

## CHAPTER 5

### ALTERNATIVE SKILL TEST (AST)

#### 5.1 INTRODUCTION

It was shown in the last chapter that some of the test exercises in the MOST were better skill discriminators than others. This knowledge was used in the second experiment to investigate how successfully riders of varying levels of skill perform tasks in a situation where they are required to respond in one of several known ways, but without prior knowledge of the current task.

An Alternative Skill Test (AST) was designed to measure the critical perceptual-motor skills addressed by the MOST, but also to incorporate elements of surprise and decision making. The intention with the AST was to create a test which is more representative of actual on-street situations where a rider has to respond to a variety of randomly-sequenced traffic events.

#### 5.2 SELECTION OF TEST MANOEUVRES

In order to determine which manoeuvres would be most useful for the Alternative Skill Test, the following criteria were established:

- tasks should be important to safe riding
- the task difficulty should be variable
- tasks should be sensitive to rider skill level
- elements of actual street riding, i.e. decision making and surprise, should be incorporated

- problem(s) found in the MOST should be overcome
- the feasibility of application in a licensing program should be considered

The manoeuvres in the MOST which were determined by the Task Analysis of the NPSRI (1974) as being highly critical to safe riding, and which were found in the first experiment to be the most difficult were:

exercise 7: quick stop - straight  
 exercise 8: obstacle turn  
 exercise 9: quick stop - curve

The analysis in the previous chapter showed exercise 7 to be a good test exercise in terms of score frequency distribution and, to produce a significant difference in score between McPherson and McKnight's 'pilot study group' and the more skilled riders in the present study group. Their 'operational test group' (another less skilled group) also scored worse than the present study group on this exercise. Exercise 7 was therefore chosen as a manoeuvre for the AST.

The avoidance manoeuvre, exercise 8, also had a good score frequency distribution and showed a significant difference between the pilot study group and the present study group, although for the operational test group the test score difference was not likely to be significant. Manoeuvres similar to exercise 8 have been used in previous studies to investigate skill differences. For example, Rice (1978) observed and recorded the performance of three riders of varying skill levels in a lane-change manoeuvre and commented as follows:

"This manoeuvre, when performed at near limit conditions, calls into play the full skill and willingness characteristics of the rider and thereby offers a suitable means for differentiating rider actions".

This manoeuvre has a self-evident relation to accident avoidance and is considered, in many situations, to be preferable to braking, since braking sharply may put the vehicle in conflict with a following vehicle (McPherson and McKnight, 1976).

In exercise 9 the present study group's performance was poorer than for the two other groups, which is not consistent with the results obtained for exercise 7 and 8. Possible reasons for the poorer performance of the (assumed) more highly skilled group were discussed in Section 4.5. It seems that scores in this exercise may be rather sensitive to the characteristics of the particular motorcycle used. In addition, this manoeuvre was found to be undesirably hazardous for routine skill testing: one relatively skilled rider dropped the motorcycle and several others very nearly did so.

Of the three exercises considered, therefore, straight line braking and obstacle avoidance were selected for the AST. As employed in the MOST, these two exercises satisfy several of the criteria presented earlier. A number of modifications to the exercises, and to the general test procedure were made to satisfy the other criteria.

### 5.3 DEVELOPMENT OF TEST MANOEUVRES

Whereas in the MOST, riders knew in advance precisely what each exercise entailed, in the AST they were required to detect, and respond appropriately to, a variety of 'traffic' situations simulated by an array of signal lights. Figure 5.1 shows the various 'hazard' situations encountered by the riders as they rode along a straight traffic lane (depicted in Figure 5.2). Different trials, therefore, could require a mandatory stop or an avoidance manoeuvre in a commanded direction, or a choice between braking and avoidance, interspersed with 'no event' trials in which no special action was required.

The task difficulty for the braking and obstacle avoidance manoeuvres was also manipulated by sometimes introducing a time delay into the circuit for triggering the signal lights, thereby reducing the manoeuvring length available. If the manoeuvring length for the

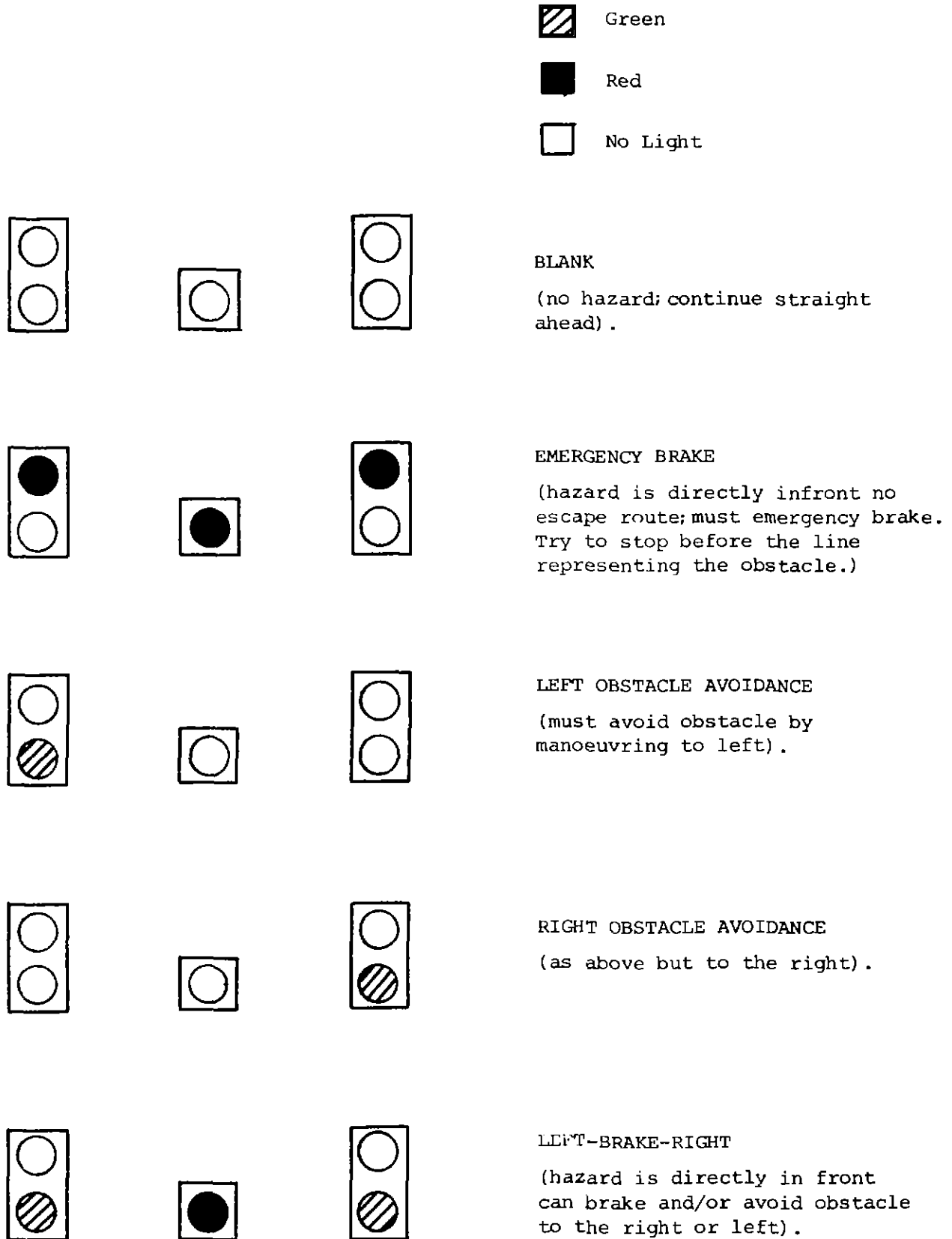


Figure 5.1 Signal light combination conveying to the rider the manoeuvre to be performed.

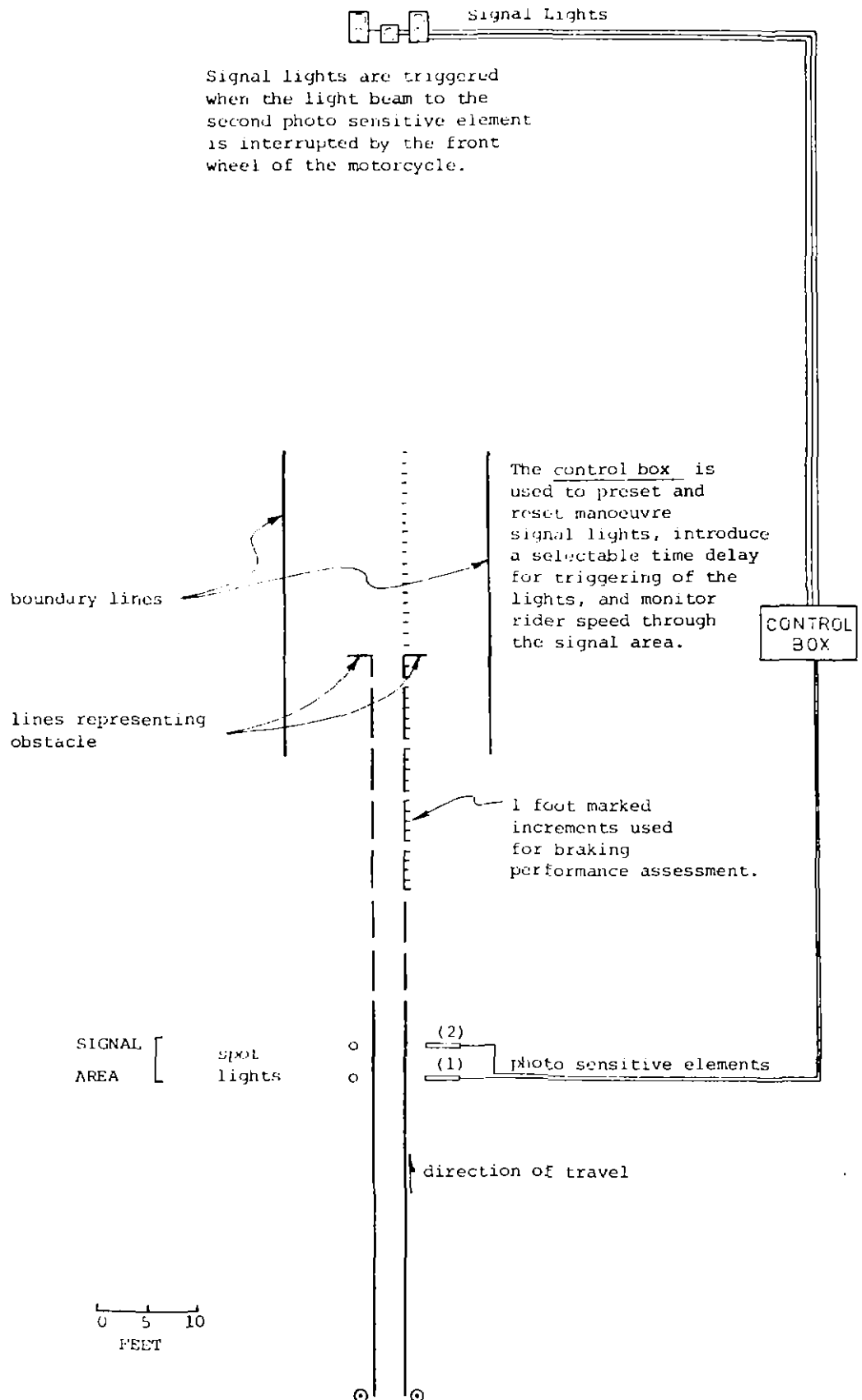


Figure 5.2 Layout of the alternative skill test.

task is reduced, the rider must brake harder to succeed. For the obstacle avoidance manoeuvre higher roll rates and angles must be achieved in order to perform successfully.

Task difficulty was set at two levels. At the first level the braking and obstacle turning tasks were performed at the 'normal' MOST level, i.e. the signal lights were triggered when the front wheel of the motorcycle interrupted a light beam pointed at a photo-sensitive element 11.6 m ahead of the 'obstacle'. At the second level, once the trigger for the signal lights was established, a 0.2 second time interval elapsed before the signal lights were activated. With a 0.2 second time delay, and travelling at the required 32 km/h, the available manoeuvre distance was reduced from 11.6 m to 9.8 m.

A time delay of 0.2 seconds was selected following experiments with a skilled rider. The rider was required to perform the obstacle turn manoeuvre repeatedly, while both turn direction and time delay were varied randomly. The time delay was chosen such that the rider could perform the obstacle avoidance manoeuvre in the given manoeuvre length successfully, at near limit conditions. Comments made by the rider aided in ascertaining when the manoeuvre was being performed under these conditions.

Figure 5.3 shows the manoeuvring distance 'L' used by Watanabe and Yoshida (1973) in tests conducted to investigate obstacle avoidance performance for motorcycles with a group of riders with different riding skills. Points representing 'L' for level 1 (MOST) and level 2 of the obstacle avoidance manoeuvre in the AST are also shown. 'L' for Watanabe and Yoshida's experiments was established as follows:

"The distance 'L' is set, based on our test experience, at a value for each of the test velocities such that an average rider will be able to avoid the obstacle in 50% of his attempts".

