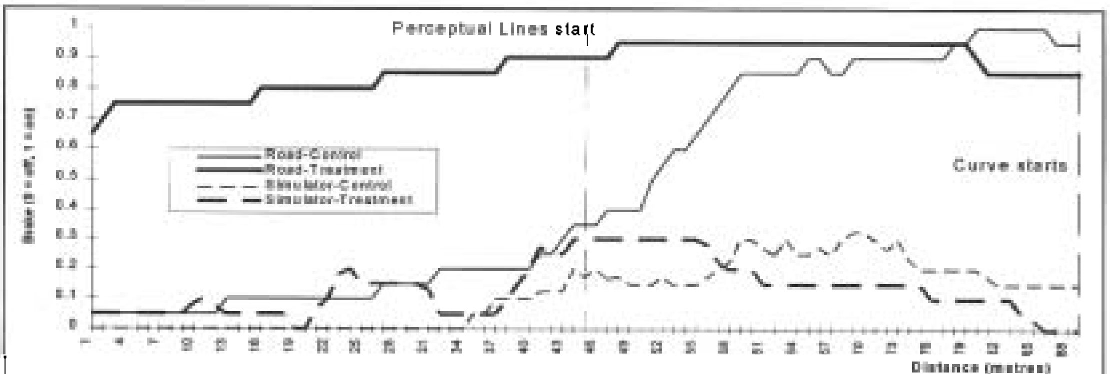

Figure 4.8 . Brake on the approach to the Left Curves

4.2.4 Deceleration

The deceleration correlations are shown graphically in Figures **4.9** to **4.12** and are described below.

Figure 4.9* - *STOP SZGNAPPROACH: The correlation for deceleration on the approach to the stop sign was significant but negative **($r_{(2,\ -0.5,\ 40.5}$ =-0.525)** showing that while they are statistically related, the trend for the road trials was opposite to that obtained in the simulator. This can be seen in Figure **4.9** where reverse patterns were obtained for the treatment effect on the road and in the simulator (i.e., when the treated site had ***less*** deceleration than its control on the road, ***greater*** deceleration was observed in the simulator).

This should be viewed with some caution, however. Up to the final 20 metres before the stop sign, there was more deceleration generally in the simulator than on the road. This could have been due to the characteristics of the road at these sites as there was a slight uphill section of road leading to the intersection and so less deceleration would have been needed in coming to a complete stop. By contrast, the same intersection in the simulator was completely flat and would have required more deceleration up to the stop line. In short, the negative correlation **was** probably the result of shortcomings of the matching up of sites between experiments, rather than any real difference between the simulator and the road.

Figure 4.10* - *ROUNDABOUT APPROACH: The correlation between treatment and control deceleration in the simulator and on the road at the roundabout site was not significantly different ($r_{(2,-0.5,27)}$=-.042), thus this measure was not reliable. Interestingly, the pattern of results for both sets of trials appeared to be quite similar, even though the treatment differences were not statistically related.

Figure 4.11* - *RIGHT CURVE: For the right-hand curve approaches, there was not a significant correlation between treatment and control differences in deceleration on the road and in the simulator **($r_{(2,\ -0.5,\ 27)}$ = 0.053).** Again, though, the pattern of deceleration was quite similar, even if the treatment differences were not robust.

Figure 4.12* - *LEFT CURVE: The correlation between the treatment differences on the road and in the simulator in the approach to the left-hand curve was significant, however, ($r_{(2\text{-}0.5,41.5)}$=0.378).

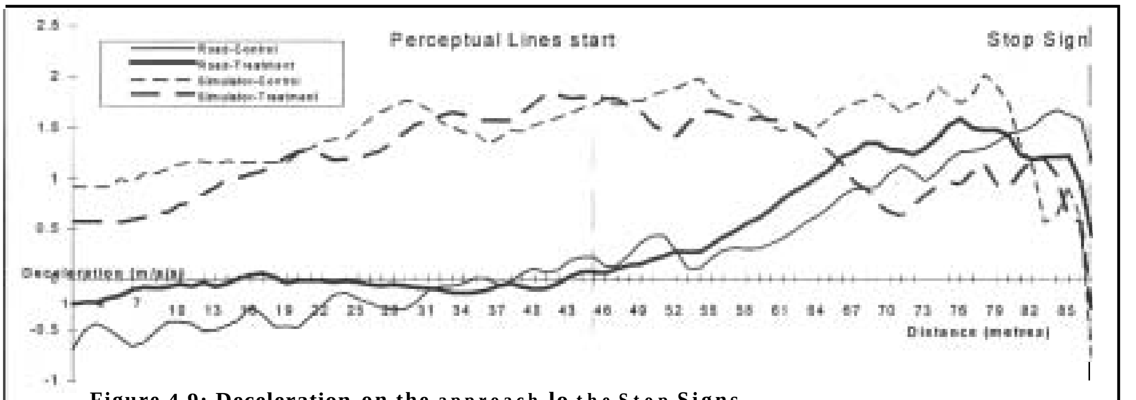

Figure 4.9: Deceleration on the approach lo the Stop Signs

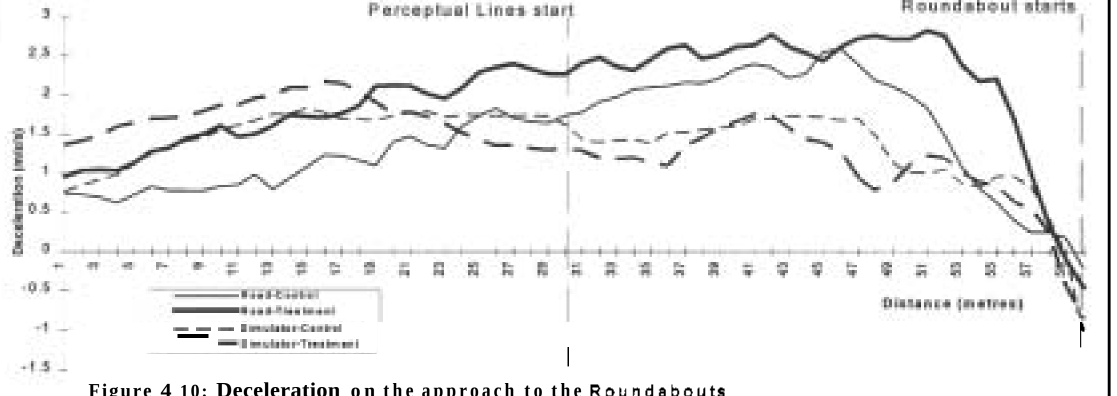

Figure 4 10: Deceleration on the approach to the Roundabouts

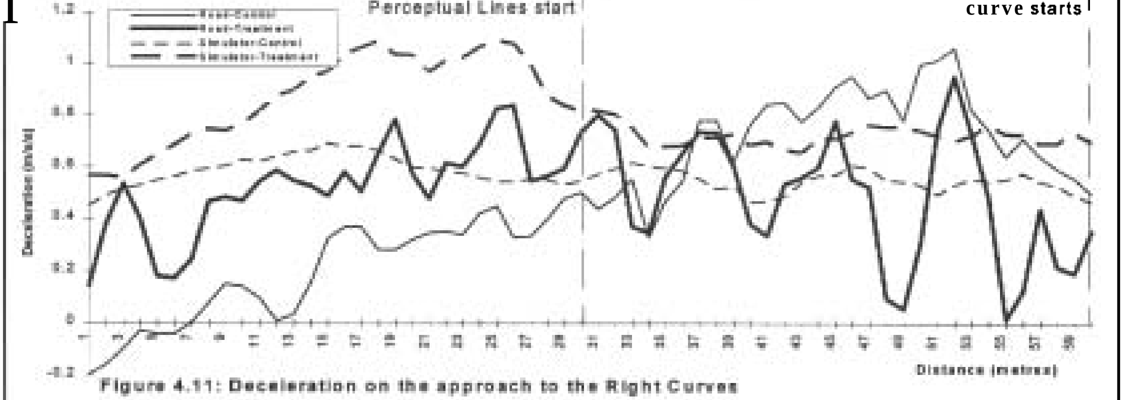

Figure 4.11: Deceleration on the approach to the Right Curves

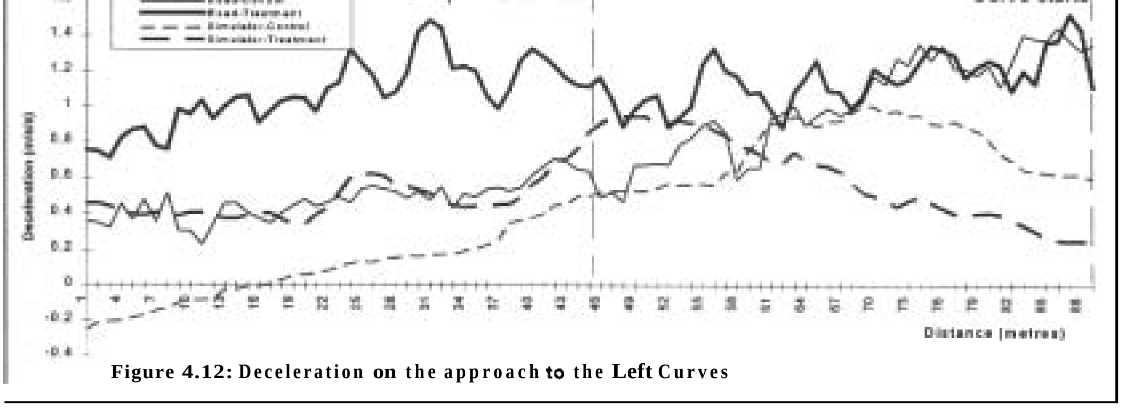

Figure 4.12: Deceleration on the approach to the Left Curves

4.2.5 Deceleration Change

The pattern of deceleration change occurring every metre between the treatment and control sites did ***not*** correlate at all between the road and simulator trials for any site as can be seen in Figures 4.13 to 4.16 opposite.

These non-significant correlations were:

- for the stop sign approach ($r_{(2, -0.5, 40.5} = 0.017$),
- for the roundabout approach ($r_{(2, -0.5, 27)} = -0.139$),
- for the right-hand curve approach ($r_{(2, -0.5, 27)} = 0.208$), and
- for the left-hand curve approach ($r_{(2, -0.5, 41.5)} = -0.074$).

These findings confirm that deceleration change per metre is not likely to be a valid measure of driver performance when testing perceptual countermeasures in the TAC Driving Simulator. Interestingly, though, the overall pattern of results was similar in both test environments, even if the treatment effects could not be statistically validated.

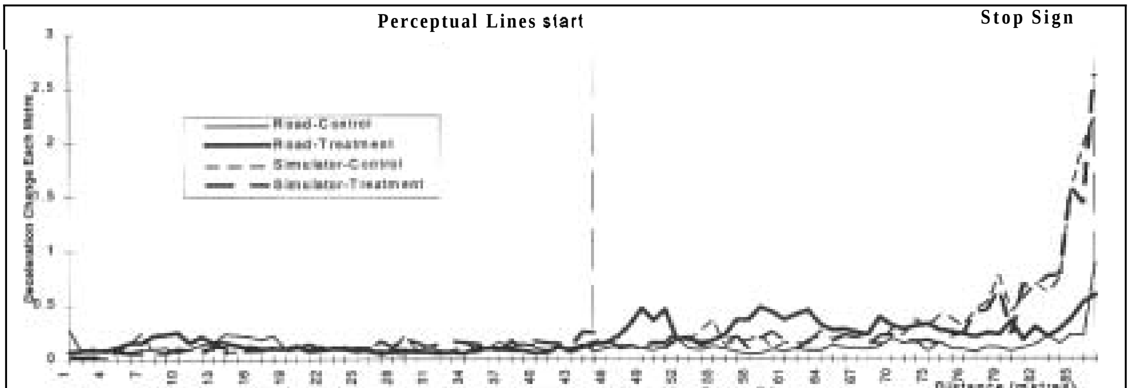

Figure 4.13: Deceleration change each metre approaching the Stop Sign

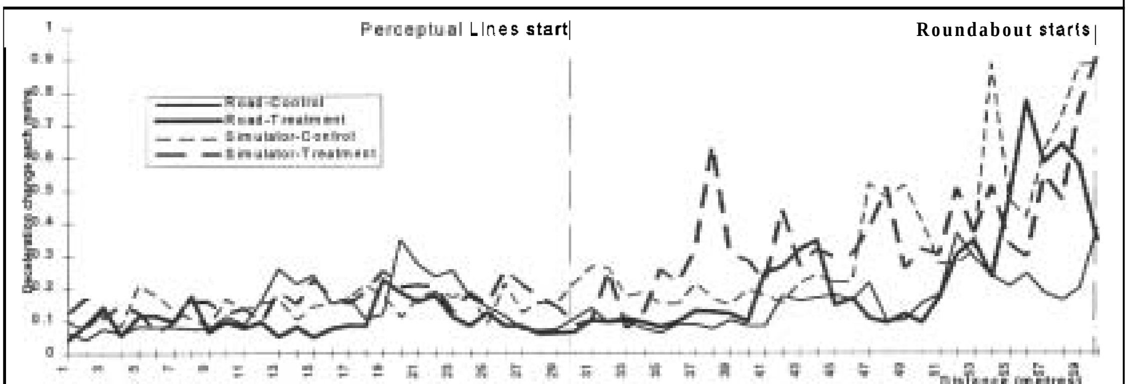

Figure 4.14: Deceleration change each metre approaching the roundabout

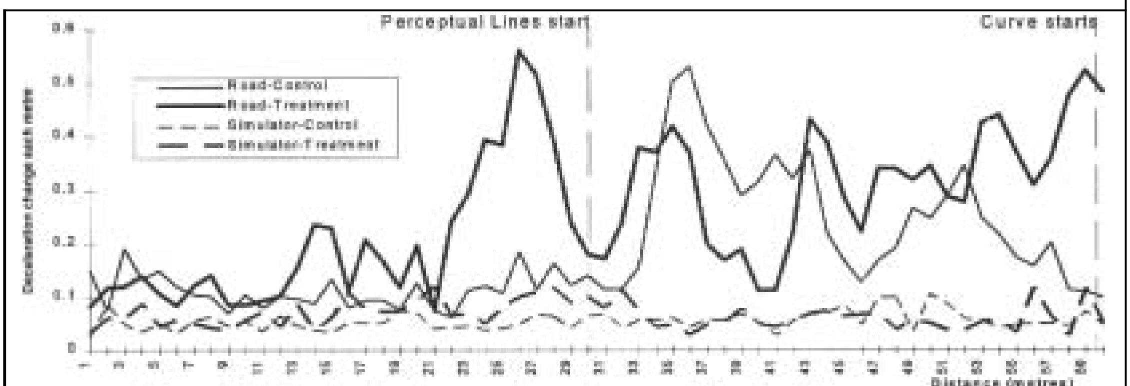

Figure 4.15: Deceleration change each metre approaching the RH curve

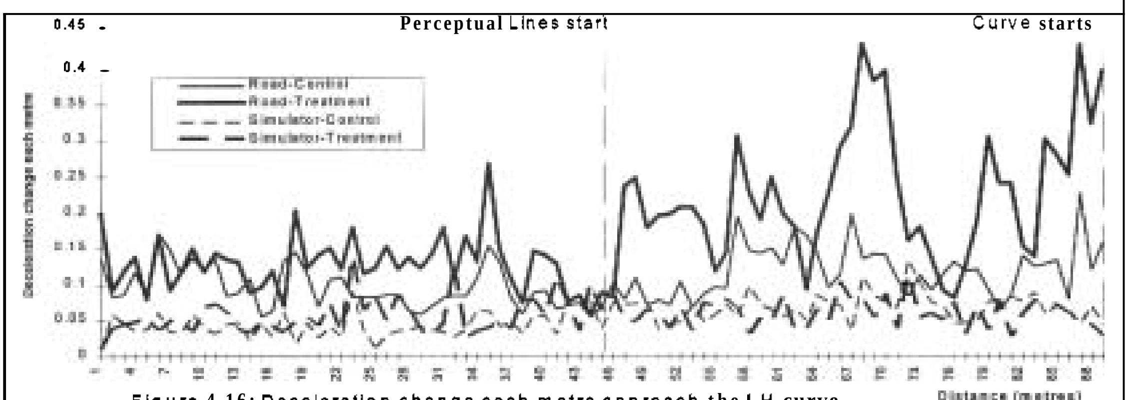

Figure 4.16: Deceleration change each metre approach the LH curve

4.2.6 Lateral Placement

The lateral placement results are shown in Figures **4.17** and **4.18** below. The correlations for both the right-hand and left-hand curves were not significant ($r_{(2,-0.5,27)}=-0.297$ and $r_{(2,-0.5,41.5)}$ = **0.214** respectively). **This,** again, is possibly a function of the large amount of variance obtained for the road trials because of interruptions in the centreline and its reliance in determining the vehicle position by its on-board measuring equipment.