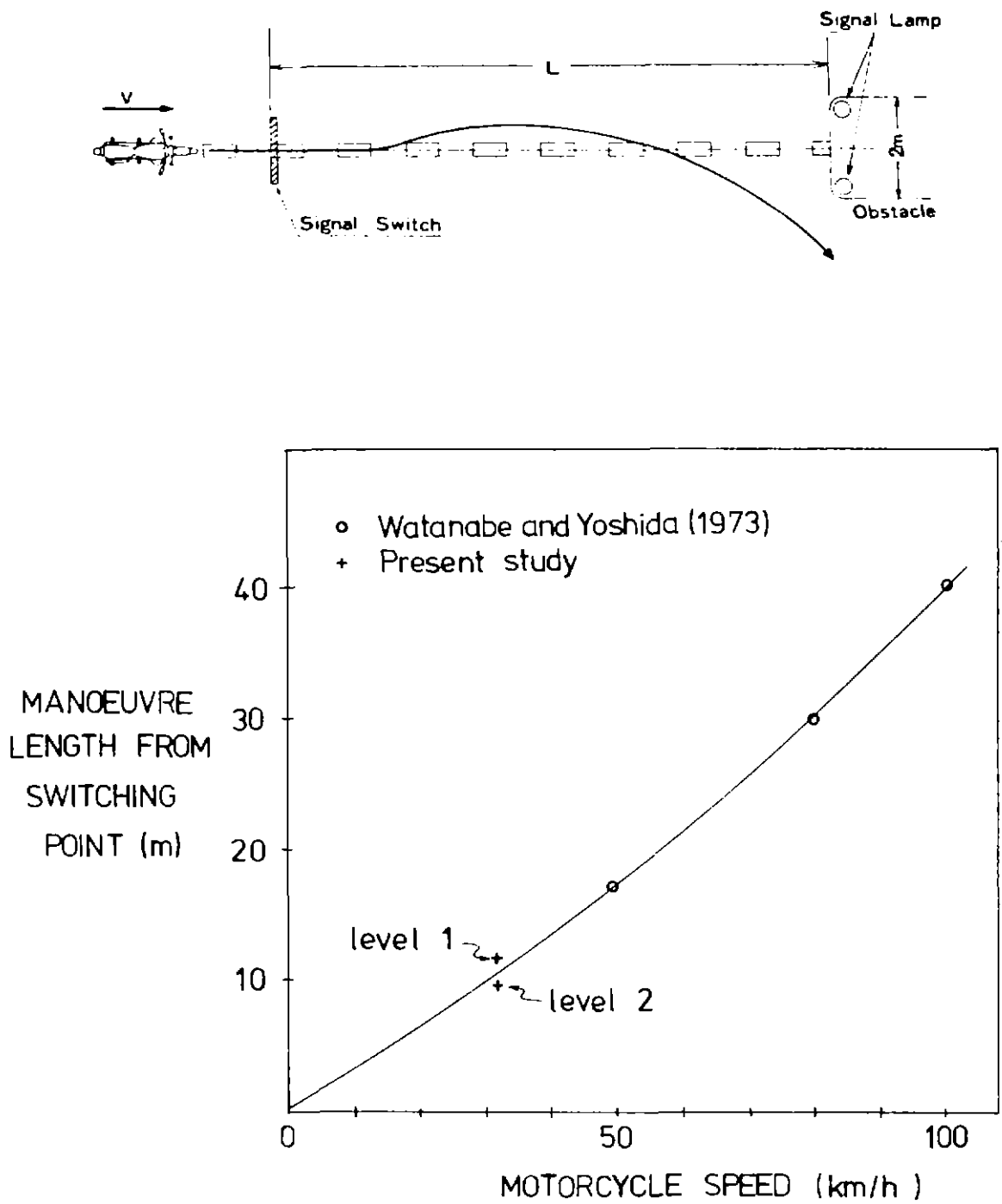


Figure 5.3 Manoeuvring lengths for obstacle avoidance manoeuvres used by Watanabe and Yoshida (1973), compared to those used in the present study.

Figure 5.3 indicates, therefore, that the manoeuvring lengths chosen for level 1 and level 2 of the obstacle avoidance manoeuvre in the AST represent, respectively, an 'easy' and a 'hard' task. Note that the obstacle line for the present study was slightly wider (2.6 m) than for Watanabe and Yoshida's experiment (2.0 m), and furthermore, the riders in the present study had to avoid encroaching the furthest lateral boundary of the course.

The manoeuvre devised to incorporate decision-making involved a choice between a left obstacle turn, a right obstacle turn, and an emergency straight line braking task. This requirement was conveyed to the rider by displaying a green-red-green signal light combination. This meant, in 'real life' terms, that it was not possible to proceed straight ahead because of the presence of an obstacle, e.g. a car, directly ahead. It was however possible to turn left or right and/or brake to avoid the obstacle. The choice of the most appropriate avoidance strategy was left to the rider's discretion. Recall from the accident reports reviewed in Section 2.3.3 that in a situation where riders have a choice of braking or manoeuvring to avoid a collision, often the 'wrong' choice or no attempt is made.

Design of the decision task was based on the data of Figure 5.4 taken from Watanabe and Yoshida (1973). This comparison between braking and obstacle avoidance performance indicates that at around 30 km/h braking and obstacle avoidance require roughly similar distances (approximately 11 m). However the range of distances for obstacle avoidance suggests that this manoeuvre may be performed in a slightly shorter distance (down to approximately 6 m). At higher velocities, the distance for evasion is seen to be substantially less than braking distance. Assuming, at this stage, that an obstacle avoidance strategy was the most appropriate one, and given the present study test conditions, it was believed that this choice would be apparent to the more skilled riders. For the less skilled riders the choice would be more difficult and lead to more failures.



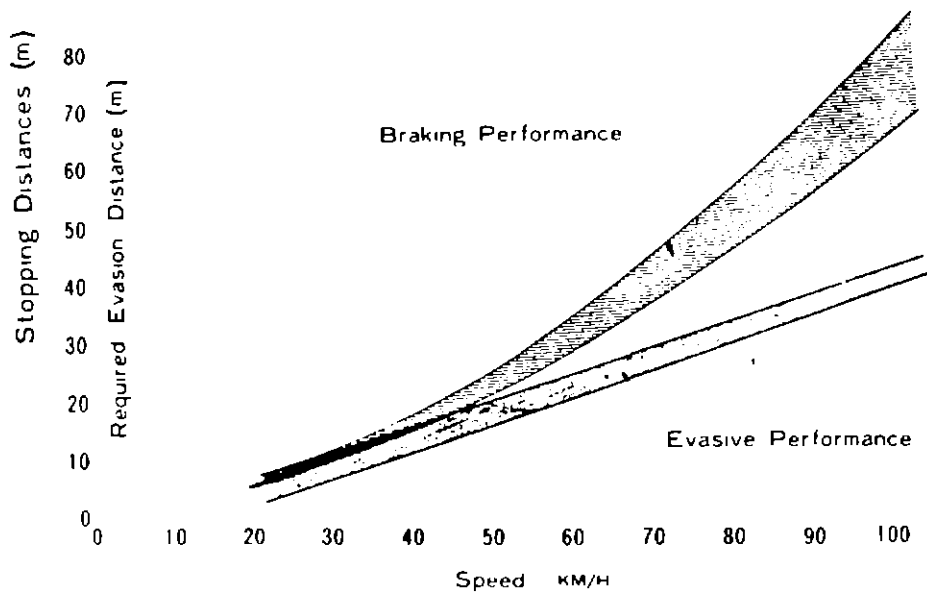


Figure 5.4 Comparison between obstacle avoidance turn and emergency braking for riders with a range of skills (Watanabe and Yoshida, 1973).

All the manoeuvres mentioned thus far - the obstacle avoidance manoeuvre, the straight line braking task, and the decision task - were performed at the two levels of difficulty. Each rider performed a set of 30 of these manoeuvres in a random sequence. Riders were therefore unaware of the sequence of manoeuvres and could not prepare for any particular task. In addition, 'blank' runs, where riders were not required to do anything, were incorporated at random to further increase the task uncertainty. Figure 5.1 illustrates the possible combinations of lights and their associated meanings. In total there were 9 tasks - the five shown in Figure 5.1, plus the last four shown in the figure performed with a 0.2 second time delay.

#### 5.4 SUBJECT SELECTION

The requirement which the sample of subjects had to fulfil for this test was that it should contain a wide range of riding skills. The sample used for the MOST experiment was a 'good' source since a file had been established for each rider and a measure of each rider's skill level had been obtained.

Four riders were selected randomly from each of the score groups shown in Table 5.1 so that the size of the sample of riders for the AST would be twenty-four. Although these subjects were perhaps atypical in that they had already performed the MOST, the differences which were of importance were relative differences. The skill distribution of the sample chosen, based on scores obtained from the MOST is shown in Table 5.2. Note that five riders could not be obtained; difficulty was experienced in organizing some riders to participate again. Although replacement riders in the relevant score group were contacted, mutually suitable times could not always be arranged.

#### 5.5 SET-UP AND ADMINISTRATION

Since the Alternative Skill Test consisted only of obstacle avoidance and emergency braking manoeuvres, the area on which the MOST was set-up was appropriately modified. Electronic circuitry was developed

TABLE 5.1

## SCORE RANGE DISTRIBUTION OF THE MOST SAMPLE OF RIDERS

Score range	0-3	4-7	8-11	12-15	16-19	>20
Number of riders	8	16	10	9	8	8

TABLE 5.2

## DISTRIBUTION OF MOST SCORES FOR ALTERNATIVE SKILL TEST SAMPLE

Score range	0-3	4-7	8-11	12-15	16-19	>20
Subject	3	5	8	13	18	24
score		5	10	14	18	25
on		5	11	15	18	29
MOST			11	15	19	
Total	1	3	4	4	4	3

to introduce a selectable time delay for the triggering of the signal lights. The set-up is depicted in Figure 5.2.

As with the MOST, at the beginning of each day of testing the group of riders was taken around the course on foot, and verbally given details of the possible combinations of lights and associated manoeuvres. Riders were instructed to maintain a constant speed. In the absence of signal light changes, they were to maintain their speed until they were well past the manoeuvre area. This was to ensure they did not slow down during a possible time delay period after the

trigger point for the lights had been passed. Verbal instructions given to the riders are shown in Appendix H.

Riders were permitted to familiarize themselves with the instrumented motorcycle, in an area remote from the AST set-up, in the same way as for the MOST.

During the conduct of the test, riders were given continuous feedback regarding their success in maintaining speed within the acceptable range of 29 to 35 km/h.

## 5.6 PERFORMANCE ASSESSMENT

As with the MOST, scoring was based primarily on the subject's ability to achieve prescribed vehicle responses.

It will be recalled from section 4.8 that in the MOST braking tasks, performance is assessed by comparing the braking distance achieved with a table of 'standard' distances which are judged to represent adequate performance for various initial speeds. One penalty point is assigned for each foot by which the actual braking distance exceeds the standard distance, up to a maximum of five points. It was argued in section 4.8 that the MOST table of standard distances was not soundly based, as it in fact implies quite a wide range of braking performance over the range of allowable entry speeds.

For the AST it was decided that the braking task criterion should be based on deceleration performance, and that level 1 of the task should correspond to the demands of the MOST quick-stop (exercise 7). Thus, for level 1, the available manoeuvre length between the signal light trigger point and the 'obstacle' was set at 11.6 m. Allowing for the mean braking reaction time of 0.41 seconds measured in the MOST, riders would travel an average of 3.6 m at the specified entry speed of 32 km/h before applying the brakes, so that the actual braking distance available would be 8.0 m, corresponding to a deceleration of 0.50 g. For level 2 of the task a delay of 0.2 seconds was introduced between triggering of the lights and their being turned on, thus

reducing the available braking distance by 1.8 m and requiring a deceleration of 0.65 g. Thus the criterion decelerations for levels 1 and 2 of the AST were set at 0.50 g and 0.65 g respectively.

Analysis of the AST data showed that the greater uncertainty in this task resulted in longer reaction times than were measured in the MOST. As is discussed in more detail in Section 5.7.2, the mean braking reaction time was increased from 0.41 seconds in the MOST to 0.55 seconds in the AST, so that the actual deceleration performance required if riders were to stop at the 'obstacle' from the entry speed of 32 km/h was increased to 0.60 g for level 1 and 0.82 g for level 2. Because the 'design' criteria of 0.50 g and 0.65 g were considered more reasonable for the purposes of the AST, scoring of riders performance was based on these figures.

Because the difficulty of the obstacle avoidance manoeuvre is strongly related to the entry speed, and because any trial might require such a manoeuvre, the speed discipline imposed in the MOST exercise 8 was required in all the AST trials. That is, subjects were required to maintain their entry speed between 29 and 35 km/h, and were advised if their speed was outside this range.

In assessing performance, speeds slower than 29 km/h attracted an unconditional penalty of 5 points for all trials. If the entry speed exceeded 35 km/h no special penalty was applied; the scoring criteria for the manoeuvre itself were applied. No braking distances beyond that provided for a speed of 35 km/h were allowed.

Table 5.3 shows the 'standard' braking distances (measured from the signal light trigger point) which satisfy the level 1 and 2 deceleration criteria for the allowable range of entry speeds. It can be seen that the level 2 distances are not very different from those for level 1. In the interests of simplicity in test scoring, therefore, it was decided to adopt the level 1 distances as the standard for both levels of the braking task in the AST. As for the MOST, one score point was lost for each 0.3 m (1 ft) by which the standard distance was exceeded, up to a maximum of 5 points. However, runs for which

TABLE 5.3

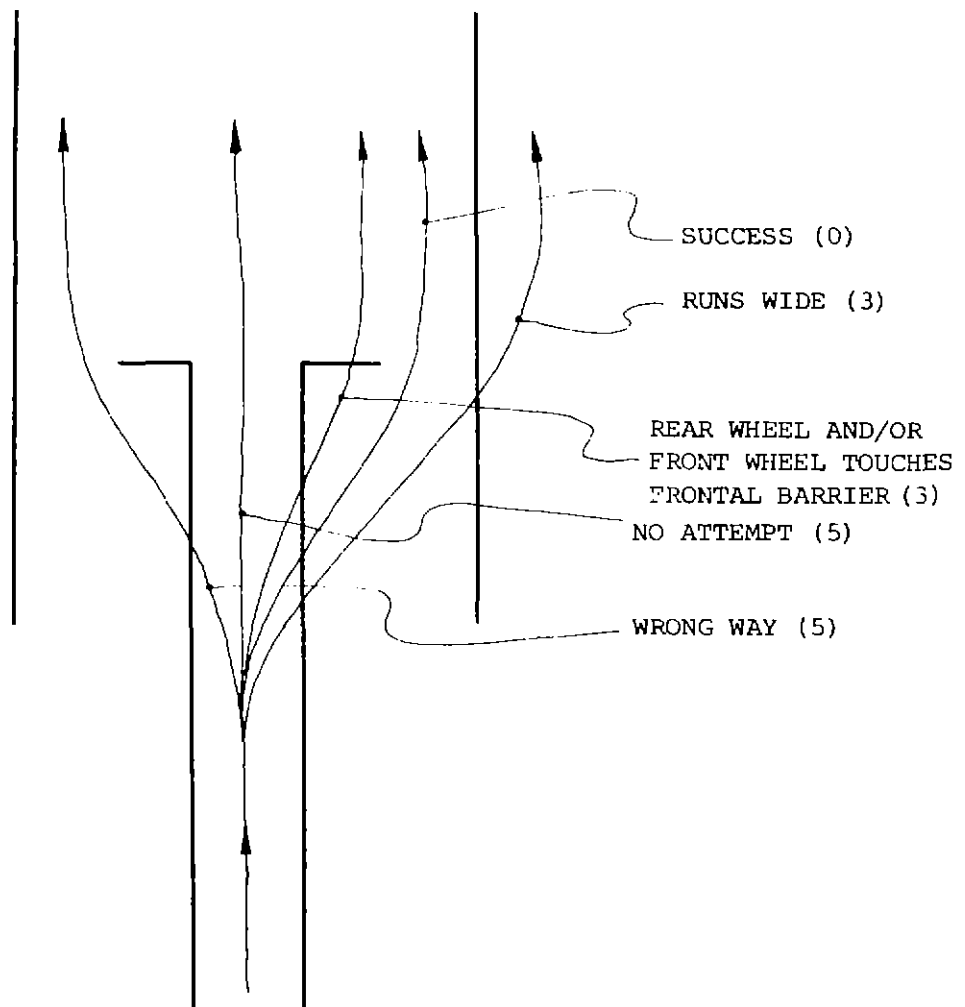
## AST TIME/DISTANCE CHART

Speed-Gate Time (s)	Braking Distance (m)	
	Level 1	Level 2
0.090 - 0.091	15.4	15.1
0.092 - 0.093	14.9	14.6
0.094 - 0.095	14.4	14.1
0.096 - 0.097	13.9	13.7
0.098 - 0.099	13.4	13.3
0.100 - 0.102	13.0	12.9
0.103 - 0.104	12.4	12.3
0.105 - 0.106	12.0	12.0
0.107 - 0.108	11.6	11.7
0.109 - 0.110	11.3	11.4
0.111 - 0.112	11.0	11.1

Note: Braking distances based on a 0.55 s reaction time and minimum decelerations of 0.5 g and 0.65 g for levels 1 and 2, respectively.

the speed-gate times were greater than 0.109 s and in which the standard braking distance was exceeded, but in which the 'obstacle' line was not crossed, attracted no penalty points. This ensured consistency with the instructions given to subjects (see Appendix H).

Scoring criteria used for the obstacle avoidance manoeuvre were slightly different from those in the MOST, and are depicted in Figure 5.5. As can be seen, various levels of failure were established to increase the sensitivity of the manoeuvre to rider skill level. 'Almost succeeding', i.e. either wheel touching the line representing the obstacle, or 'running wide', mean that the rider's initial control



SPEED TOO LOW AND SUCCESS	(4)
SPEED TOO LOW AND UNSUCCESSFUL ATTEMPT	(5)
SPEED TOO HIGH AND SUCCESSFUL	(0)
SPEED TOO HIGH AND UNSUCCESSFUL ATTEMPT	(5)

Figure 5.5 Scoring criteria used for the obstacle avoidance manoeuvre.  
Example showing a right-hand turn.

inputs were correct and caused the motorcycle to move in the required direction.

'No attempt' or 'wrong way' were penalized by 5 points for obvious reasons. Points assigned for high speed errors were as for the MOST. However since the 30 runs were performed continuously, manoeuvres performed at too low a speed were penalized. The acceptable speed range was as for the MOST.

Assessment of the decision task was based on whether the rider decided to brake or avoid the obstacle. If the rider decided to brake then the braking criteria were applied. If the rider decided to perform an obstacle turn or a combined braking/obstacle turn, then the obstacle turn criteria were applied. On the blank run, if speed was too low, 5 points were deducted.

Since the manoeuvres were performed in random sequences, the number of repeated manoeuvres assigned to each rider varied. Assigning the manoeuvres in this fashion ensured that riders could not predict, and hence prepare themselves for, a manoeuvre in advance. Overall assessment was based on the sum of the average scores obtained in each of the 9 tasks. For example, if a particular rider received three right-hand avoidance manoeuvres, two of which were executed successfully (zero penalty points assigned), and one unsuccessfully (5 points), the average score for this task would be 1.67.

Since riders were required to perform each manoeuvre at least once, the possible bias in the MOST scores related to the different success rates for left- and right-hand obstacle avoidance manoeuvres was reduced. Similarly, for the braking tasks, the average stopping distance should represent more closely the rider's braking ability than the result of a single trial.



## 5.7 ANALYSIS OF THE ALTERNATIVE SKILL TEST (AST) SCORES AND COMPARISONS WITH THE MOST

### 5.7.1 Introduction

The scores assigned to riders in the AST are examined in this section and where appropriate comparisons with the MOST are made. For the MOST, only data corresponding to the subjects who participated in the AST was considered. To determine the usefulness of the various tasks in the AST as skill discriminators, scores assigned to riders were examined by way of histograms of score frequency distributions and by comparing computed success rates for the various tasks. To compare the scores for identical exercises for the MOST and the AST, it was found necessary to firstly determine rider reaction times (which are discussed in some detail).

### 5.7.2 Reaction Times

Rider reaction times - from the turning on of the signal lights to the application of some braking or steering control input - were determined from the recorded instrument data in the same way as described in section 4.9.2 for the MOST. To enable comparison with the MOST data, the AST reaction times were measured for the first administration only of the braking, avoidance and decision tasks.

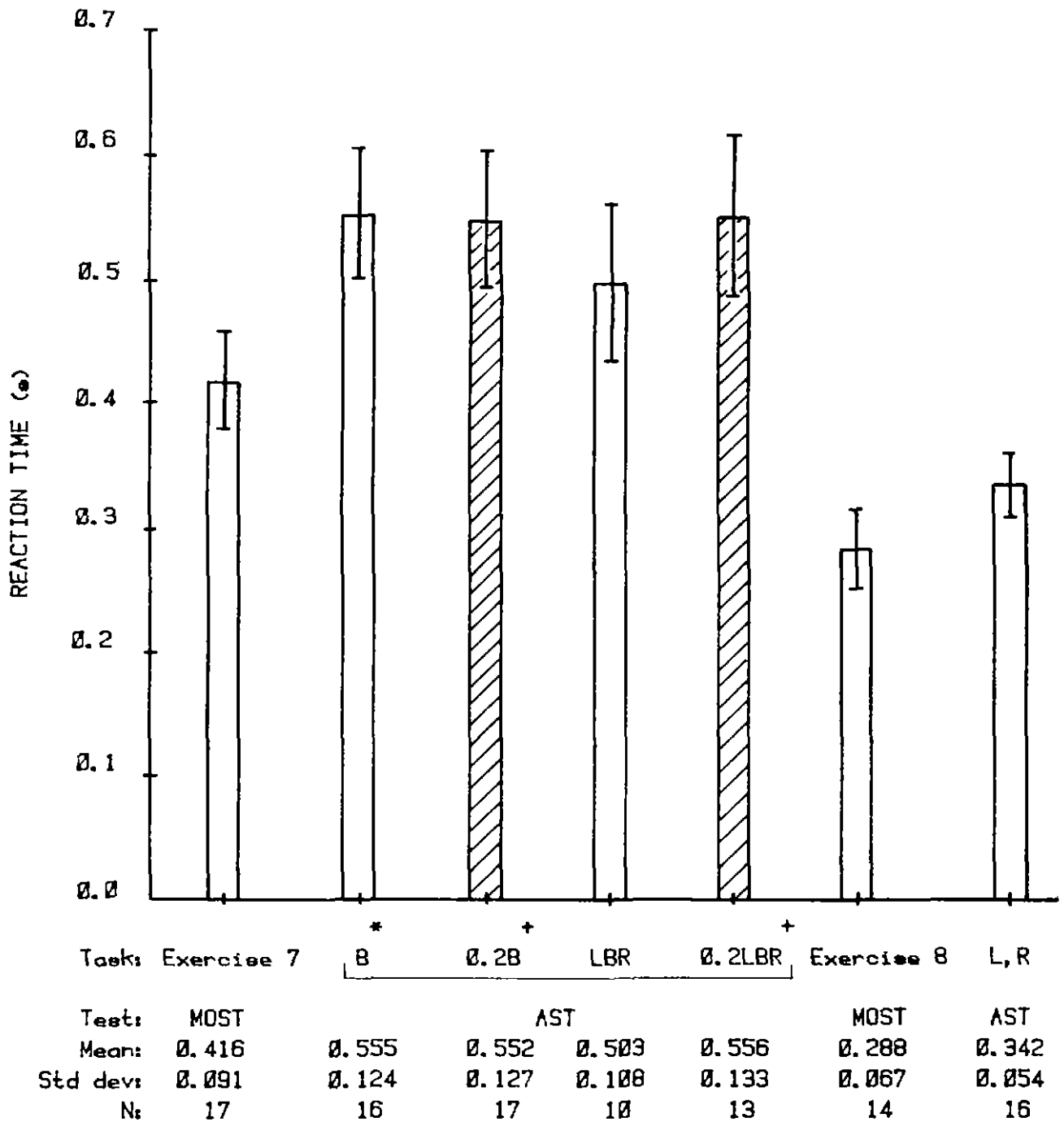
It was found that there were no statistically significant differences between the mean reaction times for the two levels of difficulty of any of the manoeuvres, or for the left and right turn directions of the avoidance manoeuvres. In the decision task the great majority of riders opted to brake rather than go around the obstacle. The mean reaction time for these braking attempts was no different from that for the prescribed braking tasks.

The mean reaction times for levels one and two of the prescribed braking task and decision task where riders chose to brake, and the prescribed obstacle avoidance task (since most subjects chose to brake

for the decision task) in the AST are compared with the corresponding MOST times for the same group of subjects in Figure 5.6. The AST times are significantly longer than those for the MOST ( $p < 0.05$ ) and, for both tests, the braking reaction times exceed the obstacle avoidance times ( $p < 0.01$ ).

The longer reaction times in the AST are consistent with the general psychological finding that reaction time increases with task uncertainty (McCormick, 1970). In the MOST riders had only to resolve uncertainty as to whether a signal had occurred and, in the case of the avoidance manoeuvre, the required turn direction. In the AST, riders had to additionally determine which of the three tasks was being presented and, in the case of the decision task, choose between a braking or avoidance response.

The difference between the mean reaction times for braking and avoidance indicates that it takes longer for a rider to effect a change in the motion of the motorcycle when braking than when manoeuvring to avoid an obstacle. This difference between the reaction times for the two exercises can be attributed to the nature of the required rider response. The difference can be explained as follows: Reaction time, in general, is composed of a variety of delays associated with the various receptor and neuro-muscular processes in the body. In considering physical responses, reaction time can be divided into two basic components: simple reaction time, or the time required to process a signal and determine a response, and movement time, which corresponds to the time from the activation of the muscles of the hand or foot until completion of the movement (McCormick, 1970). Swink (1966) reports the mean reaction time of subjects responding to a visual stimulus of light by depressing a button located under the index finger of the preferred hand as being 0.240 s. For the present discussion, this value will be used as a conservative estimate of simple reaction time. The position of the hand and foot brake levers adds to this lag a movement time delay. McCormick (1970) cites evidence suggesting that a minimum movement time of about 0.300s can be expected for most control activities, however, the nature and position of the response mechanism can influence the total time.



\* L = Left obstacle turn.

B = Emergency braking.

R = Right obstacle turn.

LBR = Decision task for which rider chose to brake.

0.2 prefix denotes run was conducted with a 0.2s time delay.

+ The value for the reaction time does not include the 0.2s delay.

Figure 5.6 Mean reaction time of the AST subjects for emergency braking and obstacle avoidance in both the MOST and AST with 90% confidence intervals for the means.

These values suggest a reaction time for emergency braking, as presented in the MOST, of about 0.540s. For the MOST obstacle avoidance exercise the simple reaction time will be longer than for the emergency braking because the rider has to resolve the uncertainty of turn direction. This will increase the estimated simple reaction time to approximately 0.350s (McCormick, 1970). By contrast, the movement time for obstacle avoidance will be shorter, because the riders response, transmitted via the handlebars, will occur almost instantaneously. These estimates, which are based on the data from the literature, although conservative, are comparable to the values shown in Figure 5.6.