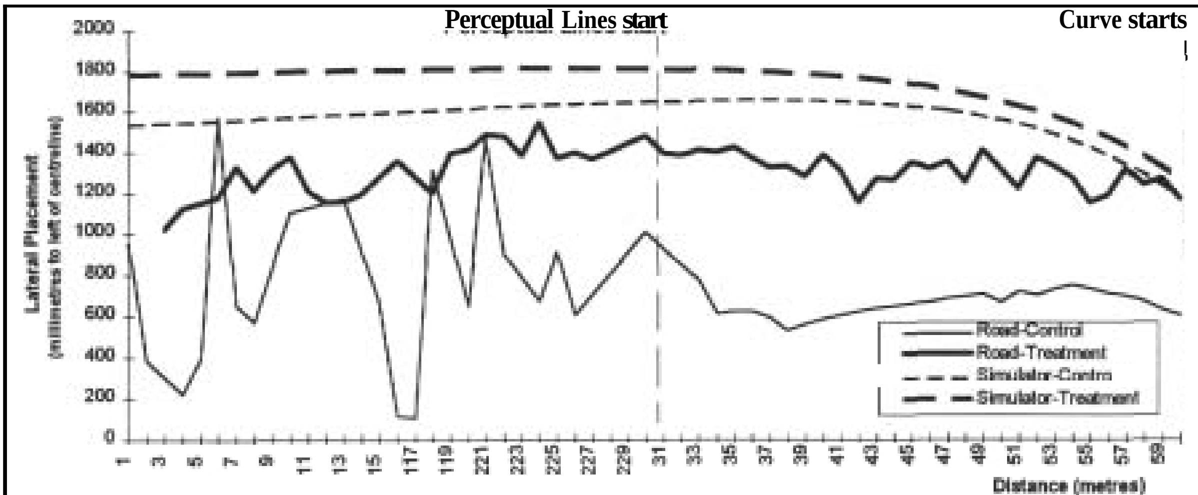

Figure 4.17: Lateral Placement on the approach to the Right Curves (with interpolation for missing data)

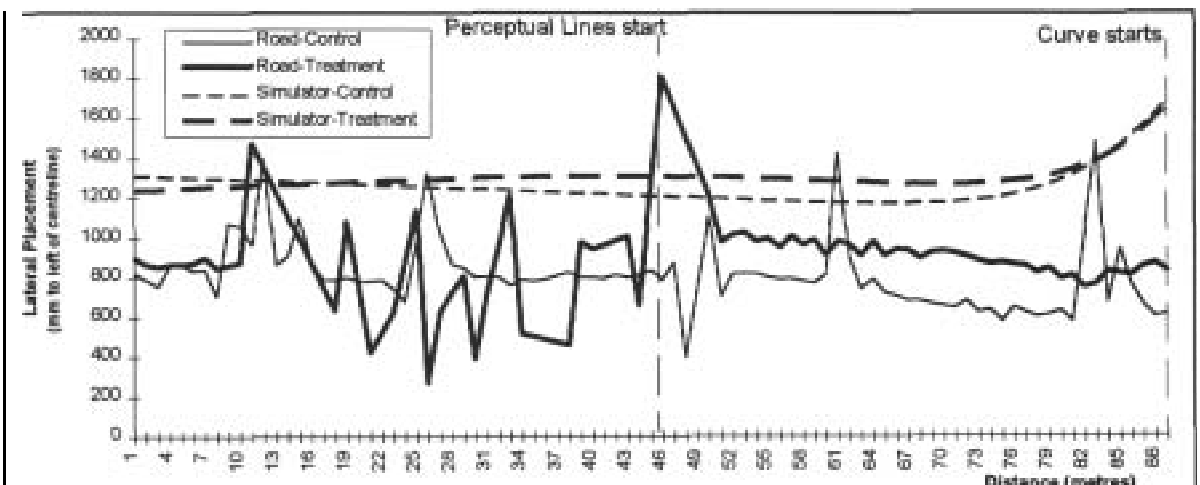

Figure 4.18: Lateral placement on the approach to the Left Curve
(with **interpolation for missing data)**

4.3 DISCUSSION

The canonical correlation analysis was undertaken to assist in the process of validating the TAC Driving simulator as a test environment for perceptual countermeasures in terms of the various dependant measures available. It was considered important that statistical validation be established in addition to the general validation carried out in the previous Chapter **3.** As well as confirming that the simulator is a valid test environment for these road treatments, the two approaches are also useful in helping to decide which measures can legitimately be used in the simulator and which ones cannot. The following discussion is based primarily on the statistical correlations, but also incorporates the findings of the earlier chapters.

4.3.1 Speed

Correlation was established for speed at the stop sign and left-hand and right-hand curve approaches, but not for the roundabout approach. All three of the correlated sites, in both the simulator and road trials, showed that transverse lines did lead to slower approach speeds when approaching a curve or intersection, with speed reductions starting in advance of the transverse lines. The simulator did produce a *greater* speed difference between its treatment and control sites and this difference started to occur *earlier* on the approach than it did on the road. Thus, the simulator may enhance speed effects slightly at these locations but this is unlikely to be a problem for future experimentation.

The fact that the roundabout did not produce a similar between-experiment speed relationship probably has more to do with the way people generally reacted to the simulated roundabout, regardless of whether it was a treatment or control site. This seems to have been a function of the roundabout used in the simulator and the adverse consequence of severe steering movements in a simulated environment that cannot perfectly reproduce real world driving forces. It would be desirable not to use roundabouts in future perceptual countermeasure experiments as they cannot be relied on to generate accurate speed results as well as tending to produce simulator discomfort among the participants.

The graphical representation of the speed results seen in Figures 4.1 to 4.4 between the road and simulator experiments were slightly different in that the simulator trials were more smooth than those obtained on the road. This is due to slight differences in the measurement methods, rather than any real difference in driving patterns. The instrumented car in the road trials did not respond to every minute change in speed, but only if the speed did not return to the original level after several data collection periods at 30Hz, resulting in greater jumps in the speed profiles. The simulator however recorded each specific speed as it was at each measurement, resulting in the smoother curves seen in the above figures. It is very likely that the correlations found here would be even higher than they were if the measurement methods had been identical.

4.3.2 Braking

Three of the four sites had significant correlations for the amount of braking, with the only exception being the stop sign approach. Thus, it would seem that the level of braking using the foot brake was similar between the simulator and the road. However, there were considerable differences in the levels of braking between the two experiments as shown in Figures 4.6 to 4.8 and discussed in the previous Chapter. In general, the level of braking on the simulator was less than it was in the road trials and this was evident both before and during the treatment for both treated and untreated locations. In fact, the simulator responses were clearly more variable than those on the road which offers a higher degree of sensitivity for judging performance differences. So, while the braking response was clearly different in the simulator, it is still a valid measure and likely to be more useful in this test environment than on the road.

It **was** also noted earlier that the amount of braking was a more gross measure of performance and that braking pressure might be a more useful measure. It was not possible to test this feature on the road as the instrumented vehicle had no provision for measuring braking other than whether the brake was on or off. The simulator, in fact, does allow for measuring brake pedal pressure. It might be useful, therefore, to use the braking pressure facility of the simulator as a supplementary measure in further experimentation, even though it has not been tested in terms of its validity.

4.3.3 Deceleration & Deceleration Change

Deceleration correlation was only significant and positive for the left-hand curve, even though the deceleration patterns were quite similar for the roundabout and all curves. In addition, the differences between treatment and control fluctuated much more on the road than in the simulator where responses were more smooth (this was also noted in the discussion of the simulator results in the previous Chapter). This may have been a function of the different methods of measurement in both test settings, where the road measures were obtained from an on-board accelerometer and the simulator measures derived from speed and time differences. While speculative, correlations may have been higher if these measures had been the same. In any event, these findings cast doubt on the reliability of using deceleration as a measure of a driver's performance to perceptual countermeasures in the simulator.

The deceleration change variable did not seem to be at all sensitive in the simulator producing no significant results for the simulator trials even though it did for the road trials. When the two experiments were compared, it did not result in any significant correlations. It would seem therefore that deceleration change each metre is not a valid dependant variable to be using in future simulator experiments dealing with perceptual countermeasures.

4.3.4 Lateral Placement

The correlation analysis **was** a little disappointing for the lateral placement measures because of the presence of considerable fluctuations in lateral position in the on-road data set. **As** noted earlier, this was because of the use of a standard broken centreline in these locations and the periodic lack of a baseline measure for the vehicle's scanning device when adjacent to a gap. In addition, some of the centrelines had deteriorated substantially and the scanner was unable to log these low contrast lines. It was argued that the correlations would likely have been significant had these two data sets been of similar quality.

Even so, the findings for lateral position results on the road and in the simulator do suggest a degree of consistency between these data when the lines were available, albeit of different magnitude of effect. In both trials, drivers choose to move further away from the centreline in the presence of the transverse lines with a greater effect present in the road trials than those in the simulator. In light of this, future experiments using the simulator should not disregard the lateral placement measures at curves on the grounds of these results, although caution should be taken before claiming validity of this measure to the real world.

4.4 CONCLUSION

Collectively, these results confirm that the TAC Driving Simulator at the Monash University Accident Research Centre is a suitable test environment for developing and evaluating drivers' speed responses to perceptual countermeasures.

The results showed that the most important measure for future simulator experimentation in perceptual countermeasures is travel speed. The speed effect was consistent and significantly correlated in the on-road and simulator responses and displayed similar patterns of response in both data sets. The effect of the amount of braking was also well correlated in the road and simulator data, although the patterns of these two sets of responses were a little more varied. It was argued that braking pressure might also be a useful supplementary measure, even though it was not evaluated here. The lateral placement findings were disappointing because of poor quality road data and statistical correlations could not be established. However, the patterns of responses in the simulator and on the road were sufficiently similar to suggest it be included as a dependant variable in future PCM experiments. Deceleration change does not appear to be a valid simulator measure and it is recommended that it *not* be used in future experimentation in this area.

Importantly, though, the validation study did confirm that a full research program aimed at evaluating (and possibly developing) a range of additional perceptual countermeasures is warranted using the relatively safe driving environment away from the potential dangers of on-road experimentation. **A** detailed plan of a full experimental research program aimed at reducing travel speed at various road locations has been developed and will be reported on in subsequent reports.

Chapter 5 Perception Versus Alerting Mechanisms

Previous reports of the effectiveness of perceptual countermeasures have questioned Denton's (1971; 1973) theoretical account of the mechanisms behind these treatments. Denton argued that PCMs operate by influencing the perceptual array presented to the driver thereby leading to a more conservative behavioural response. Fildes, Fletcher and Corrigan (1987) and Fildes, Leening and Corrigan (1989) also argued that the road and road setting can have a marked influence on driving through perceptual modification. In subsequent testing of a series of transverse line treatments on roads in rural Victoria, however, Jarvis (1989) claimed that the speed reductions measured at transverse line locations relative to similar control sites could also be explained simply in terms of their "alerting influences" on the driver.

Many of these treatments also create a rumble effect as cars pass over them because they commonly comprise thick cross-sections of either paint or plastic materials that cause the car to "bump" as the wheels pass over them. However, as drivers generally visually negotiate the road approximately 3 seconds ahead of their Current position (Shinar 1977) and at times up to 8 seconds ahead of their current position (McLean & Hoffman, 1973), the perceptual effects of these treatments on driving should be apparent well ahead of them. Of course, another type of alerting mechanism is simply their visual presence, what is sometimes called a "novelty effect". However, as most of the drivers who pass over these sites are locals who would be expected to adapt to their presence, these effects usually disappear with time. Jarvis (1989) did report long lasting speed reductions which could not be fully explained through such novelty effects.

This validation study presented an opportunity for a preliminary test of the theoretical basis of perceptual countermeasures, namely whether they achieve speed reductions through a purely perceptual mechanism or whether there are also alerting mechanisms to these treatments. This could be achieved simply by manipulating the rumble effect in the simulator. A third experiment was undertaken to address this issue.

5.1 METHOD

A second simulator experiment was undertaken using the same materials and procedure as that reported in Chapter 3. The same road database was presented to the participants, only this time with the perceptual lines but without the associated motion platform "bump". By comparing the results from this experiment with the previous ones, it was possible to compare perceptual aspects with and without rumble.

A second group of *20* participants (12 male and 8 female) of mean age 30.75 years (range 22 to 49 years) was recruited and tested in exactly the same manner as previously. Instructions, practice and experimental procedure from the previous experiment were used again including the same randomisation of presentation order.

5.2 DATA ANALYSIS

An Analysis of Variance (ANOVA) was used to compare the results of the transverse line effects, with and without rumble. The analysis design consisted of a between-subjects factor (two levels of experiment to represent the rumble effect) and two within-subjects factors as in previous analyses. Main and simple effects analysis were undertaken to highlight differences between and within each experiment. The previous ANOVA analysis reported in Chapter 3 represented the simple effects analysis for the line plus rumble treatment "***Rumble***" and a similar analysis was undertaken here for the transverse line only treatment ***"PaintedLine".***

As both these experiments were undertaken on the simulator, it was possible to include a measure of both amount and pressure of braking. For these data, zero indicated that the pedal was not depressed and 100 indicated that the pedal was being pushed as hard as possible towards the floor. In addition, as deceleration change was not validated between the road and simulator for the reasons previously mentioned, it was excluded from the analysis.

For the analysis of the between-subjects contrasts, the data needed to be normalised to control for gross differences in response level and ensure the comparisons were unambiguous and meaningful. For each experimental condition, z score transformations were used as specified by Ferguson (1971). Treatment site data were transformed into z scores by using the mean and standard deviation values from ***its own control site*** to control for differences between the two experimental conditions from the use of different participants.

5.2.1 Critical Statistical Levels And Weightings

A two level approach was taken with regards to statistical significance of the planned orthogonal contrasts used in the analysis. One level involves controlling the Hays decision-wise error rate at 5%, with the other involving a Bonferroni adjusted family-wise error rate of 5%, taking into account the number of dependant variables being analysed for a particular site. The stop sign and roundabout approaches had ***three*** dependant variables for analysis (speed, brake, and deceleration) while the right- and left-hand curves had ***four*** variables (the same three above plus lateral placement). Thus when a Bonferroni adjusted family-wise critical F is exceeded, the result will be recorded as ***statistically significant.*** When however the decision-wise F is exceeded but not the Bonferroni adjusted family-wise F, the result will be recorded as a ***judgement reserved.*** If the decision-wise value is not exceeded, it will be recorded as a ***non-significant*** result.

The simple effect within-subjects contrasts have a decision-wise critical F of $F_{0.05;1,19}$ = 4.381, and a Bonferroni adjusted critical F of $F_{0.05/3;1,19}$ = 6.891 for the stop sign and roundabout approaches, and $F_{0.05/4;1,19}$ = 7.610 for the right and left curves. The between-subjects contrasts (comparing across the rumble and paint only conditions) have a decision-wise error rate of $F_{0.05;1,38}$ = 4.098, with the Bonferroni adjusted F of $F_{0.05/3;1,38}$ = 6.273 for the stop sign and roundabout approaches, and $F_{0.05/4;1,38}$ = 6.876 for the right and left curve approaches.