It is of interest that, although the braking reaction time exceeded the avoidance reaction time, and appeared to be more adversely affected by the increased uncertainty of the AST, most riders elected to brake when given the choice in the decision task. Furthermore, the mean reaction time in the decision task for those riders who chose to brake is no different from that for the prescribed braking task, suggesting that these riders simply treated the decision task as a braking task. The distances travelled at the specified speed of 32 km/h during the reaction times are compared with the available manoeuvre length in Figure 5.7.

The present data for the MOST and level-one AST avoidance manoeuvres are compared with Watanabe and Yoshida's (1973) results in Figure 5.8. Their subjects performed over a range of speeds and manoeuvre lengths and, as in the MOST, knew that an obstacle avoidance manoeuvre was required, the only uncertainty being the turn direction. It can be seen that for the tasks of comparable uncertainty, the present MOST data agree very well with Watanabe and Yoshida's results.

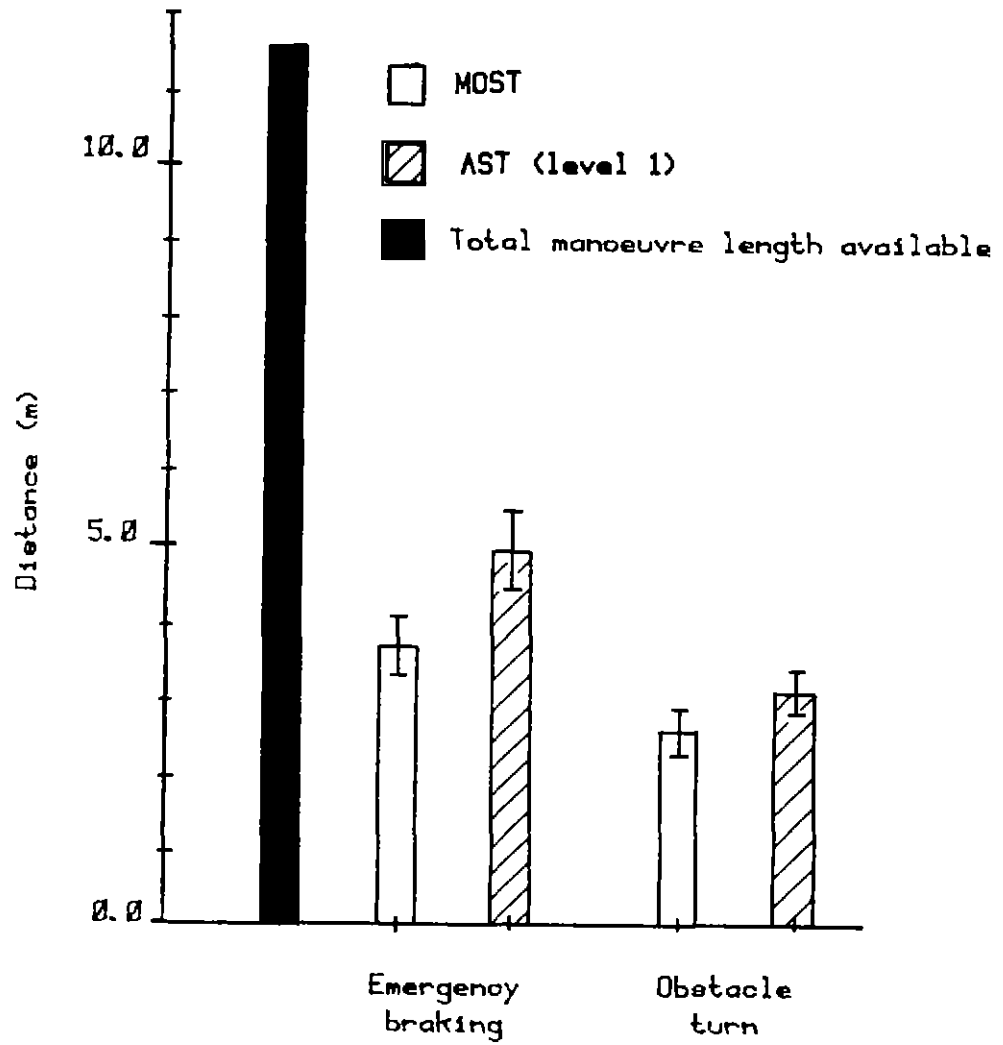


Figure 5.7 Distance travelled at 32 km/h during the mean reaction time for the tasks, with 90% confidence intervals shown.

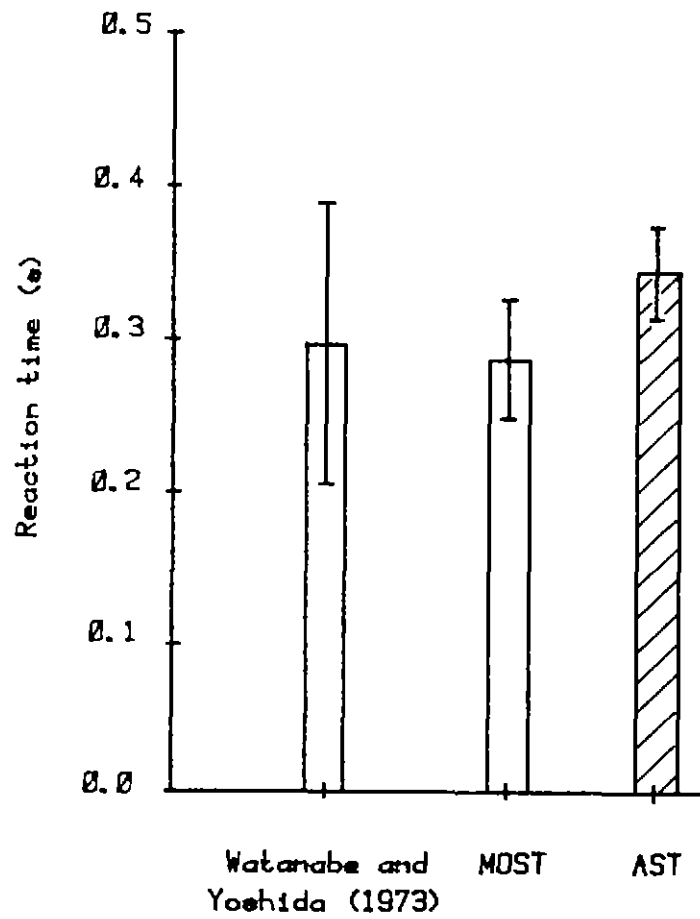


Figure 5.8 Mean reaction times and 95% confidence intervals for obstacle avoidance comparison of the present data with those of Watanabe and Yoshida (1973).

### 5.7.3 AST Score Distribution

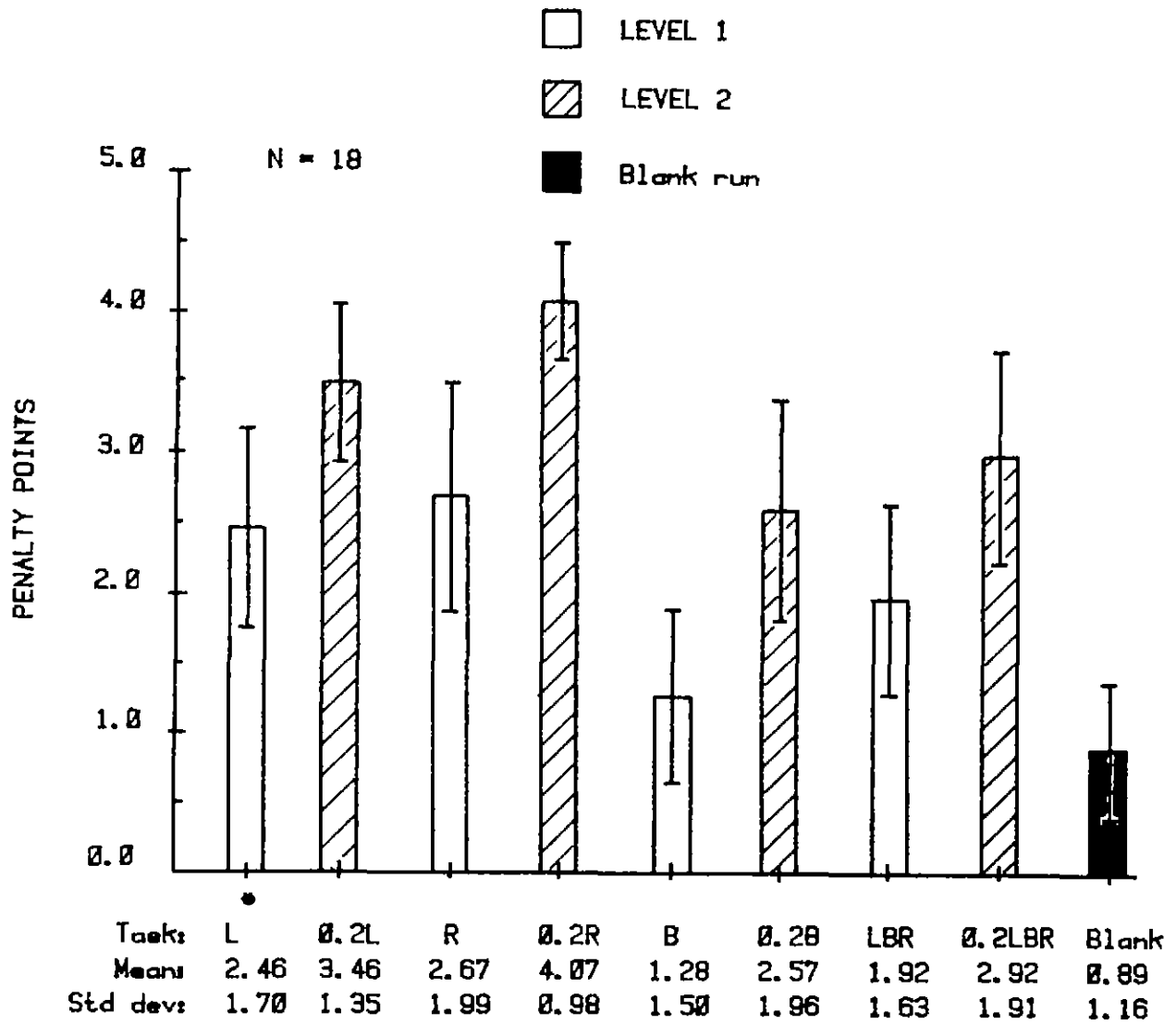
The results obtained in this section, and the ensuing sections, depend on the following variables:

- (i) the difficulty of the test manoeuvre,
- (ii) the scoring criteria,
- (iii) the skill level of the sample of riders.

The first two variables are quite easy to alter as they relate to test design. The third variable for the present work remains fixed. Recall that two objectives of this study are; to establish characteristic patterns of rider/cycle behaviour associated with level of skill, and, to develop a practical skill test for inclusion in a motorcyclist licensing program. To achieve these objects requires two samples of riders with different characteristics. One should possess a wide range of riding skills, such as the present group, and the other skills representative of 'typical' licence applicants. The second group would presumably be less-skilled than the first and their range of skills narrow. Since a major portion of the work and time was devoted to identifying characteristics of skilled performance, the second sample was never recruited. The evaluation of the test exercises therefore provide an indication of their usefulness with the present sample of riders, and will hopefully indicate how they can be modified to improve their sensitivity to a group of less-skilled riders.

Figure 5.9 present the score means, standard deviations and 90% confidence intervals for the means for each task in the AST. The overall mean score was 22.2, with a standard deviation of 9.2 points, the actual range of scores obtained by the eighteen test riders being 8.2 to 35.7. The objective of obtaining a wide distribution of scores was thus realized.

The means indicate that the obstacle avoidance tasks are the most difficult ones, the braking tasks are the easiest, and the decision tasks, for which most riders chose to brake, merely reflect the emer-



Notes: The maximum number of points which a subject can lose on any task is five.

- L = Left obstacle turn.
- B = Emergency braking.
- R = Right obstacle turn.
- LBR = Left - Brake - Right

Ø.2 prefix denotes manoeuvre is performed with a 0.2s time delay.

Figure 5.9 Mean task scores for the AST with 90% confidence intervals for the means indicated.



gency braking trends. The reason for the larger means for the decision task can be attributed to the larger number of 'no attempt' runs which occurred for this task. The blank run mean indicates that the correct entry speed was maintained quite well by subjects.

The statistical significance of the difference between the mean scores for the AST tasks is shown in the following tabulation, where \*\*\* denotes  $p < 0.01$ , \*\* denotes  $p < 0.05$  and, \* denotes  $p < 0.10$  (2-tailed test).

0.2L	*							
R								
0.2R	***		**					
B	**	***	**	***				
0.2B				***	**			
LBR		***		***				
0.2LBR				**	***		*	
BLANK	***	***	***	***		***	**	***
	L	0.2L	R	0.2R	B	0.2B	LBR	0.2LBR

To summarize the results in the tabulation, at the 0.01 level of significance, the tasks (excluding BLANK) with a mean score higher than at least one of the other exercises are:

0.2R , time delayed right obstacle-turn  
 0.2L , time delayed left obstacle-turn

At the 0.05 level of significance, the following additional tasks have a mean score higher than at least one of the other exercises.