5.3 RESULTS

These data have been analysed in terms of the dependent variables of interest, namely speed, braking, deceleration and lateral position. Results from the first simulator experiment reported in Chapter **3** are re-presented here in conjunction with the results found from this experiment as a contrast of the effects of transverse lines with associated rumble and transverse lines without rumble.

For reasons of clarity in presenting these data, the previous results will be referred to as the rumble effects while the new findings are referred to as ***painted line only*** effects. It should be stressed that any "rumble effects" are derived from both transverse lines and rumble stimuli, not just rumble effects alone.

The results are presented as a series of graphs as in previous Chapters. **As** interest was principally in the effect with and without rumble, the results will only highlight any differences between the previous line plus rumble and this line only experiment. The graphs and associated descriptions are presented on adjacent pages for ease of reading and interpretation.

5.3.2 Speed

The speed results can be seen in Figures **5.1** to 5.4, showing the treatment and control speed profiles for each experimental condition on the same graph and are described below.

Figure 5.1* - *STOP SIGN APPROACH: In contrast with the earlier results, there was ***no*** significant overall difference between the treatment and control speeds on the approach to the stop sign for the line only condition ($F_{1,19}$=0.29, p=0.596). In addition, there was a significant interaction observed between the treatment and control sites ($F_{1,38}$=6.63, p=0.014). The rumble plus painted line treatment speed was ***slower*** overall than its control (3.63 km/h) while the painted line only treatment and control were not statistically different. The interaction was the result of the speed difference reversal between treatment and control observed for the painted line only condition was did not happen with the line plus rumble condition. None of the three way interactions were significant ($F_{1,19}$=1.42, p=0.240 & $F_{1,19}$=1.63, p=0.209 resp.).

Figure 5.2 - ROUNDABOUT APPROACH: Consistent with the earlier finding, there was again no significant overall speed difference in the approach to the roundabout for the line only condition ($F_{1,19}$=2.81, p=0.110). The speed differences between treatment and control from these two experimental conditions were also not significantly different from each other ($F_{1,38}$ = 0.05, p = 0.822). There were no significant 3-way interactions across the distance sections, sites and experimental conditions ($F_{1,38}$=0.08, p=0.777, $F_{1,38}$=0.12, p=0.728 & $F_{1,38}$=0.01, p=0.909 resp.).

Figure 5.3 - RIGHT CURVE: Figure 5.3 shows similar treatment effects in the approach to right-hand curves with or without rumble effects. For the painted line only condition, overall speeds at the treatment site were again slower than at the control ($F_{1,19}$=5.72, p=0.027, judgement reserved). There was no significant interaction between the rumble and painted conditions for the differences in their treatment and control sites ($F_{1,38}$=0.71, p=0.404), although there was a significant three-way interaction where the treatment effect was smaller during the first section and greater during the last three sections for the rumble condition, but opposite for the painted condition ($F_{1,38}$=4.35, p=0.044, judgement reserved).

Figure 5.4 - LEFT CURVE: The treatment speed was again slower approaching the left-hand curve in both data sets. For the painted line only condition, the approach speed was 3.9km/h slower at the treated site than at its control ($F_{1,19}$=17.18, p=0.001). There was a significant interaction between treatment effect and experiment where the addition of rumble lead to an even slower approach speed (8.92 km/h) than for the painted line only condition (3.94 km/h; $F_{1,38}$=6.61, p=0.014, judgement reserved). There were however no significant three-way interactions ($F_{1,38}$=0.69, p=0.412, $F_{1,38}$=0.14, p=0.715 & $F_{1,38}$=0.13, p=0.717 resp.).

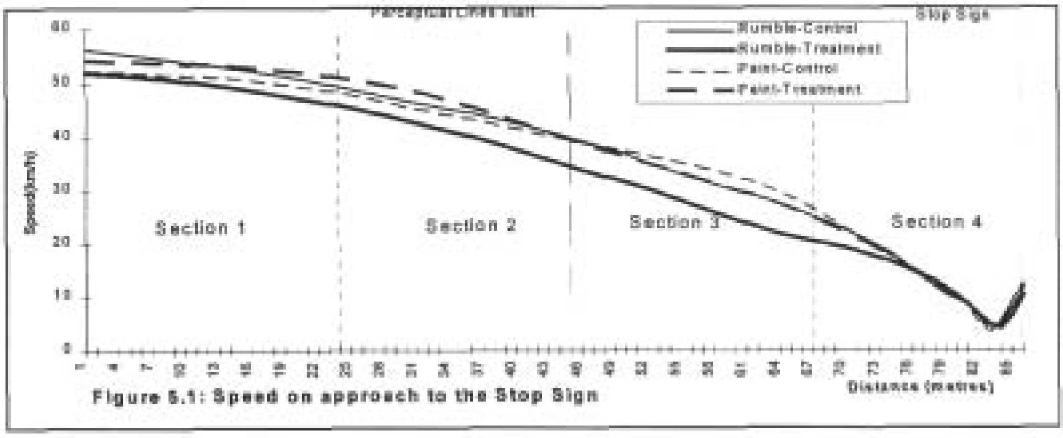

Figure 5.1: Speed on approach to the Stop Sign

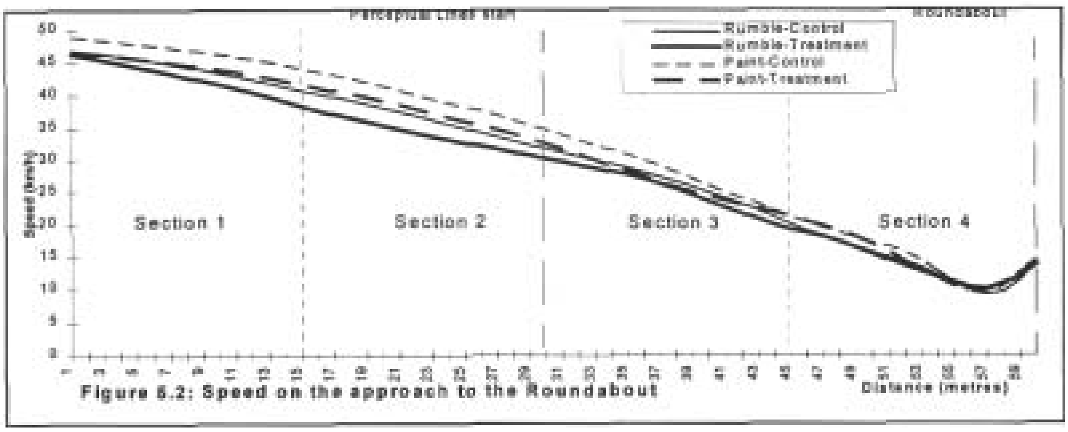

Figure 5.2: Speed on the approach to the Roundabout

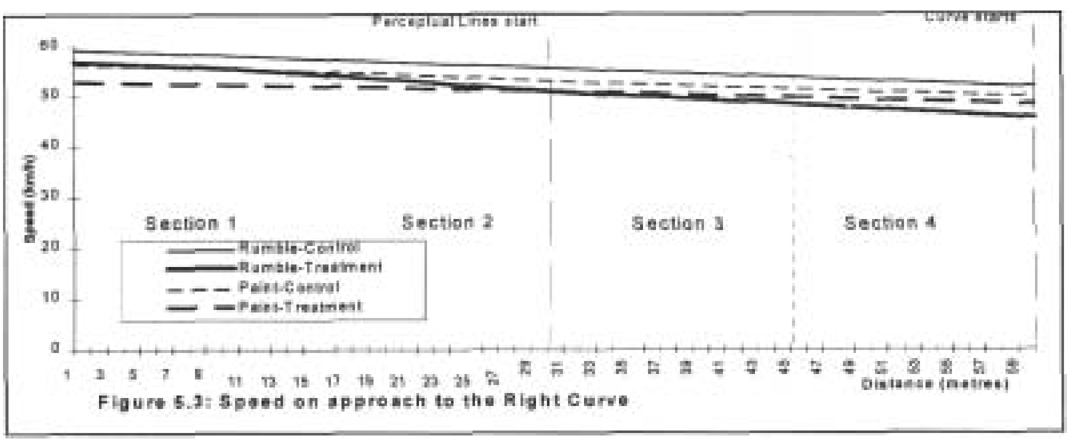

Figure 5.3: Speed on approach to the Right Curve

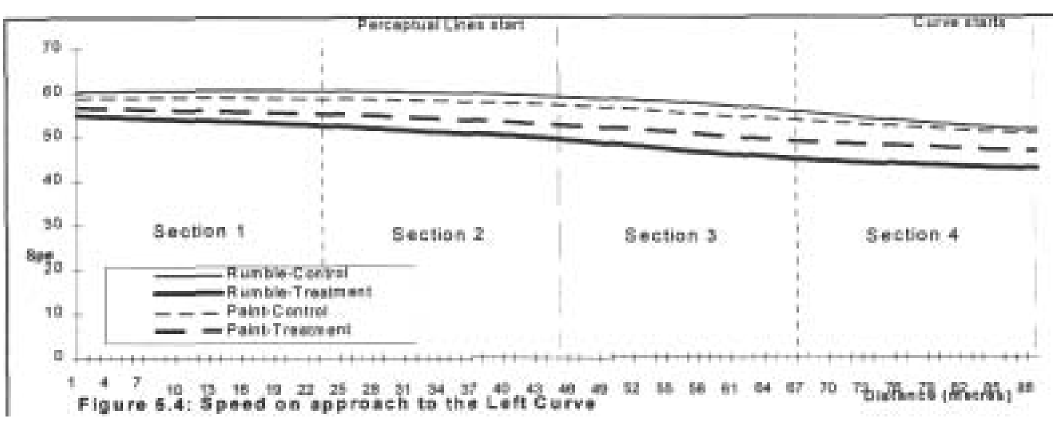

Figure 5.4: Speed on approach to the Left Curve

5.3.3 Brake

The results for braking reported here were for how hard the brake foot pedal **was** depressed and are shown in Figures 5.5 to 5.8 opposite and described below.

Figure 5.5 - STOP SIGN APPROACH: For the rumble only condition, treatment lead to the participants applying less pressure than for the same controls ($F_{1,19}$=5.56, p=0.028, judgement reserved). For the painted line only condition, there was no significant difference in the amount of brake pressure applied between the treated and untreated sites ($F_{1,19}$=0.09, p=0.355). Not surprisingly, there was a significant interaction between treatment and experiment where the rumble condition had significantly ***less*** braking pressure overall than the painted line condition ($F_{1,38}$=6.31, p=0.016). There were no higher order interactions observed with the distance sections ($F_{1,38}$=0.82, p=0.370, $F_{1,38}$=0.04, p=0.842 & $F_{1,38}$=0.02, p=0.890 resp.).

Figure 5.6 - ROUNDABOUT APPROACH: For the rumble only condition, there was no overall difference in the amount of brake pressure applied on the approach to the roundabout between treatment and control ($F_{1,19}$=0.02, p=0.893) while for the painted line only condition, marginally less braking pressure was applied at the treated sites ($F_{1,19}$=4.84, p=0.040, judgement reserved). There was, however, no significant difference overall in the amount of brake pressure applied at the treated roundabout sites with or without rumble ($F_{1,38}$=0.71, p=0.403) and no significant higher order interactions either ($F_{1,38}$=0.66, p=0.421, $F_{1,38}$=0.02, p=0.886 & $F_{1,38}$=0.43, p=0.517 resp.).

Figure 5.7 - RIGHT CURVE: There **was** no significant difference in braking pressure approaching the treated right-hand curves than the untreated equivalents for the rumble condition ($F_{1,19}$=4.17, p=0.055). During the first distance section for the treated site in the painted-line only condition, none of the participants applied the brake at all, resulting no variance. However, after that, no significant difference in braking pressure was again found between the treatment and the control sites ($F_{1,19}$=2.20, p=0.154). There was a hint of a significant interaction between treatment effect and experiment ($F_{1,38}$=6.29, p=0.017, judgement reserved) but this can probably be explained solely by the lack of variance for the treated site in the first sector of the painted line only condition. Surprisingly, though, there were no significant three-way interactions with each of the four sectors ($F_{1,38}$=1.13, p=0.293, $F_{1,38}$=1.36, p=0.250 & $F_{1,38}$=0.22, p=0.642 resp.).

Figure 5.8 - LEFT CURVE. For the rumble condition, there was no brake pressure at all during the first distance section at the control site (and practically none at the treated site), resulting in little variance, Moreover, there was no significant difference in the amount of braking pressure applied after that either ($F_{1,19}$=0.02, p=0.879). Similarly, there was no brake applied at all during the first distance section at the control site in the painted line only condition and again no significant difference in the amount of braking pressure between the treatment and control sites for the remaining sections ($F_{1,19}$=0.14, p=0.717). Consequently, there was no treatment difference across the two experimental conditions either ($F_{1,38}$=0.05, p=0.822) and no higher order interactions ($F_{1,38}$=0.26, p=0.612, $F_{1,38}$=0.29, p=0.594 & $F_{1,38}$=0.69, p=0.410 resp.).