R , right obstacle-turn  
 L , left obstacle-turn  
 0.2B , delayed emergency braking

The usefulness of each task in the AST can be examined by way of the histograms of score frequency shown in Figure 5.10, as was done for the MOST. As discussed in the previous chapter, tasks which have an even score distribution are useful as they tend to increase the range of overall scores obtained from a group of riders with a wide range of skill.

The histograms show that more frequent, higher point loss is associated with the level two tasks. Level one of the avoidance manoeuvres have fairly uniform distributions and are therefore considered to be good test exercises. The level two distributions for the avoidance manoeuvres are skewed towards the higher points-lost region, reflecting the increased difficulty of these tasks. The level one emergency braking task distribution is skewed to the lower points-lost region, making this manoeuvre a less effective discriminator than the obstacle avoidance task. The results also indicate that the braking task is easier than the obstacle avoidance task, for the prevailing test conditions. By contrast, the scores for the level two emergency braking accord more with the desired uniform distribution. The decision task distributions for both levels simply reflect the corresponding braking task distributions because most riders chose to brake in this task. Finally, for the task requiring no response (BLANK), the distribution indicates it to be a poor contributor to overall score. Recall, however, that this run was included to increase the task uncertainty for riders and was not intended to be a test exercise.

As was done for the MOST exercises, the linear relationship between the score assigned to each rider for each task, and overall test score, was next examined to ensure that the contribution of each task score to overall score was in the same direction. Furthermore, the correlations between task scores were also determined as they indicate whether the information given by two different tasks is identical. The linear correlations between scores for the various tasks, and overall test score and task score, are given in Table 5.4.

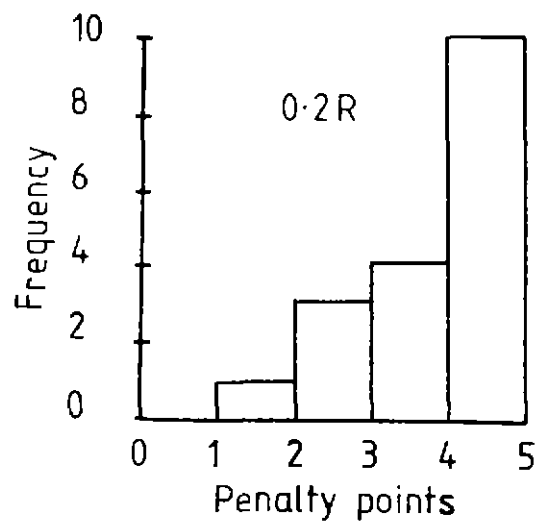
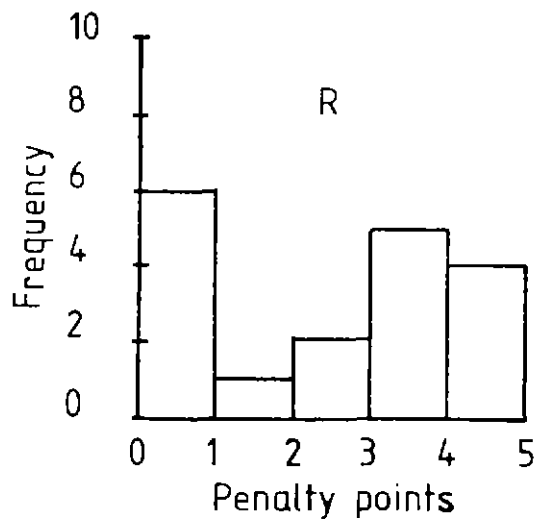
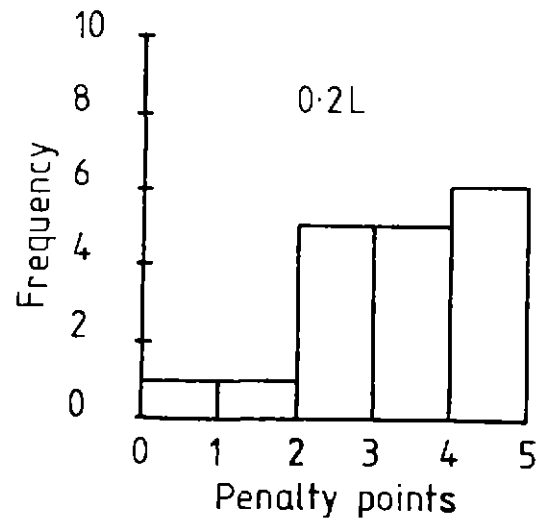
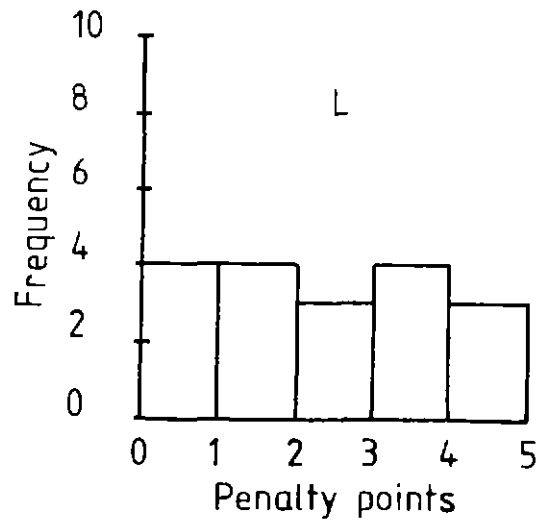


Figure 5.10 Frequency histograms of AST scores for the various tasks. (continued on following page)

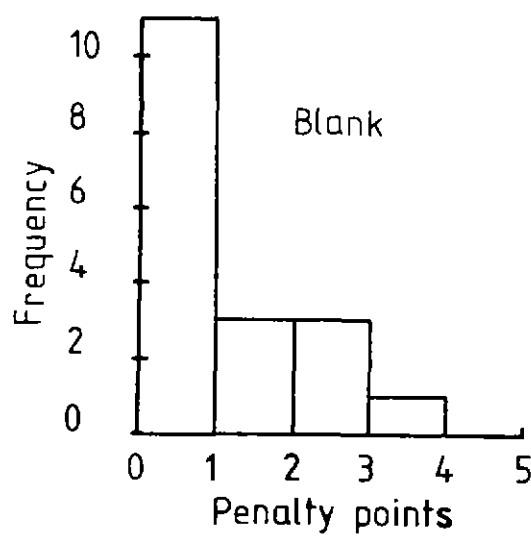
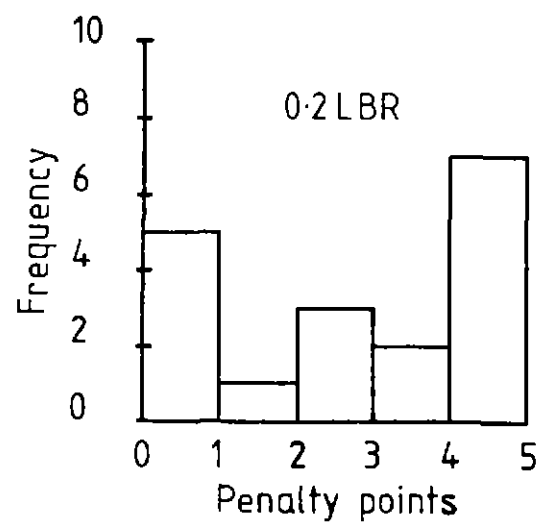
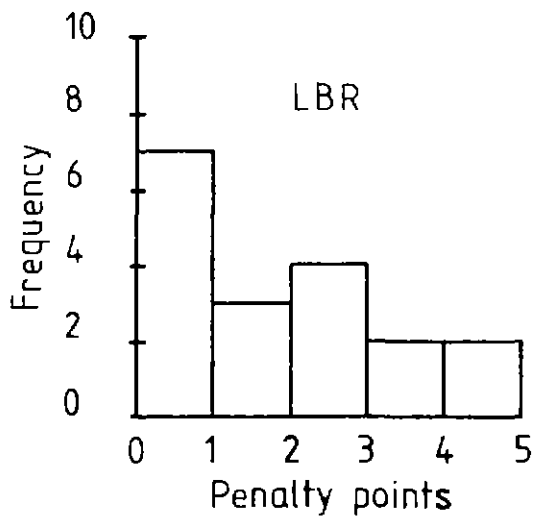
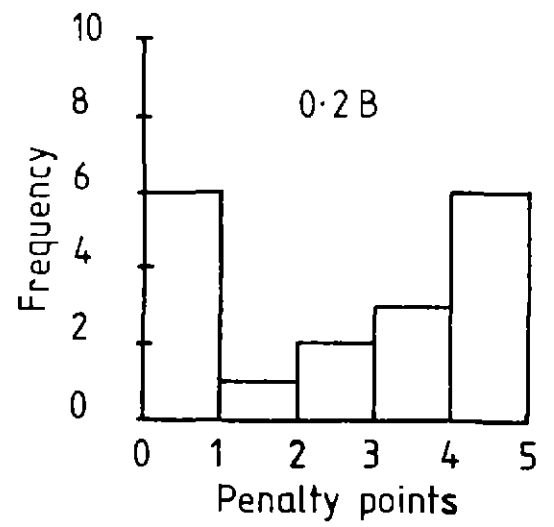
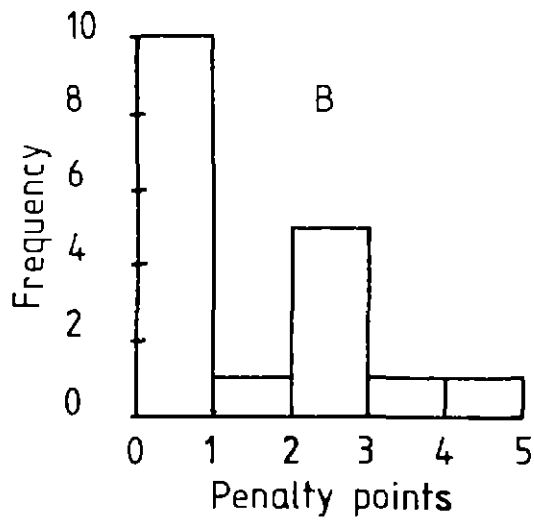


Figure 5.10 Frequency histograms of AST scores for the various tasks. (continued from previous page)

TABLE 5.4

## AST TEST AND TASK SCORE INTERCORRELATIONS

	Overall score	L*	0.2L	R	0.2R	B	0.2B	LBR	0.2LBR
L	0.727								
0.2L	0.266	0.219							
R	0.661	0.394	0.241						
0.2R	0.766	0.551	0.142	0.568					
B	0.621	0.197	0.061	0.244	0.330				
0.2B	0.608	0.315	-0.055	0.218	0.512	0.345			
LBR	0.661	0.343	0.141	0.482	0.422	0.617	0.065		
0.2LBR	0.729	0.528	-0.074	0.289	0.533	0.456	0.629	0.255	
BLANK	0.500	0.553	-0.054	0.140	0.282	0.165	0.191	0.411	0.285

\* Refer to Figure 5.9 for explanation of abbreviations

The correlations between the task scores and overall test score are quite good, with the exception of 0.2L. A close examination of the data for 0.2L revealed three data values which were atypical: Two riders who scored well overall lost the maximum number of points on this task, while the third rider, who scored poorly overall, received no penalty points for this task. Repeating the calculation with these scores omitted, resulted in a correlation coefficient of 0.746. Each task therefore contributes 'positively' to overall score. Tasks which are highly correlated with each other are 0.2B and 0.2LBR (0.629), and B and LBR (0.617), which indicates that these tasks measure the same skill. This result is not surprising, given that most subjects chose to brake in the decision tasks. The decision tasks therefore give approximately the same information as the emergency braking tasks, suggesting that the test conditions for the decision tasks were perhaps inappropriate. It is interesting to note that there is only a moderate correlation between the left (L) and right (R) prescribed

obstacle turns and a poor correlation between the equivalent level 2 tasks. One would expect these tasks to be highly correlated, as they would appear to be measuring the same skill. The observation of the left/right asymmetry in the ability of riders to perform obstacle turns (discussed in section 4.6.4) provides a possible explanation for this result.

#### 5.7.4 Probability of Success for the Various AST Tasks

Rather than examining the scores assigned to the riders for the various AST tasks directly, the success rates for each task were compared. Conceptually, it is thought that this provides a more palpable measure. It also provides a normalized measure for the comparisons with the MOST which will be made subsequently. Furthermore, success rates had to be calculated to determine the appropriateness of choices made by riders in the decision task.

Success rate was defined in terms of the probability of success and was calculated for the prescribed tasks and the decision tasks.

##### (a) Prescribed tasks

The prescribed tasks were the left and right obstacle avoidance manoeuvres and the emergency braking task. These could occur with no time delay (level 1), or with a 0.2 second time delay (level 2), as discussed earlier. When the rider received a prescribed task, any response other than that indicated by the signal lights was regarded as a failure. Since each rider performed each prescribed task at least once, a probability of success for each rider for each task was determined. Subsequently, an overall mean probability of success for each task was determined for the entire sample by taking the average of the estimates for probability of success obtained for all the riders. This ensured that each rider's contribution to the overall probability of success received equal weighting.

The probability of success for a rider was defined as follows:

Probability of success

$$= \frac{\text{Number of successes}}{\text{Number of (successes + failures + no attempts)}} \quad (5.1)$$

For the obstacle avoidance task the number of successes was the number of times the obstacle was successfully avoided. Note that runs where speed errors occurred were not included, except that if the speed for a particular run was too high, and the attempt was successful, then data for the run were used.

The probability of success for the emergency braking task for a rider was also defined by equation 5.1, where the number of successes was the number of times the criterion stopping distance was satisfied. Note that the criterion for success for this task relates to whether or not the rider achieved the required stopping distance and not whether the obstacle was 'struck'. This was because the emphasis was on the mean deceleration level achieved, rather than the total stopping distance, which varies with entry speed. However, it is important to note that for the emergency braking task, the criterion stopping distance corresponding to the lowest acceptable speed was approximately equal to the distance from the trigger point to the obstacle line (refer to Table 5.3). This ensured that the 'target' for the riders was the obstacle line and was therefore consistent with instructions given (see Appendix H). To maintain this consistency, riders whose speed was within the acceptable range and who stopped before the obstacle line, but did not satisfy the stopping distance criterion, were not penalized, i.e. the run was a success. This condition occurred for a small proportion of all the runs.

As for the obstacle avoidance manoeuvre, runs where speed errors occurred were not considered, except for runs where the rider's speed was too high but the criterion stopping distance for the highest acceptable speed was achieved.

Figure 5.11 shows the mean probabilities of success for the six prescribed AST tasks. The mean speeds at which the various tasks were performed were not found to be statistically different.

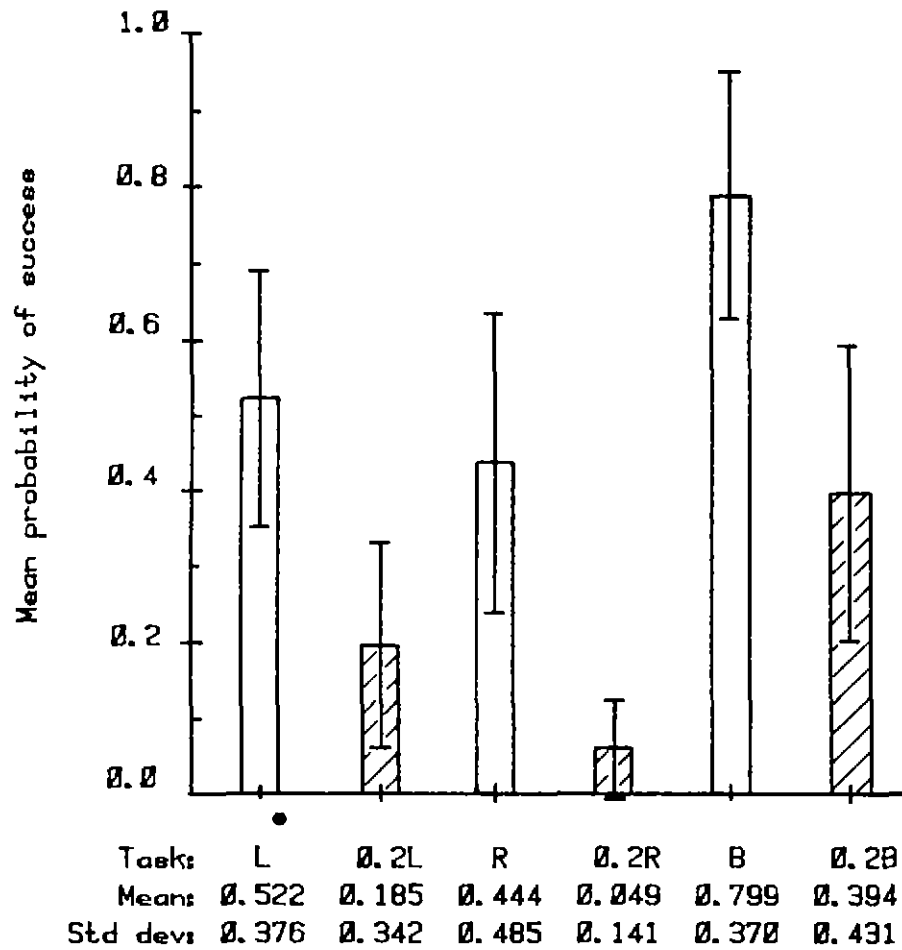
Testing for a difference between the means for level one of the prescribed tasks showed the mean probability of success for emergency braking to be significantly higher than for both the left and the right avoidance manoeuvres ( $p < 0.05$ ). The mean success rate for the left avoidance direction is slightly greater than for the right direction; however this difference is not statistically significant.

For level two all of the means are smaller than for the equivalent level one task ( $p < 0.01$ ) - obviously as a result of the increased task difficulty. As for the level one tasks, braking was more successful than avoidance. Again, obstacle avoidance was more successful for the left turn direction than for the right, but the difference between the mean success rates is not statistically significant. This trend is consistent with that obtained in section 4.6.4 for the MOST. Note that for the more extreme level two conditions, the asymmetry appears more pronounced than for the level one conditions. The success rate for level two emergency braking was greater than for the level two right turn ( $p < 0.01$ ). The differences between the means of the other possible combinations of the level two tasks are not significant.

#### (b) Decision tasks

The decision tasks required that riders brake and/or manoeuvre to the left or right to avoid the 'obstacle'. This manoeuvre was also performed at the two levels of difficulty. The task should reflect the riders preference for braking, or obstacle avoidance, or a combination of both, for the prevailing test conditions. The subjects tested generally attempted either braking or obstacle avoidance but not both. As was discussed in section 5.3 by referring to the data of Watanabe and Yoshida (1973), it was believed that obstacle avoidance was the more appropriate choice because it required a slightly shorter manoeuvre distance than for braking.





• refer to Figure 5.9

Figure 5.11 Mean probability of success for the prescribed AST tasks with 90% confidence intervals for the means indicated.

Table 5.5 shows the riders' task preferences for the decision task. The values shown in the table were determined as follows: Say a rider received four level one decision tasks, choosing to brake for three and manoeuvre to the left for one. The task preference for this particular rider would be 0.75 for braking and 0.25 for left turn. These values were determined for each rider, summed, and divided by the total sample size. Note that the mean speeds for each task were not statistically different.

TABLE 5.5

## RIDER TASK PREFERENCE FOR THE DECISION TASK

TASK*	Left turn	Emergency brake	Right turn	No attempt
LBR	0.085	0.676	0.144	0.095
0.2LBR	0.049	0.721	0.061	0.169

\* LBR = Left-Brake-Right decision task.

0.2 prefix denotes manoeuvre was performed  
with a 0.2 second time delay.

From the table, the preference for braking is clearly evident for both level one and level two of the decision task. To determine how appropriate this choice was, the mean probabilities of success determined previously for the prescribed tasks were examined. The probabilities defined earlier for the obstacle avoidance task are directly comparable; those for the braking task are not. Recall that the aim of the decision task was to choose the best way to not 'hit' the obstacle line. The criterion defined earlier for braking related to achieving a criterion deceleration level and provided a fair comparison between riders for the overall test. However, for the comparison being made here, the following criterion for success (used in conjunction with equation 5.1) was defined.

● Stopping line criterion

A subject was regarded as having succeeded if the motorcycle initial speed was within the acceptable range and was stopped before the line representing the obstacle.

The mean probabilities of success calculated with the stopping line criterion for the emergency braking tasks are shown in Table 5.6 together with the values for the prescribed obstacle tasks. Because of the small number of riders attempting to manoeuvre around the obstacle for the two levels of the decision task, meaningful estimates of success rates for avoidance could not be made for this task.

TABLE 5.6

## PROBABILITY OF SUCCESS USING THE STOPPING LINE CRITERION

Task	Prescribed				Decision			
	B	0.2B	L	R	0.2L	0.2R	B	0.2B
Mean								
probability of success	0.597	0.209	0.522	0.444	0.185	0.049	0.495	0.179
Standard								
deviation	0.472	0.328	0.376	0.485	0.342	0.141	0.450	0.323
Sample								
size	18	17	16	18	18	17	15	13
90%								
confidence interval for mean	0.791, 0.403	0.348, 0.070	0.687, 0.357	0.643, 0.245	0.325, 0.045	0.109, -0.011	0.700, 0.290	0.339, 0.019

The results indicate that braking performance was less successful in the decision task than in the equivalent prescribed task. However, the less successful performance can be attributed to the larger number of 'no attempts' in the decision tasks. Since reliable estimates for the obstacle turn means in the decision tasks could not be obtained, it is only possible to speculate as to the appropriateness of the choice of braking for the decision task. Since the emergency braking means were lower for the decision task, it seems likely that the means for the decision task obstacle-turn would also have been less than the corresponding prescribed task means. As can be seen in Table 5.6, the riders performed more successfully in the prescribed braking tasks than in the corresponding prescribed avoidance tasks. Thus, for the decision task speed of approximately 32 km/h, the choice of braking appears to have been an appropriate one.

#### 5.7.5 Comparison of the Probabilities of Success in the MOST and AST

The mean probabilities of success for the AST, and the equivalent tasks for the MOST (exercise 7 and 8), can now be examined.

##### (a) Obstacle avoidance

The mean probability of success defined in section 5.7.4 (a) was used to compare performance in this manoeuvre in the two tests. Data for the same turn directions only were compared. For example, if a subject received a left turn in the MOST, then only that subject's performance on the left turn (level one) task in the AST contributed to the overall mean. The results are summarized in Table 5.7.

The results show that the success rate means for both turn directions was higher for the AST than for the MOST. This difference is however not statistically significant.

## (b) Emergency braking

The stopping distance criterion, discussed in section 5.7.4 (b), was used to compare success rates for emergency braking in the two tests. To make a fair comparison, the MOST data was modified by using the AST speed range and a modified table of criterion stopping distances based on a constant 0.5g deceleration requirement (see Section 4.9).

The results in Table 5.8 show that riders were more successful in the AST. This difference is however not statistically significant. Assuming that this result is indicative of the direction of the difference in success rates for a larger sample, this difference could be due to an improvement in each subject's riding ability during the less-than-two-months interval between tests. Alternatively, it may be that the averaged response obtained from the AST is more representative of the rider's true ability than the single performance measure in the MOST. The difference between the mean speeds for the two tests was found to be statistically different. As the stopping distance criterion covers a range of entry speeds however, speed differences should not be important to this comparison.

TABLE 5.7

COMPARISON OF SUCCESS RATES FOR THE OBSTACLE AVOIDANCE  
MANOEUVRE IN THE MOST AND THE AST

Test	Mean		Standard		Sample	
	probability		deviation		size	
	of success					
	Left	Right	Left	Right	Left	Right
MOST	0.444	0.250	0.527	0.463	9	8
AST	0.646	0.459	0.350	0.502	8	8

A better comparison of performance in this task for the two tests can be made by examining the mean deceleration levels, as they relate purely to the rider's ability to stop the motorcycle and are independent of reaction time. These were calculated by using each rider's actual reaction time and are shown in Table 5.9, together with the level 2 results for the AST.

The decelerations achieved by riders in the AST were higher than for the MOST. However, these differences, and the differences between all possible combinations of decelerations in the table, are not statistically significant. It is of interest to note that the mean deceleration level in the more demanding AST braking task was not substantially different from that for the level one task. This suggests that riders were braking to their full capacity in the 'easier' task.

TABLE 5.8

COMPARISON OF SUCCESS RATES BETWEEN THE AST AND MOST FOR  
THE EMERGENCY BRAKING EXERCISES BASED ON CRITERION STOPPING  
DISTANCE

Test	Mean probability of success	Standard deviation	Sample size	90% confidence interval for mean
MOST <sup>+</sup>	0.643	0.497	14	0.878 , 0.408
AST <sup>*</sup>	0.799	0.370	18	0.951 , 0.645

+ These were calculated using a modified Table of  
stopping distances (see Section 4.8)

\* Level one of the AST.

TABLE 5.9

CALCULATED MEAN DECELERATIONS FOR THE EMERGENCY  
BRAKING TASKS IN THE MOST AND AST

Test	Average decel'n (g)	Standard deviation	Sample size	90% confidence interval for mean
MOST	0.525	0.115	17	0.574 , 0.476
AST Level 1	0.562	0.122	16	0.615 , 0.509
AST Level 2	0.571	0.092	16	0.611 , 0.531

Note: The AST values were determined from the rider's first attempt in each task.

#### 5.7.6 Linear Regression of AST Score on MOST Score

To determine how the overall scores for the two tests relate, a linear regression of AST score on MOST score was carried out. A scatter diagram of the overall test scores is shown in Figure 5.12 together with the line obtained from the regression.