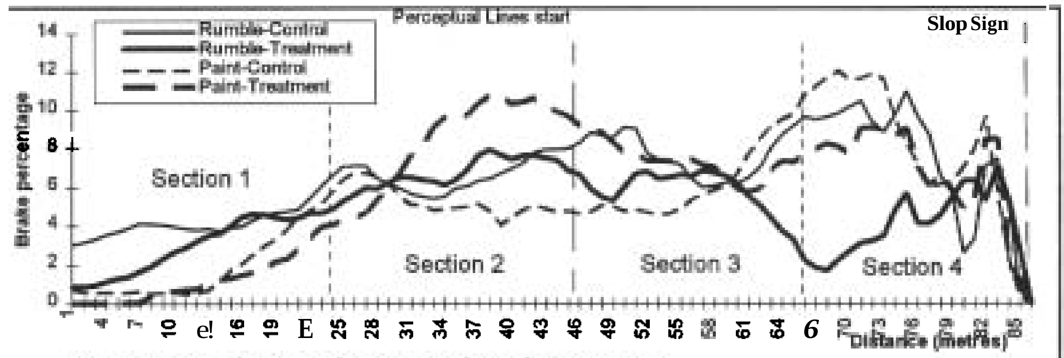

Figure 5.5: Braking on the approach to the Stop Sign

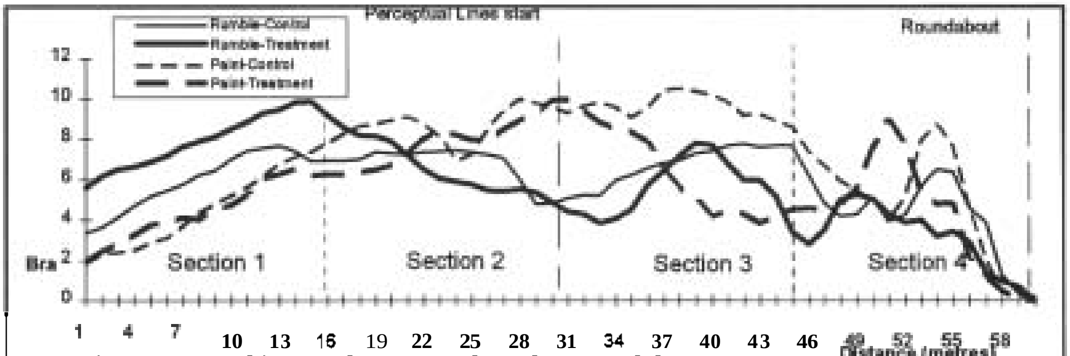

Figure 5.6 Braking on the approach to the Roundabout

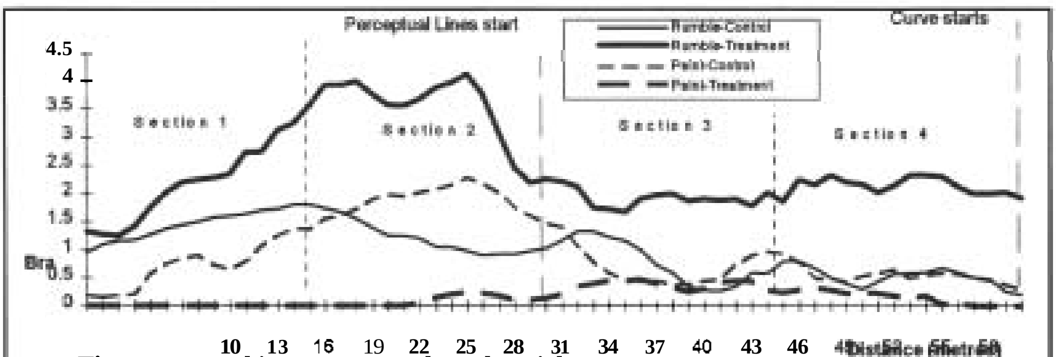

Figure 5.7 Braking on approach to the Right Curve

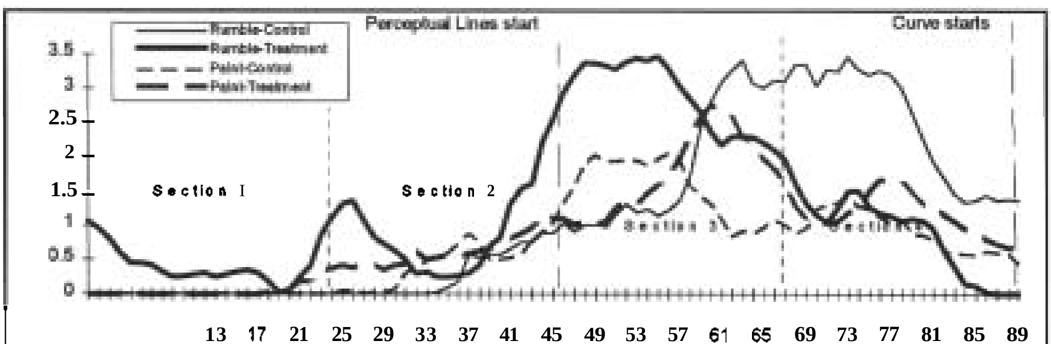

Figure 5.8: Braking on approach to the Left Curve

5.3.4 Deceleration

The deceleration results are shown in Figures 5.9 to 5.12 opposite and have been described below separately for the 4 locations.

Figure 5.9 - STOP SIGN APPROACH: While there was an apparent treatment effect for deceleration in the rumble condition ($F_{1,19}$=5.77, p=0.027, judgement reserved), there was no significant treatment effect overall in the painted line only condition ($F_{1,19}$=1.37, p=0.257). There were no significant interactions ($F_{1,19}$ = 2.83, p = 0.109, $F_{1,19}$ = 2.44, p = 0.135 & $F_{1,19}$ = 3.53, p = 0.076 resp.). Consequently, there was a small significant interaction between treatment and experiment ($F_{1,38}$=6.71, p=0.013, judgement reserved) but no significant three-way interactions ($F_{1,38}$=0.55, p=0.462, $F_{1,38}$=0.01, p=0.930 & $F_{1,38}$=0.11, p=0.747 resp.).

Figure 5.10 - ROUNDABOUTAPPROACH : No significant treatment effect was found for the rumble condition ($F_{1,19}$=0.00, p=0.980) or the painted-line only condition ($F_{1,19}$=2.57, p=0.125) at the roundabout. There were also no significant three-way interactions with any of the distance sections ($F_{1,38}$=0.64, p=0.430, $F_{1,38}$=0.09, p=0.757 & $F_{1,38}$=0.17, p=0.680 resp.).

Figure 5.11 - RIGHT CURVE: Similarly, there were no significant treatment and control differences approaching the right-hand curve in either the rumble ($F_{1,19}$=2.38, p=0.139) or painted line only conditions ($F_{1,19}$=0.94, p=0.344). There was also no significant treatment and experiment interaction ($F_{1,38}$=3.26, p=0.079) and no higher order interactions ($F_{1,38}$=0.39, p=0.532, $F_{1,38}$=2.05, p=0.160 & $F_{1,38}$=0.01, p=0.925 resp.).

Figure 5.12 - LEFT CURVE Once again, there was no sign of a treatment effect in either the rumble ($F_{1,19}$=1.07, p=0.314) or painted line only experiments ($F_{1,19}$=0.72, p=0.406). **As** a consequence, no significant differences were observed between treatment and the two experimental conditions ($F_{1,38}$=0.01, p=0.922), nor was there any sign of any significant three-way interactions ($F_{1,38}$=0.35, p=0.558, $F_{1,38}$=0.21, p=0.648 & $F_{1,38}$=0.17, p=0.684 resp.).

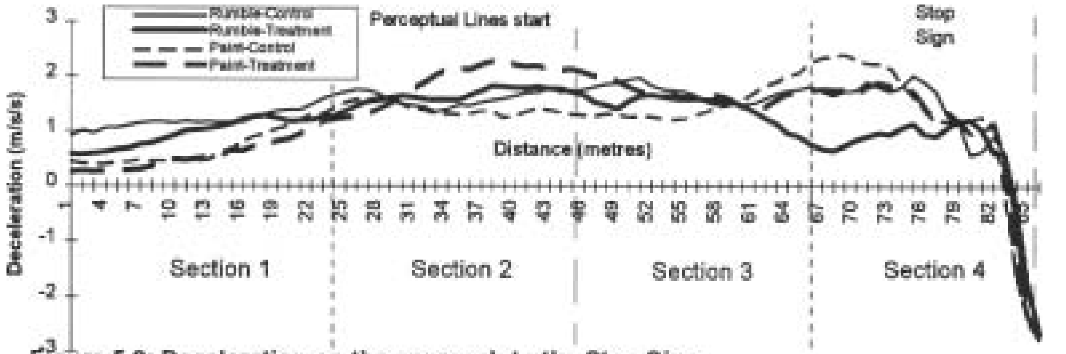

Figure 5.9: Deceleration on the approach to the Stop Sign

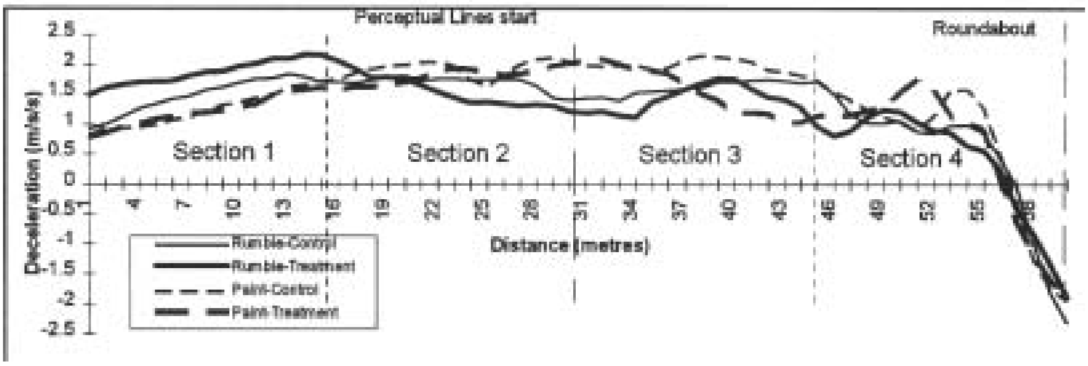

Figure 5.10: Deceleration on the approach to the Roundabout

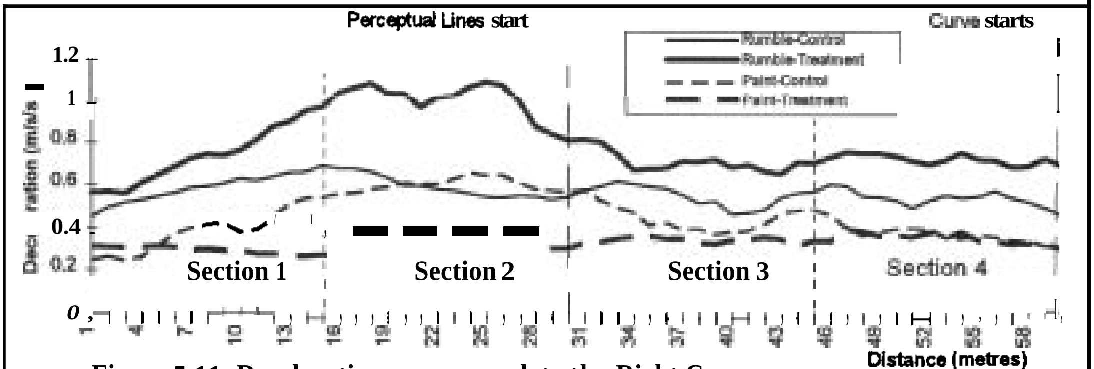

Figure 5.11: Deceleration on approach to the Right Curve

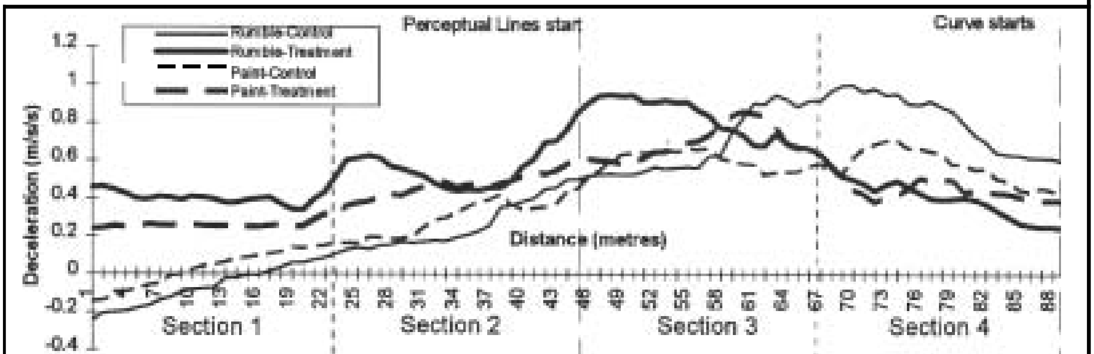

Figure 5.12 Deceleration on approach to the Left Curve

5.3.5 Lateral Placement

Lateral placement results for the rumble and painted transverse line experiments are shown in Figures 5.13 and 5.14 and described below.

Figure 5.13* - *RZGHT CURVE: In the rumble experiment, there was an apparent shift in lateral placement further away from the centreline in the approach to the treated right-hand curve ($F_{1\ 19}$=6.21, p=0.022, judgement reserved). In the painted line only condition, there was a similar shift as well ($F_{1,19}$=4.57, p=0.046, judgment reserved). Overall, however, there was no significant treatment interaction between the rumble and painted experimental conditions ($F_{1,38}$=0.00, p=0.958) and also no significant three-way interactions ($F_{1,38}$=0.03, p=0.869, $F_{1,38}$=0.03, p=0.872 & $F_{1,38}$=0.02, p=0.889 resp.).

Figure 5.14 - **LEFT** CURVE: There was no overall difference in lateral position on the approaches to the treatment and control left curves for either the rumble ($F_{1,19}$=0.36, p=0.554) or painted line only experiments ($F_{1,19}$=1.3 1, p=0.267). No significant interaction was observed between treatment and experiment ($F_{1,38}$=0.03, p=0.859) and no significant higher order interactions with the distance sections either ($F_{1.19}$=0.001, p=0.979, $F_{1.19}$=0.56, p=0.495 & F, $_{19}$=2.01, p=0.164 resp.).

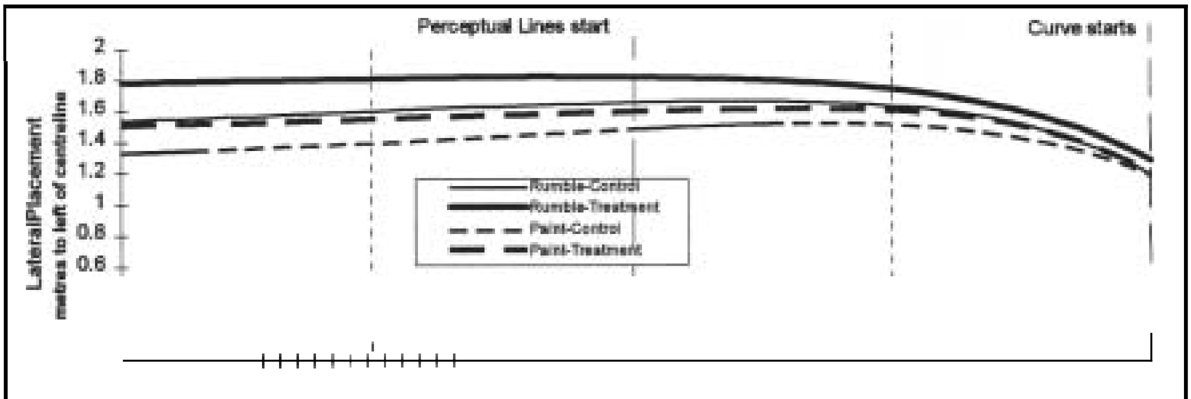

Figure 5.13: Lateral placement on approach to the RH curve

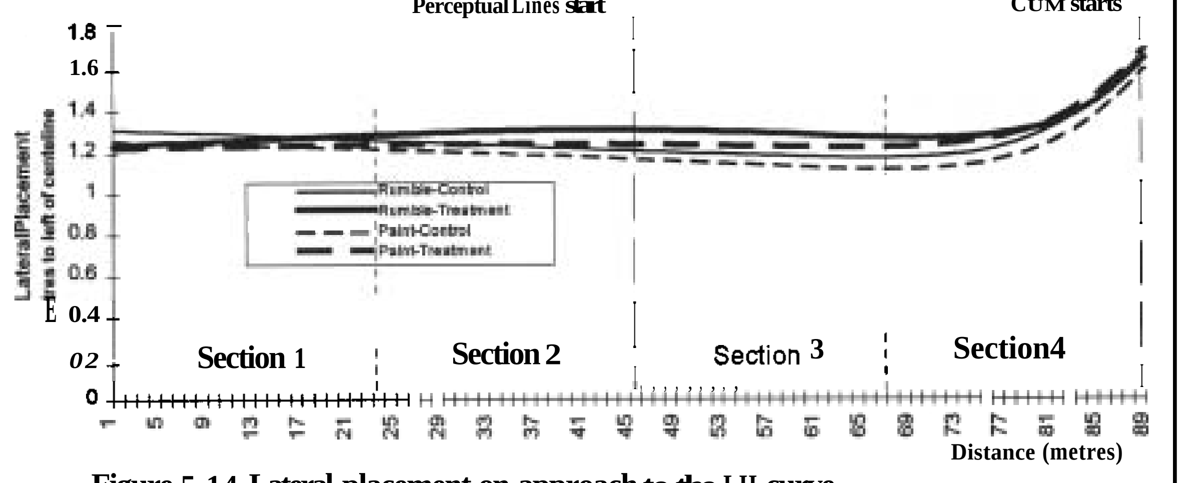

Figure 5.14 Lateral placement on approach to the LH curve

5.4 DISCUSSION

As noted in the introduction to this Chapter, an opportunity existed for examining the theoretical basis of perceptual countermeasures by conducting an additional simulator experiment where the rumble effect was manipulated. This would provide information on whether they achieve speed reductions through a purely "perceptual mechanism" or whether there are also a form of "alerting effect" to these treatments. While this would throw some light on the way drivers drive over these treatments, it could not hope to provide a total theoretical account of the way they operate as it does not address the possibility that the mere presence of these devices also acts to alert the driver ahead of actually driving over them.

As the simulator validation results showed that speed was the more valid measure on the simulator than others tested, it was appropriate to give more weight to these results in the subsequent discussion. In particular, the statistical level of judgement reserved was given more importance by itself but less importance when it interacted with the other variables. This was necessary to control the type I error rate at the decision-wise level. Thus, if speed was the only variable in the analysis, all ***judgement reserved*** results would in fact be considered ***fully*** *significant*. It would not have been appropriate to simply ignore the validation differences between the speed and the other variables in this research program.

5.4.1 Speed

The presence of transverse lines lead to a significant reduction in speed at the right-hand and left-hand curves, with or without the added rumble effects. For the right-hand curve, the speed reduction was greater while driving over the lines than immediately prior to the treatment for the rumble condition only suggesting a modest additional benefit from the rumble effect . This was not the case, however, for left-hand curves when speed reductions were consistent with or without rumble added. These results suggest that both types of lines may have either a perceptual effect or an alerting function as the driver approaches the devices. This is consistent with the concept of a preview distance for drivers of about **2** or **3** seconds ahead of the current position. Thus, for curves, transverse lines with or without rumble seem to effectively influence their curve negotiation behaviour. In addition, the rumble may also cause drivers to slow down even more when travelling over them but this was not a strong effect.

There were significant differences in the approach to the stop sign intersection across both experiments. **A** significant speed reduction was only found when the transverse lines were accompanied with rumble effects (no difference was observed between treated and untreated sites for the painted line only condition). The painted line condition only did experience some slower treatment speeds but only within the treatment and not ahead of it where you would expect perceptual effects to be more prominent. Within the lined area, the two conditions had equivalent treatment-control relationships, whereas in the pre-lined area, only the rumble treatment produced lower speeds.

This is a very interesting finding indeed as it seems to go against most accounts of how these measures operate. Unlike the effects found at the curves, the painted transverse-lines at the stop sign approach did not seem to produce any anticipatory speed reduction before reaching the lines which is counter to the notion of a purely perceptual or alerting effect. Moreover, as the effect within the treatment was roughly similar under both conditions, it is unclear if the rumble is providing any added benefit or if the lines themselves are having a perceptual influence through some form of modified streaming patterns on the driver's retina (Denton's theory). This warrants further research. What is clear from these results, however, is that the effect of transverse lines is different in the approach to straight road hazards (eg; intersections) than it is for curves. **As** noted earlier, this suggests that these devices might be more effective at reducing travel speed for an approaching curve than they are for an approaching intersection.

The roundabout site again did not produce any significant effect whatsoever, either for painted transverse lines or those accompanied by a rumble effect. While it could be said that the presence of the rumble had no effect on the results, neither did the transverse lines alone. As noted in Chapter **3,** the roundabout was a problem for many of the participants as the severe steering responses necessary to negotiate it caused severe discomfort. Thus, these results probably have more to do with the actual simulator and its display rather than transverse lines. They tell us little about the perceptual processes of transverse lines leading into roundabouts. Interestingly, it is at these very locations where transverse lines have been used extensively in the United Kingdom.

5.4.2 Brake Pressure

Because it was possible to measure braking pressure in the simulator, it was decided to analyse these results when comparing the effects of the rumble treatment, rather than simply whether the brake was on or off as previously. The stop sign produced less overall braking pressure at the treatment site compared to its control when rumble was added (there were no significant differences between treated and untreated sites for the painted line only sites). Conversely, the roundabout had less braking pressure on the approach to the painted line treatment site compared to its control site. There were no overall differences in braking pressure at any of the curves, although there was a hint of more braking within the treated area with added rumble. It should be remembered that many of the participants reported that braking did not seem to be all that real in the simulator and indeed, participants commonly came to a stop well ahead of the stop line at the intersections. This suggests that not a lot of importance should be given to these results.

5.4.3 Deceleration

On the approach to the stop sign, there was slightly less deceleration overall for the treated site relative to its control with rumble but no difference without. The slower overall speeds, starting from the beginning of the measurement period, means that less deceleration would have been necessary to come to a complete stop at the stop sign. Thus, this result seems to be more a reflection of speed consequences than deceleration effects per se.

At the other three sites (the roundabout and right and left curves), there were no significant deceleration differences between treated and untreated sites with or without rumble. This might suggest that transverse lines with rumble had little effect on deceleration behaviour, although, as discussed earlier in chapters **3** and **4,** it might also mean that deceleration may not be a sensitive enough measure for observing perceptual countermeasure effects. Given that deceleration is a reflection of both braking and less engine throttle and with less apparent motion cues available in the simulator than on the road, it is probably less important a dependent variable for further testing in this area.

5.4.2 Lateral Placement

For right-hand curves, drivers drove further away from the centreline for both the painted only and paint plus rumble conditions relative to their control sites. In addition, a greater lateral shift was also apparent ahead of the lines than in the line zone itself for both treatment conditions. This confirms that transverse lines are likely to be equally effective with or without rumble effects in shifting the vehicle away from the centreline. Moreover, it suggests that they are having more of a perceptual effect at this location, given its effectiveness ahead of the line zone itself.

By contrast, though, left-hand curves failed to produce any significant lateral shift for either treatment or ahead of **or** within the treatment zone. This is an interesting finding as similar benefits were expected for left- and right-hand curves. **As** the perception of left- and right-hand curves has been shown to differ (Fildes, 1986), it might suggest that transverse lines are likely to be differentially effective, depending on the amount of visual cues available to the driver. This is potentially an important finding for curve management on the road and warrants closer scrutiny in future perceptual countermeasure research.

5.5 CONCLUSIONS

The presence of rumble in addition to painted transverse lines in the approach to hazardous locations had it greatest effect on travel speed in these simulator trials. The combination of rumble and painted effects produced even greater speed reductions, both ahead of and within the line zone itself. Most other measures were less affected by the presence or absence of rumble. The results for braking pressure and deceleration could be explained partially by the test environment or by other means. Transverse lines, with or without rumble, had a positive benefit for lateral position in right-hand curves but no effect in left-hand equivalents, suggesting that their effectiveness may be influenced by the amount of visual information present.

This experiment was intended to throw some light on whether this treatment had a purely perceptual or more of an alerting influence on driving. To this extent, the results were a little disappointing. It would appear that transverse lines have various effects on driving performance and to some degree are influenced by the type of location where they are used. The addition of rumble did not seem to penalise the effectiveness of transverse lines in reducing speed at these locations but was more likely to be effective when traversing the lines. Whether these countermeasures operate through perceptual, alerting or some other mechanism still needs to be resolved. While transverse lines have been used extensively in the approach to roundabouts and intersections, the results obtained here suggest that they may be equally, if not more effective, in the approach zone to curves as well.

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APPENDIX A COMPUTER PROGRAMMING DETAILS AND LAYOUT OF THE TRANSVERSE LINES FOR EXPERIMENTS 1 AND 2

Transverse Lines Perceptual Countermeasures

Stage 2

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This document details the visual databases created for Stage 2 of the MUARC Perceptual Countermeasures (PCM) study. Three databases have been created; one for driver practise and another two which contain road segments with PCM treatments (routes **A** aid B)

Terminology

The following terms and abbreviations are used :

TLPCM : Transverse Lines Perceptual Countermeasure; a rectangular strip placed perpendicular to the direction of travel on the road surface.
road segment : a segment of the visual database which has a road on it. These are conceptually identical to pieces of track from model railways, Scalectrix etc. It can **be an** intersection, curve or straight piece. Most straight segments *in* the supplied databases are 300m long.
treated : **A** road segment which has had TLPCM applied to it.
MRDS : Mid Range Driving Simulator.

Document layout

Individual road segments from the existing residential visual database have been modified and assembled to create new visual databases for this study. Several new pieces have been created (curved segment and roundabout). The new pieces are described first (§ 1), including notes on the application of TLPCM where appropriate. The three routes are then described (§ 2), followed by notes on the scenarios provided (§ **3).**

Referenced Documentation

[1] "Experiment **lb** : Simulator Validation Trials". Stuart Godley, MUARC. TLPCM, route and site treatment specifications.

1. Visual database components

This section describes the road segments that were created specifically for the second stage of the PCM study. The application of TLPCM to a signed (Stop or Give Way) intersection is discussed first (§ 1.1). Issues which apply to TLPCM treatments in general are included here. This is followed by descriptions of the new treated curved road segments (§ 1.2), and the new treated roundabout (§ 1.3).

1.1 Stop Sign Intersection with Transverse lines PCM

The Transverse Lines PCM has been applied to road segments in this work. These are implemented as coloured strips 0.6m wide, aligned perpendicular to the direction of travel in the lane. The gap to the edge of the curb is 0.35m, and the gap to the centre line markings is 0.25m. The length of the line depends on width of the lane, and on the type of application. The spacings between strips for various applications (curves, roundabout and other intersections) were supplied by MUARC [1]. These were followed where possible. Any deviation from these specificationsis explained in the relevant sections.

In real world applications the strips consists of a mixture of paint and raised gravel (less than 1cm high) applied directly to the road surface. The result is a bump which is felt as they are driven over, usually forcing the driver to slow down. Bumps are implemented in the simulator using the terrain specification system. The vertex coordinates of the leading edges of the strips are specified, and the simulator motion platform is bumped as these edges are crossed. There is no mechanism for speed sensitive bumps in the MRDS, so the bump intensity is reduced as the expected speed of the vehicle decreases.

Rendering thin strips such as this countermeasure reveals **a** problem with the graphics engine. Thin ships drawn at right angles to the eyepoint flicker and shimmer (*flimmering*, a term coined by Silicon Graphics). This is also evident when approaching perpendicular intersection line markings (eg Stop Sign double lines, etc). **As** the strips are approached the amount of flickering decreases until it is no longer a problem. The distance where the flickering stops and the strips become identifiable is determined empirically. This "flicker free" distance increases as the width of the strips is increased.

Using Level of Detail switching (LOD) to swap in a lower resolution (ie wider strips) model of the treatment reduces the flickering effect. The width of the lower resolution strips is significantly greater (up to 10 times) than the width of the high resolution strips. To compensate for the increased area and therefore increased brightness the strips of the lower resolution model are coloured at 30% intensity. If the length of the entire treatment (ie the distance travelled by the simulator vehicle while over the treated road) is significantly greater than the flicker free distance then the treatment is split into two or more sections which are switched independently.

The effects of flimmering can also be reduced by significantly decreasing the distance between the near and far clipping planes. These define what geometry gets drawn based on its distance from the eyepoint, however the distances are set at a minimum anyway and decreasing them further will result in incorrect rendering for road segments some distance away.

The Stop Sign intersection from the residential visual database was treated as specified. The spacings between the lines are shown in table 1. The measurements were given as the distance between nearest edges in successive strips (ie the gap between strips). These are converted to the distance between centres of successive strips. This spacing is used in the Stop Sign intersection in route B, and at one of the Give Way intersections in the practise route.

Signed Intersection TLPCM
inter-strip distance

Strip Number	distance b/w strips ---(m)---	center to center ---distance (m)---
1st. to 2nd strip	7.8	8.4
2nd to 3rd strip	2.4	3.0
3	2.0	2.6
4	2.0	2.6
5	2.0	2.6
6	2.0	2.6
7	2.0	2.6
8	2.0	2.6
9	2.0	2.6
10	2.0	2.6
11	2.0	2.6
12	2.0	2.6
13	1.7	2.3
14	1.5	2.1
15 to road marking	0.2	0.5
Total length of treatment		42.3

Table **1**

1.2 Curved **road** segment

The curve constructed has a 100m constant radius, measured from the rotational centre to the centre of the lane. It is built using the single lane road segment profile from the existing residential visual database. **A** 90° curve has the inner curb approximated using **15** polygons, the lane boundary (centre of road) using 12 polygons, and the outer curb using 9 polygons. This combination is a tradeoff between acceptable smoothness of the curve and the performance of the visual engine. Increasing the degree of curvature any further would significantly increase the number of polygons without any real benefit. The degree of curvature is reduced in lower resolution models which are switched in at distances exceeding 250m. The practise route has three 90" curves, one 60" and one 30". Routes **A** and B use 45" curves only. Figure 4 shows the road polygons for the highest resolution model of a treated 45° curve segment.

The specified spacings for the strips in the inner and outer curve lanes could not be followed exactly because:

1. The spacing between the centers of successive strips decreases as the curve progresses. This indicates measurement from a transitional curve (one with decreasing curve radius). For a constant curve radius the spacing should be constant.
2. No lengths were supplied for the strips, making calculation of the distance between the centres of successive strips impossible.
3. Using the specified spacings would give a path through the curve of approximately 50m (note this doesn't include the distance along the straight segment immediately before the curve). Given a curve angle of 60° and a curve radius of 100m, the treatment length for the curve should be around 100m. It is not that critical if the treatment finishes before the end of the curve, however halfway along the curve is a little soon. The solution implemented uses a 45° curve (arc length of 76.72m for the inner lane, 80.42m for the outer lane), with constant spacing between the strips on the actual curve. The spacing between centres at the curve start is 3.27m, and 3.0m for strips on the curve.

Table 2 follows the conversion from the supplied spacings for the inner lane treatment to those implemented. The spacings supplied are measured from the trailing edge of one strip to the leading edge of the next. If the angle between successive strips changed, two measurements were supplied. These are averaged to provide one.

Table 3 follows the same calculation through for the outer lane.

Curved road segment
Inner lane TLPCM
inter-strip distance

Bar Number	distance b/w bars ---(as supplied)-----	center to center dist. ---(+ 0.6m)---------	adjusted distance
1 first strip in path	9.64	10.24	10.24
2	9.64	10.24	10.24
3	9.64	10.24	10.24
4	5.8	6.4	6.4
5	**4.6**	5.2	5.2
6 (curve start)	3.65	4.25	4.25
7	(2.65 , 2.7) = 2.67	3.27	3.27
8	(2.3,2.3) = 2.3'	2.9	3.0
9	(2.45,2.55) = 2.5	3.1	3.0
10	(2.0, 2.09) = 2.04	2.64	3.0
11	(2.0, 2.09) = 2.04	2.64	3.0
12	(2.0, 2.24) = 2.12	2.72	3.0
13	(2.0, 2.24) = 2.12	2.72	3.0
14	(1.52,1.65) = 1.58	2.18	3.0
15	(1.52,1.65) = 1.58	2.18	3.0
16	(1.52,1.65) = 1.58	2.18	3.0
17	(1.52,1.65) = 1.58	2.18	3.0
18	(1.52,1.65) = 1.58	2.18	3.0
19	(1.52,1.65) = 1.58	2.18	3.0
20	(1.52,1.65) = 1.58	2.18	**3.0**
21	1.5	2.1	3.0
22	1.5	2.1	3.0
23	1.5	2.1	3.0
24	1.55	2.15	3.0
Total length of treatment		90.27	100.84

Table 2

Curved road segment
Outer lane TLPCM
inter-strip distance

Bar Number	distance b/w bars ---(as supplied)---	center to center dist. ---(+ 0.6m)---	**adjusted** distance
1 first strip in path	9.7	10.3	10.3
2	4.56	5.16	5.16
3	4.56	5.16	5.16
4	4.56	5.16	5.16
5 to curve start	3.4	4.0	4.0
6	(2.3, 2.25) = 2.27	2.97	3.0
7	(2.3, 2.25) = 2.27	2.97	3.0
8	(2.3, 2.25) = 2.27	2.97	3.0
9	(2.3, 2.25) = 2.27	2.97	3.0
10	(2.3, 2.25) = 2.27	2.97	3.0
11	(2.3, 2.25) = 2.27	2.97	3.0
12	(2.3, 2.25) = 2.27	2.97	3.0
13	(2.3, 2.25) = 2.27	2.97	3.0
14	(2.3, 2.25) = 2.27	2.97	3.0
15	(2.3, 2.25) = 2.27	2.97	3.0
16	(2.3, 2.25) = 2.27	2.97	3.0
17	(2.3, 2.25) = 2.27	2.97	3.0
18	(2.3, 2.25) = 2.27	2.97	3.0
19	(2.3, 2.25) = 2.27	2.97	3.0
20	(2.3, 2.25) = 2.27	2.97	3.0
21	(2.3, 2.25) = 2.27	2.97	3.0
22	(2.3, 2.25) = 2.27	2.97	3.0
23	(2.3, 2.25) = 2.27	2.97	3.0
24	(2.3, 2.25) = 2.27	2.97	3.0
25	(2.3, 2.25) = 2.27	2.97	3.0
Total length of treatment		89.18	89.78

Table 3

1.3 Roundabout

The roundabout in the existing residential database was considered unrealistic and has been rebuilt. Figure 5 shows the road polygons of the new treated roundabout intersection. Several factors were considered in the new design.