To analyse the significance of the linear model, an analysis of variance was performed. The computations for the analysis are summarized in Table 5.10

The regression equation is as follows:

$$\text{AST Score} = 0.732x(\text{MOST Score}) + 11.957 \quad (5.2)$$

The computed F statistic exceeds the critical value for a 0.01 level of significance. It is concluded that there is a significant amount of variation in AST score accounted for by the postulated

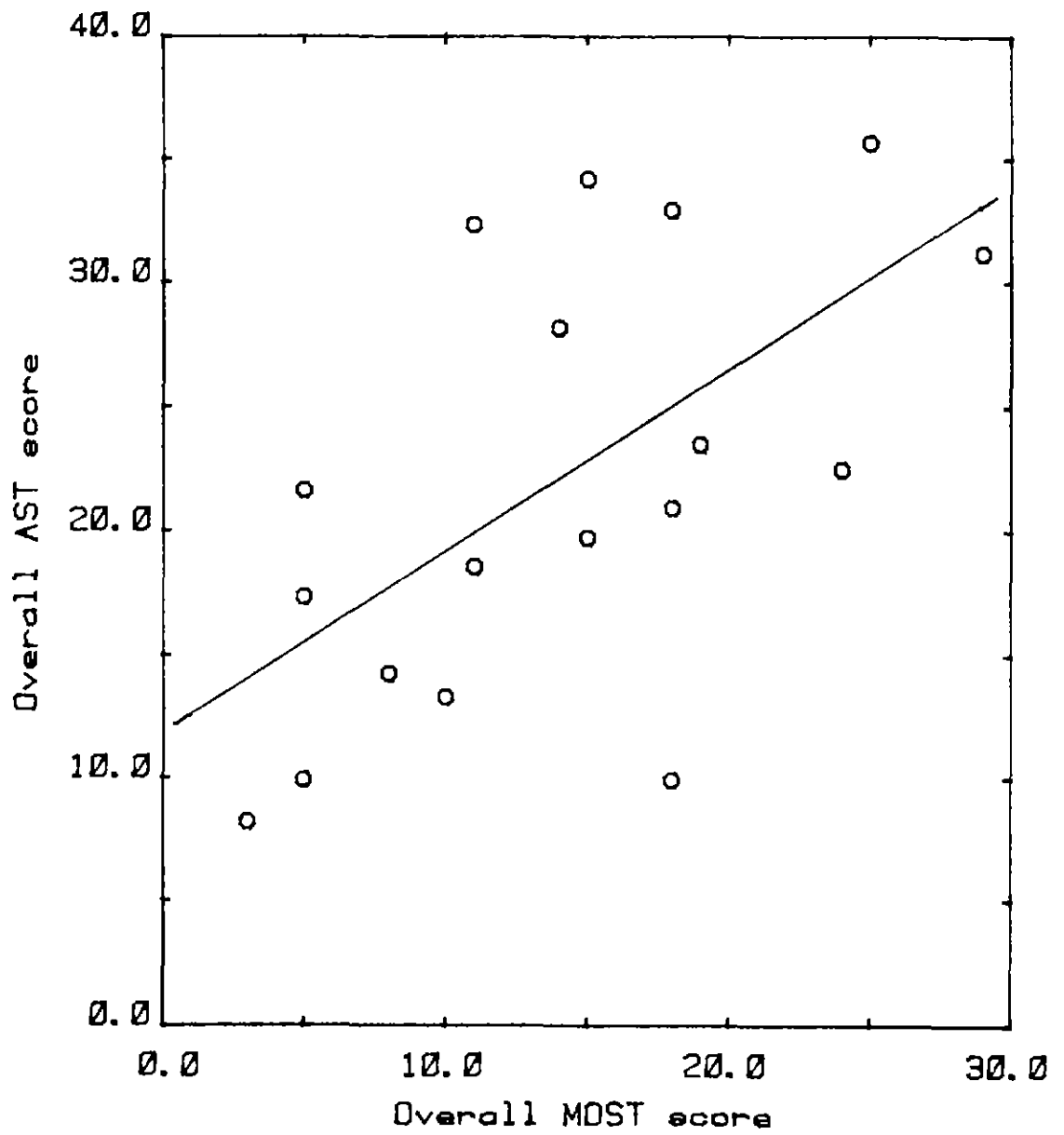


Figure 5.12 Scatter diagram of the MOST and AST scores.



straight-line model, and an insignificant lack of fit; i.e. the data suggest that there is no need to consider terms higher than first order. Taking MOST score as the dependent variable, and regressing MOST score on AST score leads to an identical conclusion. Equation (5.2) indicates that for a perfect MOST score (0) the equivalent AST score would be about 12. Thus a skilled rider would be expected to lose, on average, 1.5 points per task in the AST.

TABLE 5.10

ANALYSIS OF VARIANCE FOR TESTING THE SIGNIFICANCE  
OF THE LINEAR RELATIONSHIP BETWEEN THE OVERALL  
MOST AND AST SCORES

Source of variance	Sum of squares	Degrees of freedom	Mean square	Computed F
Regression	511.0	1	511.0	8.98
Error	910.8	16	56.9	
Lack of fit	365.4	10	36.5	0.40
Pure error	545.5	6	90.9	
Total	1421.8	17		

Regression coefficient = 0.600

Sample variance explained by regression = 35.9%

Estimate of population  $R^2$  = 31.9%

Standard error of regression in prediction = 7.545

The correlation of 0.600 for the regression is quite good when it is considered that the test-retest correlation for the MOST, determined by McPherson and McKnight (1976) for a group of 20 licensed riders who were administered the MOST twice, the second time immediately upon completion of the first, was only 0.784. Recall that there was an interval of about two months for the present study group, dur-

ing which time there may have been improvements in each subject's riding ability. According to McPherson and McKnight:

"The abilities measured by the Skill Test are the result of many, many hours of motorcycle operation. They should, therefore, represent highly stable characteristics. So too should the results obtained in administration of the Skill test. Any sizeable differences in scores obtained by given individuals over a short period of time suggests that the Test is measuring something other than skill".

The relatively high correlation between the MOST and the AST thus suggests that similar skills are measured in the two tests.

#### 5.7.7 Pass Rate for the MOST and the AST

If we assumed that the sample of riders selected was representative of the riding population at large, it would be of interest to examine the pass rate of the riders in the two tests. To determine the pass rate, it was firstly necessary to define a 'pass' score for each test. For the MOST a level was established by consulting previous MOST studies.

Anderson (1978) used twelve as the maximum number of penalty points which a rider could accumulate in the MOST. The first administration pass rate for the Anderson group, with no remedial training, was 48.7%. This pass score was also adopted by Jonah and Dawson (1979); however a smaller percentage (25.9%) of their subjects were able to satisfy it. Compared to Anderson's group this pass rate is low; it may reflect differences in administration of the tests.

Taking the criterion pass mark as twelve (i.e. a rider may accumulate no more than twelve penalty points), the pass rate for the 59 riders in the present study MOST sample was 59.3%. Considering that fifty-two of the riders tested were licensed riders, this pass rate seems low. The remaining seven riders were holders of current Victorian learner permits. Of these only two failed in the MOST!

To establish a pass mark for the AST, the regression equation determined in Section 5.7.6 was used. For a MOST score of twelve, the equivalent AST score is approximately twenty-one. With this standard, approximately 50% of the AST subjects would have passed - a rather small percentage when their riding experience is considered. Riding experience aside, the test results indicate that half of the riders do not possess the skills tested for. For a pass score of twenty-five (which is within one standard error of the predicted equivalent AST score using the regression equation), a 67% pass rate (two-thirds of the AST sample) is achieved, which is perhaps more acceptable.

#### 5.7.8 Re-Evaluation of the AST Exercises

After having analysed the scores for the various AST tasks in the preceding sections, we are now in a position to suggest what modifications can or cannot be made to improve the sensitivity of those exercises found to be poor or ineffective skill discriminators.

The first task re-evaluated was the prescribed emergency braking exercise. The score distribution for level one of this task indicated that it was too easy. By contrast the level two distribution was more uniform and indicated that it was properly 'tuned' for the sample of riders tested. This suggests that a level two standard should be adopted for level one, and a higher degree of difficulty set for level two. Further, it was shown in Section 5.7.5 (b) that the mean decelerations for the two levels of difficulty are not substantially different. As noted in that section, riders appeared to be braking to their full capacity in the easier task. This would suggest that the two levels of difficulty increased task uncertainty but did not provoke subjects to brake harder as was intended. In view of the poor distribution for level one of the emergency braking, this result may have differed had the degree of difficulty been higher for both levels. For this reason, and because two levels of difficulty cover a wider range of skills - the first level is sensitive to the less-skilled riders and the second the more-skilled ones - the two levels should be retained.

The second task re-evaluated was the decision task. Recall that the purpose of the decision task was to test the riders' ability to choose the most appropriate evasive action when in conflict with another 'vehicle'. For reasons given in Section 5.3, it was believed that manoeuvring around the 'vehicle' would be the most appropriate choice. However, the results from the score analysis indicated that most riders chose to brake for this task and, in view of the success rates for the prescribed tasks, this choice appears to have been an appropriate one. Design of this task was complicated by the fact that the distances for braking and evasion are similar for speeds below about 40 km/h (see Figure 5.4). Because either of the two evasive actions can result in a success, there is really no clear choice. However, as mentioned in section 5.4, the distance required for obstacle avoidance can be shorter than for braking at higher speeds. If one considers the consequences of failure for the two evasive strategies, then clearly, it is preferable to collide with an 'object' at a reduced speed - the case for braking - than at a higher speed from an unsuccessful obstacle avoidance attempt. To set up the task such that manoeuvring to avoid the obstacle will lead most often to success, and emergency braking to failure, requires that the test speed be increased to at least 50 km/h (see Figure 5.4). This is undesirable for two reasons; firstly, higher test speeds would necessitate use of a much larger test area and adjoining safety zones; secondly, in the event of an accident, there is higher risk of serious injury. These design constraints do not allow this exercise to be modified so as to achieve the original objectives.

On the whole the scoring criteria provide the desired sensitivity, giving a wide distribution of scores. With the suggested modifications applied, the AST would consist of the following test exercises:

- (i) Left and right obstacle turns,
- (ii) Emergency straight-path braking,
- (iii) Blank runs, where no response is required.

#### 5.7.9 Test Conditions for Less-Skilled Riders

The test conditions and scoring criteria for the AST have been determined and evaluations carried out for a group of riders with a wide range of skills. This section examines how the AST can be modified so that it can be used to grade less-skilled riders. These riders could represent, say, licence applicants. A group of less-skilled riders requires that all of the test exercises are made 'easier'. This can be achieved by decreasing the test speed or, increasing the manoeuvring length, i.e. move the trigger point further away from the obstacle line. Of the two choices the former has several advantages. A lower test speed allows the use of a smaller test area and, in the event of an accident, the risk of serious injury is reduced.

It is logical to set the overall test standard for the AST on a similar level to the MOST. This can be achieved, approximately, by reducing the test speed to about 27 km/h. For this test speed, and a reaction time of 0.55 s (from Section 5.7.2), the level one and two standards are, respectively, easier than and equivalent to the current MOST standard for emergency braking. The degree of difficulty for the obstacle avoidance tasks is also reduced. Note that a new table of standard stopping distances would have to be calculated based on the lower test speed, and a new acceptable speed range for the obstacle avoidance task determined. The scoring criteria for the new test conditions would have to be evaluated by testing a sample of riders with the desired characteristics. For license testing the AST should be no more difficult to administer than the MOST.

## 5.8 PREDICTORS OF AST SCORES

### 5.8.1 Introduction

A multiple linear regression was performed, in a similar fashion to that carried out for the MOST in Chapter 4, to determine whether the rider background factors found to be significant predictors of the MOST score were similarly related to the AST score. Rider background factors obtained from the MOST questionnaire were available for the AST subjects.

### 5.8.2 Means, Standard Deviations and Correlation Coefficients

Table 5.11 shows the means, standard deviations and number of cases for the dependent variable SCORE and the independent variables used in the analysis. Table 4.9 shown in Section 4.8.2 lists the mnemonics used in the present analysis. For the same reasons as in the MOST, the independent variable "kilometres ridden per week off-road" (KMWKO) was excluded from the analysis.

Differences between rider background factors for the total MOST sample and the AST sample are as follows:

- The AST sample had 8% more females
- The AST sample had less off-road riding experience (in years) but slightly more on-road riding experience (in years)
- There were no learner permit holders in the AST sample, i.e. all the riders were licensed

Table 5.12 shows the correlation coefficients between the variables in Table 5.11. The variables with the highest correlation with SCORE are total number of kilometres ridden per week (KMWK, -0.60), engine capacity of the motorcycle most often ridden (ENGCAP, -0.46) and age (AGE, 0.31).

TABLE 5.11

STATISTICS FOR THE VARIABLES IN THE AST MULTIPLE REGRESSION

Variable	Mean	Standard deviation
SCORE	22.30	9.42
SEX	0.53	0.87
AGE	26.50	6.59
EONRD	4.99	4.20
EOFFRD	1.38	3.47
KMWK	223.82	156.70
ENGCAP	550.29	302.49
DL	0.76	0.66
COMPEX	-0.76	0.66

Note: Sample size = 17

TABLE 5.12

CORRELATION COEFFICIENTS FOR VARIABLES  
USED IN THE AST REGRESSION ANALYSIS

	SCORE	SEX	AGE	EONRD	EOFFRD	KMWK	ENGCAP	DL
SEX	-0.21							
AGE	0.32	0.28						
EONRD	-0.06	0.09	0.32					
EOFFRD	-0.15	0.22	-0.04	0.51				
KMWK	-0.60	-0.16	-0.39	-0.37	-0.11			
ENGCAP	-0.46	0.24	-0.13	0.45	0.36	0.11		
DL	-0.19	-0.20	-0.37	-0.14	-0.45	0.41	0.26	
COMPEX	-0.16	0.20	0.41	0.44	0.39	0.17	0.40	0.13

### 5.8.3 Regression Results

Table 5.13 summarizes the results of the stepwise multiple regression analysis (Nie et al., 1975). Note that the order of inclusion into the equation is preserved in the table. 63.1% of the variance in the AST score is explained by the variables listed. The first variable listed (KMWK) accounts for 36% of the variance in score. This variable was found to be the second best predictor of score for the total MOST sample (Section 4.8.3) where it accounted for 22% of the variance in score. For this comparison the total MOST sample is biased by the subjects who did not participate in the AST. A regression was performed using only the AST subjects and taking their MOST score as the dependent variable. The details for this regression are not shown here. The 'best' predictor of score for this regression was also KMWK which accounted for 43% of the variance in score, which is twice that explained by the same variable for the total sample.