The old roundabout intersection was built using the Stop Sign / Give Way intersection as a template and then adding a round island in the centre and **4** small triangular islands in the centre of the roads leading into the intersection. Since there was no increase in the intersection road area (especially at the entry/exit lanes) the intersection was difficult to manoeuvre through. The triangular islands encouraged the driver to enter the intersection at an angle, however this was done without widening the lane. **As** a result the width of the lane at the intersection entry was 3.98m (down from 4.68m). The minimum lane width throughout the roundabout (5.69m) was insufficient for performing a right hand turn, and collisions with the curbs were common when attempting left hand turns. The diameter of the round island was 5.71m.

The new intersection increases the width of the lane at the intersection entry to 4.93m by increasing the diameter of the rounded curbs. Figure 5 shows the positions of the original and new curb rotation points. The difference in diameter is approximately 10m. The result is a much wider lane at the point where the roundabout intersection is-entered. Combined with the triangular islands, this encourages angled entry without unintentional curbside collisions.

The roundabout island in the existing intersection did not appear to be round enough. It was octagonal in shape and did not have any dnveable areas. The new roundabout island is 16 sided, and has an outer concrete ring which can be driven over (8cm high), and a central curb (18cm high) which cannot [1]. The total diameter of the island is 8m, the diameter of the inner island being 5m.

The diameter of the roundabout island was determined by examining a photo of the real life example at Finlayson St., Rosanna. The ratio between the roundabout diameter and the lane width was approximately 2:1. This gives a roundabout radius of around 8m (including the outer ring). Although the diameter of the new roundabout island is larger, the effective minimum lane width (measured from the roundabout island's outer ring to the closest curb, in the direction of the normal to the circle) has increased to 6.8m. If the outer ring is included this becomes 8.3m, or almost twice the standard lane width. It should be noted that movement over the outer ring will move the motion platform appropriately, and that this is severe enough to discourage the driver from using the outer ring in the normal course of driving.

The centre island is textured in the same manner as the sidewalks. The outer ring used the same concrete texture as the curbs. The small vertical polygons which join the inner and outer rings to the road surface are coloured to match.

The roundabout intersection in the Route **A** database has been treated. The TLPCM application consists of strips on one entry lane (6), and through the intersection (11 strips) and the exit lane (3 strips) on the other side. The strips' center position is determined by defining a spline along the expected driver path through the roundabout, and then applying the strips the required distance apart along the spline. The strips were aligned perpendicularly to the spline. The points for the spline are shown in figure 6. It was found that using the centre of the entry lane for the spline's first few points resulted in an undesirably excessive crossing angle for drivers already on the roundabout, moving from the right to left ("other traffic" path). By using points midway between the driver's entry path and the path of traffic already on the roundabout for the spline's definition points, the crossing angle was reduced.

The centre to centre distance between splines was matched as closely as possible to the specifications, however some adjustments had to be made. Table 4 lists the distances as specified, and follows through their conversion into adjusted centre. to centre distances. Where two measurements are supplied, they are averaged first to obtain one, Note that one strip is skipped at the point where the roundabout (RA) dashed lines are crossed (line 6). This explains the larger adjusted distance (5.6m). The center to center distances between strips on the roundabout (lines 7 to 17) are not constant, nor is there any linear increase or decrease in their spacing. Assuming that the expected speed through the intersection remains constant, the spacing between successive strips can be determined by measuring the total distance along the spline path and dividing by the number of strips. Further small adjustments are necessary to ensure that strips that are rotated do not overlap with adjacent strips.

Roundabout TLPCM
inter-strip distance

Bar Number	distance b/w bars ---(as supplied)-----	center to center dist. ---(+ 0.6m)---------	adjusted distance
1 fust strip in path	9.7	10.3	10.3
2	6.3	6.9	6.9
3	4.1	4.7	4.7
4	2.7	3.3	3.3
5	1.7	2.3	2.3
6 (before RA lines)	1.7	2.3	5.6
7 (after RA lines)	(1.05, 1.4) = 1.22	1.8	1.9
8	(1.2, 0.8) = 1.0	1.6	1.88
9	(1.7, 0.9) = 1.3	1.9	1.86
IO	(1.7, 0.9) = 1.3	1.9	1.86
11	(1.9, 0.85) = 1.4	2.0	1.86
12	(1.55, 0.9) = 1.2	1.8	1.86
13	(1.45, 0.9) = 1.2	**1.8**	1.86
14	(1.1, 0.8) = 0.95	1.6	2.03
15	(1.1, 0.8) = 0.95	1.6	2.23
16	(1.1, 1.35) = 1.22	1.8	2.29
17 exit lane	(1.0, 1.85) = 1.42	2.0	2.05
18	(1.15, 1.4) = 1.27	1.9	2.03
19	(1.1, 1.4) = 1.25	1.8	2.0
Total length of treatment		53.3	58.81

Table **4**

The complete treatment covers approximately 60m of road. This exceeds the flicker free distance for this countermeasure, so it is split into three sections which **are** switched independently. The first section switches in the entry lane strips (6), the second switches the next 8 strips, and the third the remaining strips including those on the exit lane.

Collision detection for the roundabout intersection is implemented using the road terrain database. A collision is registered if the vehicle is **driven** over any of the **triangular** islands in the entry/exit lanes of the intersection, or over the inner roundabout island.

2. Routes

2.1 Practise Route

A map of the practise route is shown in figure 1. The practise route is cyclic, allowing infinite driving time should this be required.

It contains the following features:

- One PCM site at a Give Way intersection.
- Three traffic light intersections.
- Mobil and 7/11.
- Squash building, school, scout building and park.
- 1 stop **sign** intersection.
- 3 give way intersections.
- One new roundabout intersection.
- "No entry" signs at the start of all dead-end segments.
- Approximately 1.5 km of dual lane, divided road.
- Approximately **5** km of single lane road.
- Three 90" curved single lane road segments (100m constant curve radius).
- One 30° curved single lane road segment (100m constant curve radius).
- One 60° curved single lane road segment (100m constant curve radius).

2.2 Main Routes (A and B)

Routes A and B form the two main databases for the study. Based on an almost identical map, each database contains two PCM sites and two control sites. The control sites in one database are treated in the other, and vice versa. The treated sites are positioned such that there is at least 40 seconds driving time (at 60 kph) between them. It follows that there is at least 40 seconds driving time between control sites.

The following features are common to both routes:

- Two PCM sites per route.
- Squash building, and school.
- One new roundabout intersection.
- Approximately 4.1 km of single lane road along the expected driver path.
- Approximately 2.4 km of single lane road along crossroads to the expected driver path.
- Two (2) 45" curved single lane road segments (100m constant curve radius).

The following lists the differences between routes:

- Route A has TLPCM applied to the inside lane of a **45**" curve, and at a roundabout, while Route B has TLPCM applied to the outside lane of a 45" curve, and at a stop sign (SS) intersection.
- The positions of the school and squash building are slightly different. They have been moved one straight road segment away **(**300 **m)** from a site if it has been treated. This reduces the peak graphics load around the location of treated sites, since rendering straight road segments containing unique features is more expensive.

Figures 2 and **3** show the plan view of RouteA and RouteB respectively.

3. Scenarios

The Scenario Tool ("rdsb") should be used to load the visual databases. It is possible to run the MRDS using "escene", however data logging and control of the traffic lights in the practise database will not be available.

Several scenarios have been provided for the three databases. The filenames of the scenarios **(Practise, RouteA** and **RouteB)** use a combination of prefixes and suffixes which should make them self explanatory. All prefixes are "**pcm...**".

The suffixes are :

...withCars : This scenario contains several other vehicles. The vehicles do not drive along the expected route of the driver, instead they pass in the opposite lane. This avoids situations where vehicles end **up** in front of the driver, blocking any approaching treatment, or behind the driver, where they can be distracting.

...debug : Debug version of the scenario. Running this version will display the graphics engine statistics. These scenarios should be used for tuning and debugging only.

Examples of valid scenario names include **pcmRouteA**, **pcmPractisewithCars**, **pcmRouteBdebug** etc.

Route A

Stage 2 Perceptual Countermeasures Study

Visual Database Layout

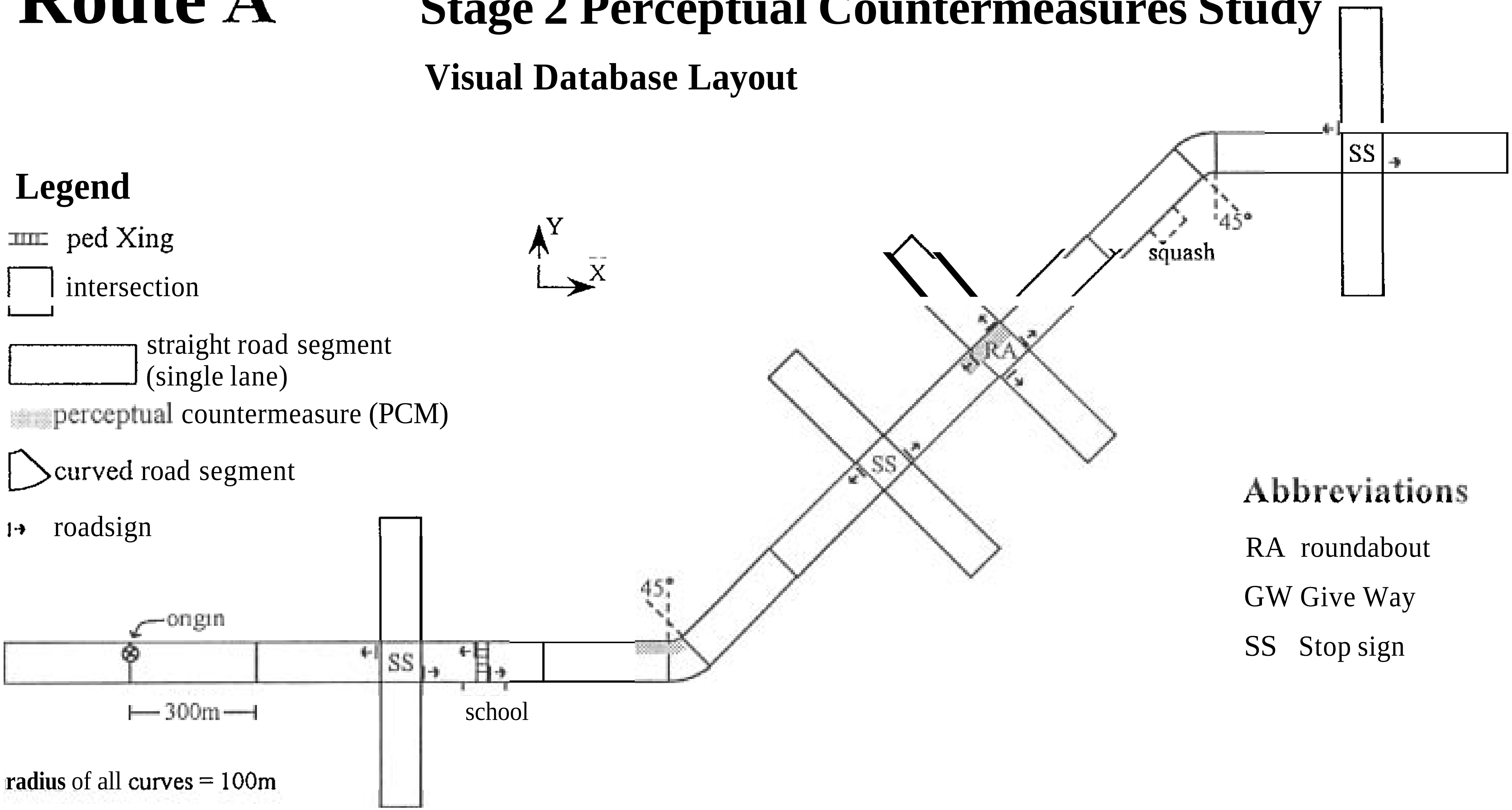


Figure 2

Revision 4

Chris Karadaglis, 3/3/96

Route B

Stage 2 Perceptual Countermeasures Study

Visual Database Layout

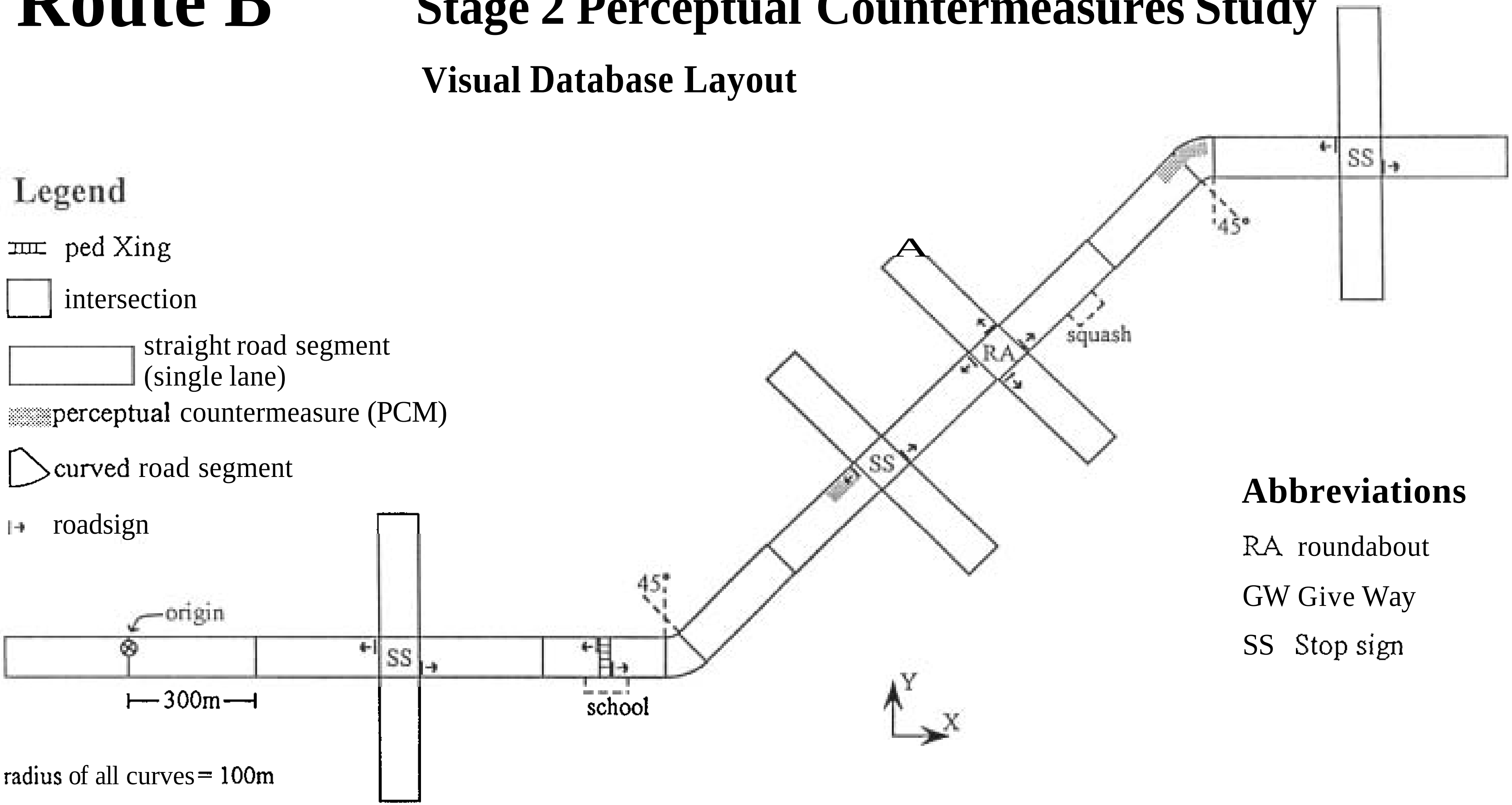


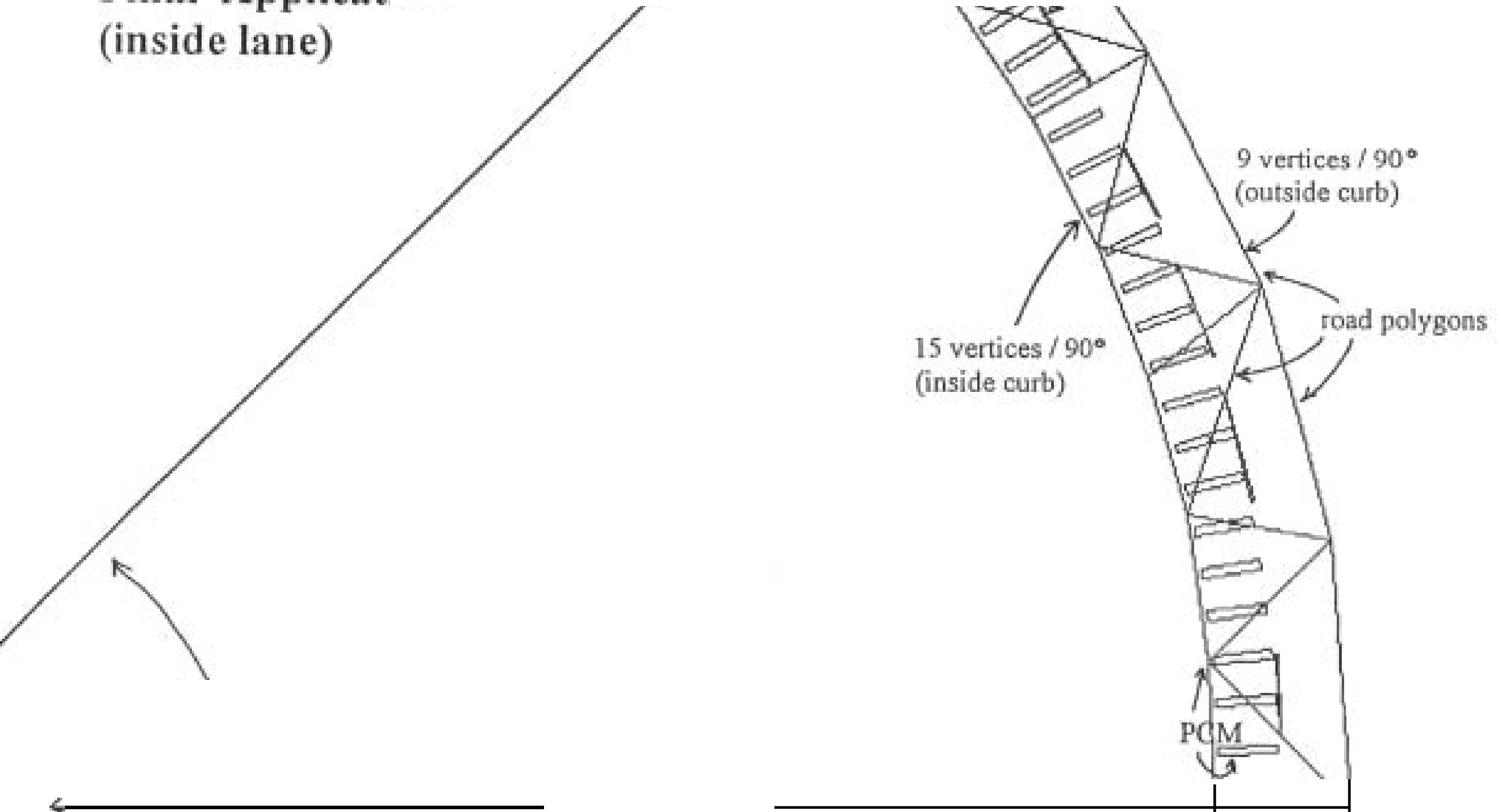
Figure 3

Revision 3

Chris Karadaglis, 13/2/96

Curved PCM

Final Applicat
(inside lane)



NB 3 PCMs on
entry lane are
not shown

Curbs and other terrain
geometry not shown

Figure 4

3

Revision 1

Chris Karadaglis, 3/3/96

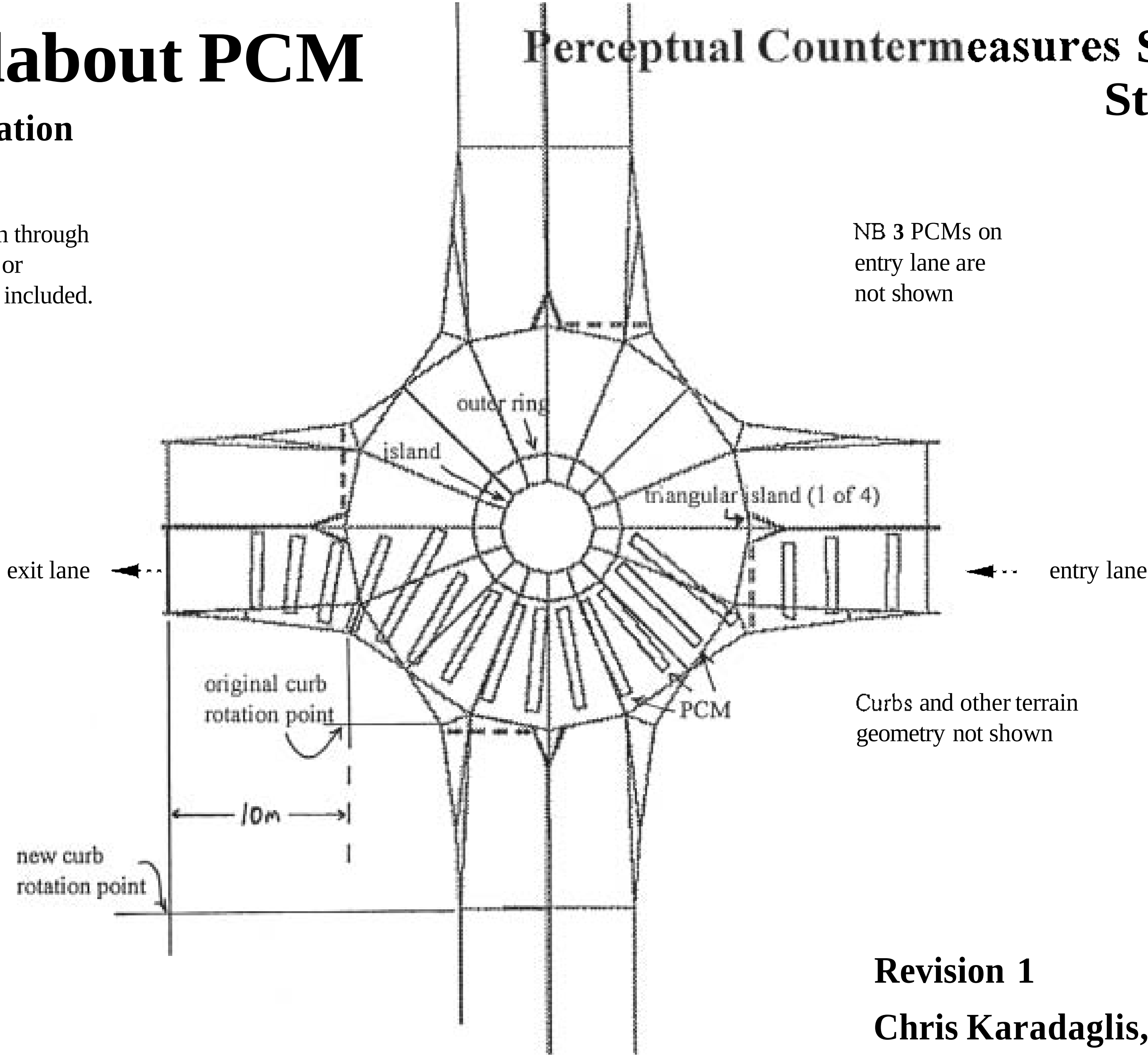
Roundabout PCM

Final Application

Perceptual Countermeasures Study
Stage 2

Minimum lane width through roundabout = 6.8m, or 8.3m if outer ring is included.

NB 3 PCMs on entry lane are not shown



Curbs and other terrain geometry not shown

Figure 5

Revision 1

Chris Karadaglis, 3/3/96

Roundabout PCM

Driver Path Spline

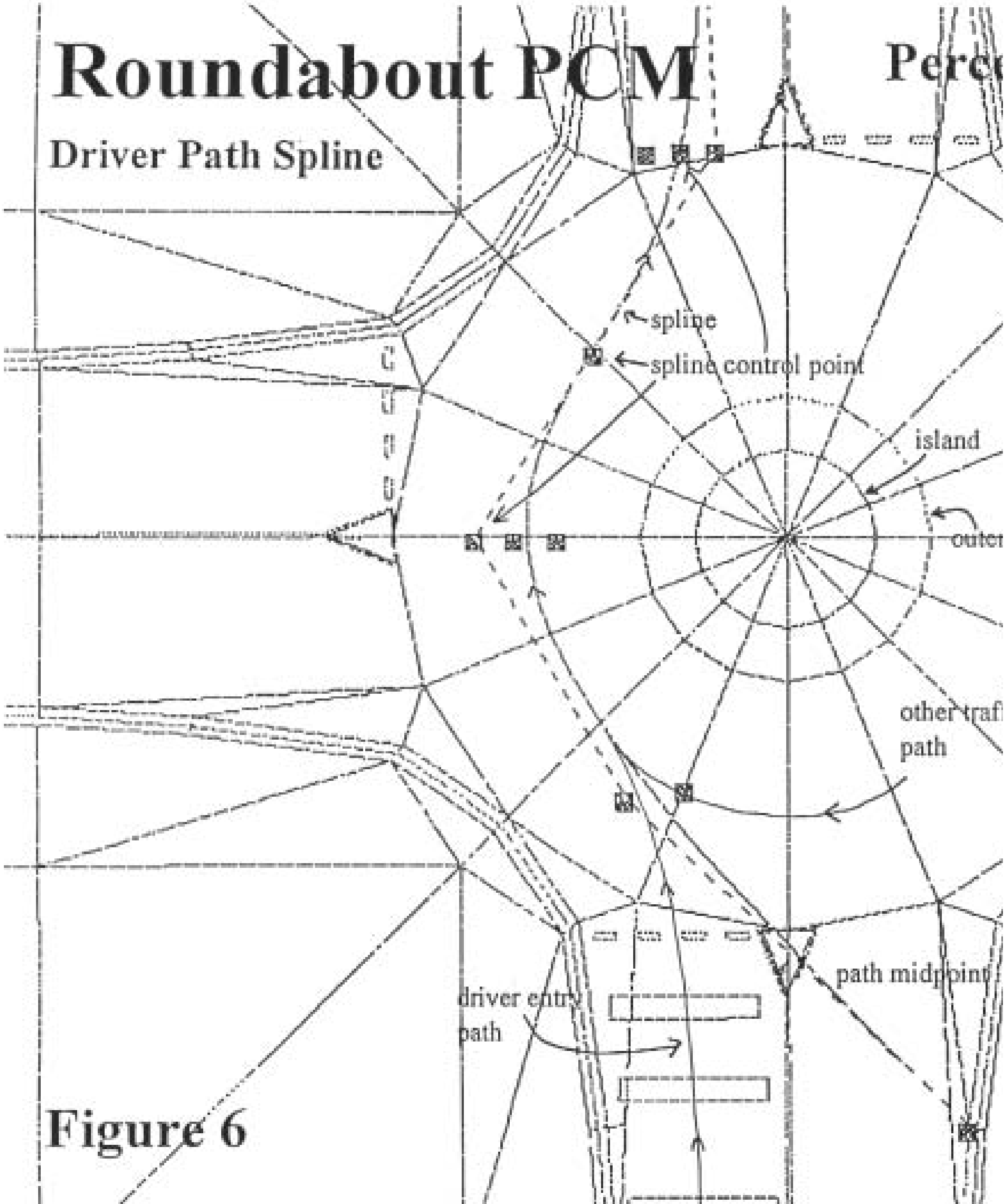


Figure 6

APPENDIX B EXPERIMENT 1 (ON-ROAD TRIALS) - INSTRUCTIONS FOR PARTICIPANTS

Thank you for agreeing to participate in this road experiment.

The study is attempting to measure driving performance in various residential streets around Melbourne along with the problems and difficulties associated with normal driving in these areas.

We will be taking you along a pre-determined route through the Heidelberg area and making a number of measurements of the vehicle's performance along the way.

Your task is to drive the car along this route at what you consider to be normal speed for the circumstances, but at all times please drive in a normal safe and law abiding manner.

This is not a speed trial and we are not assessing your driving ability. Our interest is in how easy or difficult it is for you to travel through these streets. Please drive as normally as you can along the way and always obey the road laws.

You will be the driver and I (Stuart Godley) will give you directions of which streets we would like you to travel along. I will give you plenty of warning of where to go and when to turn and we will have some practice at driving the car before we get to the route.

As you approach an intersection, I will let you know whether to turn left, right or go straight ahead. No instruction means that you should continue to travel straight ahead. It will take around **45** minutes to drive the whole route.

Brendan Gleeson (in the back seat) is operating the equipment that measures the vehicle's performance. This will not affect you or your driving in any way.

I stress again that this is solely a research project and is not a test of your ability to drive a car in any way. We will be combining your records with those of a number of other drivers and simply examining performance of all drivers considered together at various locations.

Nothing you do during the trial will be linked to you personally and these records will be treated in strictest confidence. Monash University's ethics committee have approved this study and nothing we do today will have any influence whatsoever on your driving record or licence.

The results of this work will be used to help improve travel along residential streets. I will be happy to discuss the experiment in more detail after we have completed the study if you wish to.

Do you have any questions about what it is we require you to do during the drive ?

APPENDIX C EXPERIMENT 2 (SIMULATOR TRIALS) - ROUTE LAYOUTS

Route A

Stage 2 Perceptual Countermeasures Study

Visual Database Layout

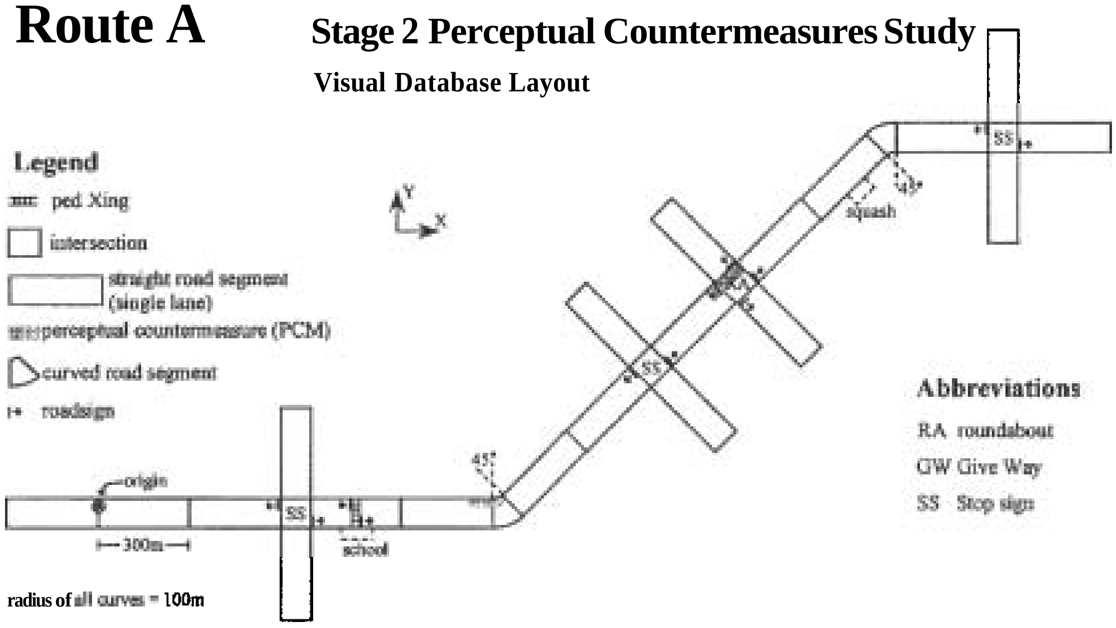


Figure 2

Revision 4

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Route B

Stage 2 Perceptual Countermeasures Study

Visual Database Layout

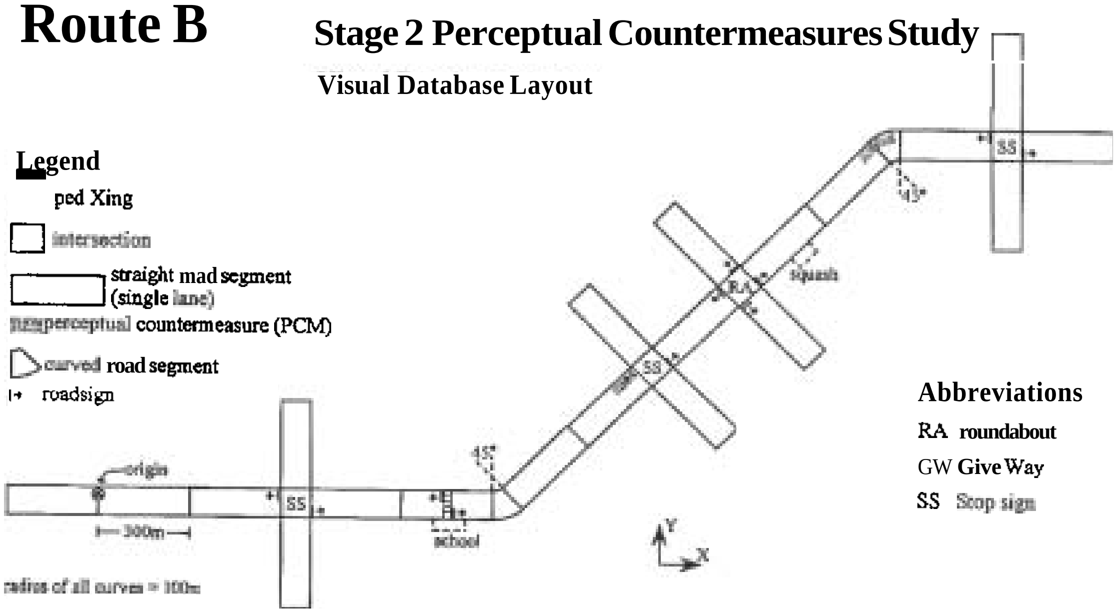

Figure 3

Revision 3

Chris Karadaglis, 13/2/96

APPENDIX D EXPERIMENT 2 (SIMULATOR TRIALS) - INSTRUCTIONS FOR PARTICIPANTS

Thank you for agreeing to participate in this driving-simulator experiment.

The study is attempting to measure driving performance in residential streets, along with the problems and difficulties associated with normal driving in these areas.

Your first task is to "drive" the simulator car on two practice tracks. This is to get you used to driving in the simulator. When you start "driving" for the first time in the simulator, please go quite slow for the first minute or two so you can experience accelerating, decelerating and braking, and cornering a few times at moderate speeds to get your body used to the feeling of the simulator's dynamics.

The first practice route is a rural road where you need only to drive straight ahead. The second practice circuit will be in a suburban setting where the experimenter, Stuart Godley, who will be sitting next to yon, will instruct you where to go. Each "drive" will take **2-3** minutes.

Following this you will "drive" on two pre-determined routes in a suburban setting. On these routes, a number of measurements of the vehicle's performance will be taken along the way.

Your task is to "drive" the simulator car along these routes ***at what you consider to be a normal speed and in a safe and law abiding way*** as ***if the current circumstances were on a real road***

This is not a speed trial and we are not assessing your driving ability. Our interest is in how easy or difficult it is for you to travel through these streets. Please drive as normally as you can along the way and always obey the road laws.

Along these routes, ***you must always drive straight ahead at every intersection you encounter,*** and *not* turn left or right at all. Each of the two routes will take around **4** minutes to complete.

It should be noted that driving the simulator occasionally produces temporary feelings of discomfort. In the unlikely event that this happens, ***please tell*** *Stuart* ***immediately and the trial will be ended.*** Remember, you are free to end the experiment at any time during the session.

I stress again that this is solely a research project and is not a test of your ability to drive a car in any way. We will be combining your records with those of a number of other drivers and simply examining performance of all drivers considered together at various locations. Nothing you do during the trial will be linked to you personally and these records will be treated in strictest confidence. Monash University's ethics committee have approved this study and nothing we do today will have any influence whatsoever on your driving record or licence.

The results of this work will be used to help improve travel along residential streets. I will be happy to discuss the experiment in more detail after we have completed the study if you wish to.

Do you have any questions about what it is we require you to do during the drive ?

APPENDIX E CANONICAL CORRELATION PROGRAM (WRITTEN IN VISUAL BASIC)

```
Sub CanCor_equal_weights0    ' control z = short cut key

Const TotalDistance = 89

Dim Originalsheet As Worksheet
Dim DifferenceSheet As Worksheet
Dim Matrixsheet As Worksheet
Dim MeanFile As Workbook

Dim Diff As Double
Dim aMean As Double
Dim bMean As Double
Const Road = 1
Const Simulator = 1

SheetList = Array("MeanSpeed", "MeanBrake",
"MeanLatPlaceChange", _
 "MeanLateralPlacement", "MeanDecelerationChange",
"MeanDeceleration")

For Each z In SheetList

' ---------------------------------------------------------------------
-----------
' Now I need a correlation matrix

Sheets(z).Select
Set Originalsheet = ActiveSheet
Sheets.Add
Set Matrixsheet = ActiveSheet
Matrixsheet.Name = z + "Matrix"

    ' first I give Matrixsheet column and row headings
    For x = 1 To Road
    MatrixSheet.Cells(1, x + 1) = "Road-C" + x
    MatrixSheet.Cells(x + 1, 1) = "Road-C" + x
    Next x
    For x = (Road + 1) To (2 * Road)
    MatrixSheet.Cells(1, x + 1) = "Road-T" + (x - Road)
    MatrixSheet.Cells(x + 1, 1) = "Road-T" + (x - Road)
    Next x

    For x = ((2 * Road) + 1) To ((2 * Road) + Simulator)
    MatrixSheet.Cells(1, x + 1) = "Sim-C" + (x - (2 * Road))
```

```
    MatrixSheet.Cells(x + 1, 1) = "Sim-C" + (x - (2 * Road))
    Next x
    For x = ((2 * Road) + Simulator + 1) To ((2 * Road) + (2 *
     Simulator))
    MatrixSheet.Cells(1, x + 1) = "Sim-T" + (x - ((2 * Road) +
     Simulator))
    MatrixSheet.Cells(x + 1, 1) = "Sim-T" + (x - ((2 * Road) +
     Simulator))
    Next x


    ' for pair of each columns,
    ' I need to find covariance and standard deviations (for
      each column)

    ' I will compare the first column with all other columns (
     ' including itself)
    ' then the second column with all other columns etc. etc.


    OriginalSheet.Select
    For a = 2 To (1 + (2 * Road) + (2 * Simulator)) ' a =
     first column
' for standard deviation of column a
    aMean = Application.Average(Range(OriginalSheet.Cells(2,
a), _
     OriginalSheet.Cells(TotalDistance + 1, a)).Value)
        aVarTimesdf = 0
        For y = 2 To (1+ TotalDistance)
        aDiffSquare = (OriginalSheet.Cells(y, a) - aMean) ^ 2
        aVarTimesdf = aVarTimesdf + aDiffSquare
        Next y
        aSD = Sqr((1 / TotalDistance) * aVarTimesdf)
' for standard deviation of column b
            For b = 2 To (1 + (2 * Road) + (2 * Simulator)) 'b
= second column
            bMean =
Application.Average(Range(OriginalSheet.Cells(2, b), _
             OriginalSheet.Cells(TotalDistance + 1, b)).Value)
                bVarTimesdf = 0
                For y = 2 To (1+ TotalDistance)
                bDiffSquare = (Originalsheet.Cells(y, b) -
                 bMean) ^ 2
                bVarTimesdf = bVarTimesdf + bDiffSquare
                Next y
                bSD = Sqr((1 / TotalDistance) * bVarTimesdf)
' for covariance of columns a and b
                abCovTimesdf = 0
```

```
                For y = 2 To (1 + TotalDistance)
                aDiff = (Originalsheet.Cells(y, a) - aMean)
                bDiff = (OriginalSheet.Cells(y, b) - bMean)
                aDiffTimesbDiff = aDiff * bDiff
                abCovTimesdf = abCovTimesdf + aDiffTimesbDiff
                Next y
                abCov = (1/ TotalDistance) * abCovTimesdf
' Now to find the correlation between column a and b
            abCorr = abCov / (aSD * bSD)
            MatrixSheet.Cells(a, b) = abCorr
            Next b
    Next a

' -----------------------------------------------------------
' Now I work out the canonical correlation

' Note: Rx = sub correlation matrix between roads subjects
'       Ry = sub correlation matrix between simulator subjects
'       Rxy = sub correlation matrix between road and
simulator subjects
'       a = vector of weightings for Road subjects
'       b = vector of weightings for Simulator subjects

' first I need to work out the matrix calculation "a'.Rxy.b"
    ' As the vectors a and b both contain only 1's and -1's,
        ' the above matrix calculation is simply 4 sums of
components
        'in 4 sub-sub-matrices
        ' and then turing two of these sums into negatives and
        'then adding the 4 sums up

    MatrixSheet.Activate
    xySum = 0
    xySum1 = 0
    xySum2 = 0
    xySum3 = 0
    xySum4 = 0
    For x = (1 + (2 * Road) + 1) To (1 + (2 * Road) +
Simulator)
        xyCurrentSum =
Application.Sum(Range(MatrixSheet.Cells(2, x), _
         MatrixSheet.Cells(1 + Road, x)))
        xySum1 = xySum1 + xyCurrentSum
    Next x
    For x = (1 + (2 * Road) + Simulator + 1) To (1+ (2 *
Road) + (2 * Simulator))
        xyCurrentSum =
Application.Sum(Range(MatrixSheet.Cells(2, x), _
```

```
        MatrixSheet.Cells(1 + Road, x)))
        xySum2 = xySum2 + xyCurrentSum
    Next x
    For x = (1 + (2 * Road) + 1) To (1 + (2 * Road) +
     Simulator)
        xyCurrentSum = Application.Sum(Range(MatrixSheet.Cells
         (1 + Road + 1, x), MatrixSheet.Cells(1 + (2 * Road),
x)))
        xySum3 = xySum3 + xyCurrentSum
    Next x
    For x = (1 + (2 * Road) + Simulator + 1) To (1 + (2 *
     Road) + (2 * Simulator))
        xyCurrentSum = Application.Sum(Range(MatrixSheet.Cells
         (1 + Road + 1, x), MatrixSheet.Cells(1 + (2 * Road),
x)))
        xySum4 = xySum4 + xyCurrentSum
    Next x
    xySum2 = xySum2 * -1
    xySum3 = xySum3 * -1
    xySum = xySum1 t xySum2 + xySum3 + xySum4

' now I work out "a'.Rx.a"
    xSum = 0
    xSum1 = 0
    xSum2 = 0
    xSum3 = 0
    xSum4 = 0
    For x = 2 To (1 + Road)
        xCurrentSum =
     Application.Sum(Range(MatrixSheet.Cells(2, x),
         MatrixSheet.Cells(1 + Road, x)))
        xSum1 = xSum1 + xCurrentSum
    Next x
    For x = (1 + Road + 1) To (1 + (2 * Road))
        xCurrentSum =
     Application.Sum(Range(MatrixSheet.Cells(2, x), _
         MatrixSheet.Cells(1 + Road, x)))
        xSum2 = xSum2 + xCurrentSum
    Next x
    For x = 2 To (1 + Road)
        xCurrentSum = Application.Sum(Range(MatrixSheet.Cells
         (1 + Road + 1, x), MatrixSheet.Cells(1 + (2 * Road),
x)))
        xSum3 = xSum3 + xCurrentSum
    Next x
    For x = (1 + Road + 1) To (1 + (2 * Road))
        xCurrentSum = Application.Sum(Range(MatrixSheet.Cells
```

```
        (1 + Road + 1, x), MatrixSheet.Cells(1 + (2 * Road),
x)))
        xSum4 = xSum4 + xCurrentSum
    Next x
    xSum2 = xSum2 * -1
    xSum3 = xSum3 * -1
    xSum = xSum1 + xSum2 + xSum3 + xSum4

' now I work out "b'.Ry.b"
    ySum = 0
    ySum1 = 0
    ySum2 = 0
    ySum3 = 0
    ySum4 = 0
     For x = (1 + (2 * Road) + 1) To (1 + (2 * Road) t
     Simulator)
        yCurrentSum = Application.Sum(Range _
         (MatrixSheet.Cells(1 + (2 * Road) + 1, x), _
          MatrixSheet.Cells(1 + (2 * Road) + Simulator, x)))
        ySum1 = ySum1 + yCurrentSum
    Next x
    For x = (1 + (2 * Road) + Simulator + 1) To (1 + (2 *
     Road) + (2 * Simulator))
        yCurrentSum = Application.Sum(Range _
         (MatrixSheet.Cells(1 + (2 * Road) + 1, x), _
          MatrixSheet.Cells(1 + (2 * Road) + Simulator, x)))
        ySum2 = ySum2 + yCurrentSum
    Next x
    For x = (1 + (2 * Road) + 1) To (1 + (2 * Road) +
     Simulator)
        yCurrentSum = Application.Sum(Range _
         (MatrixSheet.Cells(1 + (2 * Road) + Simulator + 1,
x), _
          MatrixSheet.Cells(1 + (2 * Road) + (2 * Simulator),
x)))
        ySum3 = ySum3 + yCurrentSum
    Next x
    For x = (1 + (2 * Road) + Simulator + 1) To (1 + (2 *
     Road) + (2 * Simulator))
        yCurrentSum = Application.Sum(Range
         (MatrixSheet.Cells(1 + (2 * Road) +_Simulator + 1,
x), _
          MatrixSheet.Cells(1 + (2 * Road) + (2 * Simulator),
x)))
        ySum4 = ySum4 + yCurrentSum
    Next x
    ySum2 = ySum2 * -1
    ySum3 = ySum3 * -1
```

```
          MatrixSheet.Cells(1 + (2 * Road) + (2 * Simulator),
x)))
        ySum4 = ySum4 + yCurrentSum
    Next x
    ySum2 = ySum2 * -1
    ySum3 = ySum3 * -1
    ySum = ySum1 + ySum2 + ySum3 + ySum4

' Now for the actual Canonical Correlation
    CanCor = xySum / (Sqr(xSum * ySum))
    MatrixSheet.Cells(1, 1) = "CanCor = " + CanCor

    MatrixSheet.Cells((2 * Road) + (2 * Simulator) + 6, 1) =
"CanCor = " + CanCor
    MatrixSheet.Cells((2 * Road) + (2 * Simulator) + 7, 1) =
"Rrs = " + xySum
    MatrixSheet.Cells((2 * Road) + (2 * Simulator) + 8, 1) =
"Rr = " + xSum
    MatrixSheet.Cells((2 * Road) + (2 * Simulator) + 9, 1) =
"Rs = " + ySum


Next z
' ----------------------------------------------------------------
Beep
Beep
Beep
Beep
End Sub
```