TABLE 5.13

#### SUMMARY OF MULTIPLE REGRESSION ON AST SCORES

Independent variable	R	R <sup>2</sup>	$\Delta R^2$	Simple r	Significance of variable when entered
KMWK	0.598	0.357	0.357	-0.598	0.011
ENGCAP	0.720	0.518	0.161	-0.463	0.048
SEX	0.750	0.563	0.045	-0.210	0.269
COMPEX	0.763	0.582	0.019	-0.164	0.480
EONRD	0.794	0.631	0.049	-0.057	0.252

Note: Overall significance of regression:  $p < 0.05$



The first two variables in Table 5.13, KMWK and ENGCAP, are significant at the 5% level when first entered into the equation. The estimates for the regression coefficients, with their associated confidence intervals, are shown in Table 5.14. Only the coefficient for KMWK is significantly different from zero when the other variables are controlled for. The sign of the coefficient is consistent with that obtained for the regression of MOST score on background factors for the total sample of riders, and the reduced AST sample. The sign of ENGCAP suggests that riders who normally ride larger capacity machines do better on the test; this effect was discussed in detail in Section 4.8.

TABLE 5.14

## REGRESSION COEFFICIENTS AND 95% CONFIDENCE INTERVALS

Variable	Regression coefficient	95% confidence interval
KMWK	-0.0473	-0.0782, -0.0163
ENGCAP	-0.00855	-0.0242, 0.00711
SEX	-3.23	-7.98 , 1.53
COMPEX	4.07	-3.20 , 11.4
EONRD	-0.727	-2.05 , 0.596
CONSTANT	46.0	29.7 , 62.3

SEX for the AST sample was not significant as a predictor when either AST or MOST score was the dependent variable. This is not consistent with results obtained for the total MOST sample where SEX accounted for 23% of the explained variance. This difference could partly be attributed to the smaller size of the AST sample, and partly to the fact that the MOST sample contained a relatively larger proportion of highly skilled riders, most of whom were male.

## 5.9 ADVANTAGES OF THE AST OVER THE MOST

It is natural to enquire what advantages the AST offers over the MOST. The analyses of the previous sections have indicated that the two tests would lead to a similar grading of test candidates. Some of the quantitative measures showed that subjects performed better in the AST, however the differences between the measures were not statistically significant. Further, it was not possible to ascertain whether the differences reflected real differences between the tests, or whether there had been a general improvement in each subject's riding ability during the time interval between tests.

The following advantages for the AST are considered to be important:

- The test site for the AST need only be of sufficient size to accommodate the two test exercises, namely obstacle avoidance and emergency braking, and provide the necessary safety zones. This area is approximately half that required for the MOST.
- The test is thought to be more representative of actual on-street situations where a rider has to respond to a variety of randomly sequenced traffic events.
- The AST requires that each rider perform each manoeuvre usually more than once. The rider's average performance for each task is assessed rather than the outcome of one attempt. This reduces biases due to some riders receiving only a left- or a right-hand avoidance manoeuvre, as in the MOST.
- The emergency braking task stopping distance standard proposed for the AST means that task difficulty is less dependent on entry speed than it is in the MOST.
- The test may be performed continuously. That is, once instructions are given to the rider there is no need for further communications.

## 5.10 SUMMARY AND CONCLUSIONS

An Alternative Skill Test (AST) has been designed and tested with eighteen volunteer riders who had also participated in the MOST. The conclusions which can be drawn from the analysis of the scores assigned to riders, and observation of some of the data collected on the instrumented motorcycle for the two tests, are as follows:

- (i) The AST and the MOST led to a similar grading of the test subjects.
- (ii) Riders were able to achieve higher mean decelerations during emergency braking and succeeded more often in the obstacle avoidance turns in the AST than the MOST. However it is not possible to determine whether this was due to differences between the methodology of the tests, or whether there was a general improvement in subjects' riding ability during the less-than-two-month interval between tests.
- (iii) For the decision task, in which riders were required to brake and/or manoeuvre to avoid an obstacle, the riders' preference for braking appears to have been an appropriate choice in view of the success rates for the prescribed tasks. This finding is not consistent with the experimental evidence of Watanabe and Yoshida (1973) where, for similar test conditions, braking and avoidance required the same evasion distances.
- (iv) Reaction times in the AST were significantly longer than the MOST, consistent with the greater uncertainty in the AST.
- (v) Reaction times for the emergency braking task were significantly longer than for the obstacle avoidance task for both the MOST and the AST. This result indicates that it takes longer for a rider to initiate a change in the motion of a motorcycle when braking than when manoeuvring to avoid an obstacle.

- (vi) A multiple regression analysis was performed of AST score on rider background variables. Kilometres ridden in the average week was found to be the 'best' predictor of score. A second regression was performed with the AST sample using their MOST score for which similar results were obtained. This same predictor was found to be the second best predictor of score for the same regression using the total MOST sample, rider sex being the best. This difference is attributed to the smaller size of the AST sample, and to fact that the MOST sample contained a larger proportion of highly skilled males.
- (vii) The AST has the following advantages over the MOST: The test area required is approximately half that required for the MOST; the test is thought to be more representative of actual on street situations where a rider has to respond to a variety of randomly sequenced traffic events; the rider's average performance for each task is assessed rather than the outcome of one attempt; the emergency braking stopping distance standard is less dependent on entry speed than it is in the MOST; and the test may be performed continuously.
- (viii) The AST exercises were re-evaluated to determine what modifications can or cannot be made to improve the sensitivity of those exercises found to be poor or ineffective skill discriminators. For a sample of riders with a wide range of riding skills, it is suggested that the level two standard for the emergency braking be adopted for level one of this task and a higher degree of difficulty set for level two. The decision task should be omitted because design constraints do not allow the task to be modified so as to achieve the original objectives.

## CHAPTER 6

CHARACTERISTICS OF SKILLED VERSUS LESS-SKILLED  
PERFORMANCES AS REVEALED BY THE DATA  
COLLECTED ON THE INSTRUMENTED MOTORCYCLE

## 6.1 INTRODUCTION

The performance criteria used in the skill tests allowed the rider's overall performance to be assessed in an objective manner, operator technique being largely ignored. This emphasis on the functional aspects of the task performance was necessary because the skill tests were specifically designed for licensing programs. In understanding skilled performance, however, it is important to look not only at the overall achievement but also at the manner in which it was attained (Welford, 1968). Data collected on the instrumented motorcycle make it possible to examine operator technique, providing a means by which to uncover characteristic patterns of rider/cycle behaviour related to levels of skill, task demand and motorcycle handling properties.

This chapter examines the data collected on the instrumented motorcycle for the emergency braking task (straight path), and the obstacle avoidance task for the MOST and the AST. These two tasks, which are critical to riding safety and which form an integral part of the two tests, were shown earlier to provide a means by which to discriminate between riders of different skill levels.

## 6.2 EMERGENCY BRAKING TASK

### 6.2.1 Interpretation of Data Trace

Typical data traces, showing the rider control inputs of front and rear brake force, and motorcycle speed, for a rider performing the emergency braking task (exercise 7 of the MOST), are shown in Figure 6.1. For this task, the rider was required to ride down a straight path towards signal lights at approximately 32 km/h. When the signal lights were activated (indicated by beginning of the glitch on the speed trace), the rider was required to bring the motorcycle to a complete stop as quickly and as safely as possible. If the approach speed maintained by the rider fell within the prescribed acceptable range, then that attempt was assessed. Further details of the test procedure are given in Appendix C.

### 6.2.2 Measures for the Emergency Braking Task

In order to compare the braking performance and technique of different riders, measures were devised to 'describe' different features of the data traces which characterized the rider, the rider's control inputs and the cycle's response. Following is a list of emergency braking task measures. To appreciate the quantitative significance of each measure, Figures 6.1 to 6.4 show examples of a number of different braking behaviours which will allow illustration of the meaning and purpose of the proposed measures. Table 6.1 provides the numerical values of the measures associated with each of the examples.

(1) TEST SCORE - This is the overall MOST score (the number of penalty points assigned) and is assumed to be directly related to rider skill level.

(2) MEASURED STOPPING DISTANCE - The distance measured from the point on the course at which the signal lights were activated, to the point where the motorcycle became stationary.

(3) REACTION TIME - The time period measured from when the signal lights were activated to when either the front or the rear brake transducer registered a non-zero brake lever force.

(4) APPLICATION TIME DIFFERENCE - The time interval between the application of the front and rear brake forces. A positive time interval indicates that the front brake was applied first.

(5) AVERAGE SPEED - The average speed of the motorcycle for the 130 ms period just before the signal lights were activated.

(6) AVERAGE DECELERATION - This was calculated by dividing the average speed by the time interval (referred to as the 'braking time') which began when either brake was applied and ended when the motorcycle became stationary.

(7) FRONT FORCE MEAN - The average front brake lever force over the period of application of the front brake.

(8) REAR FORCE MEAN - As for (7), but calculated for rear brake force.

(9) FRONT STD-DEV/MEAN - The standard deviation of the front force divided by its mean (i.e. a 'coefficient of variation'). The standard deviation was normalized in this manner since it was found that, in general, high standard deviations were associated with high mean force levels. For example, the front force traces in Figures 6.1 and 6.3 have similar shapes but differ in their overall scale. The coefficients of variation for these traces are quite similar (see Table 6.1). This measure thus characterizes the variability of the force application rather than its level. Figures 6.1 and 6.2 illustrate front brake applications with similarly low mean force levels but differing in the variability of modulation of the braking effort. Figures 6.3 and 6.4 provide a similar contrast for a high front brake force level.

(10) REAR STD-DEV/MEAN - As for (9), but calculated for rear brake force.

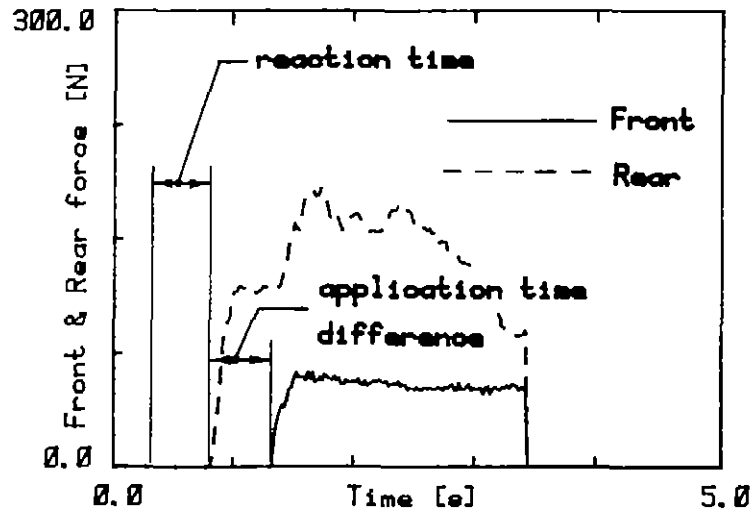
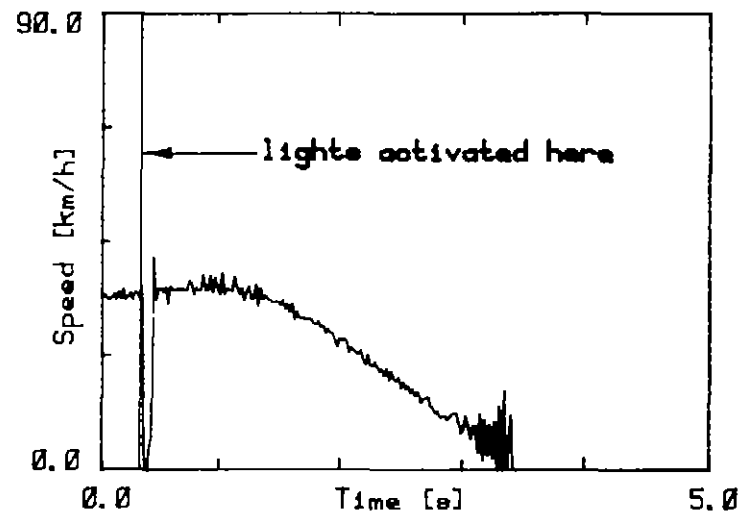


Figure 6.1 Example run to exhibit the various measures.

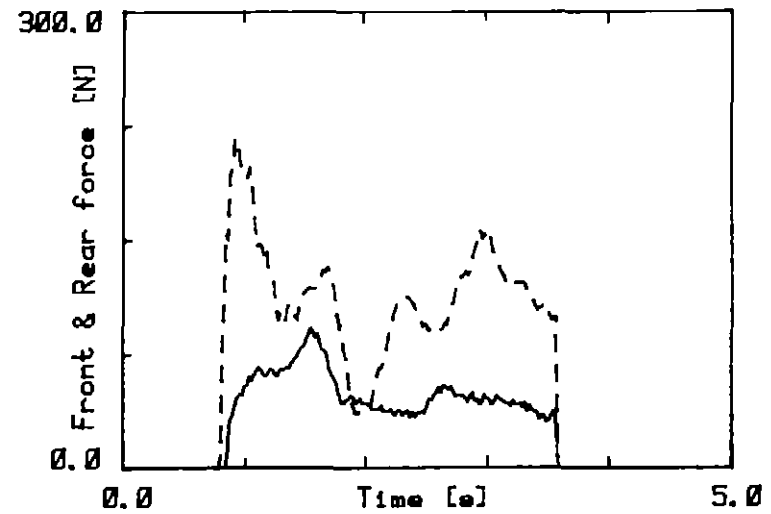
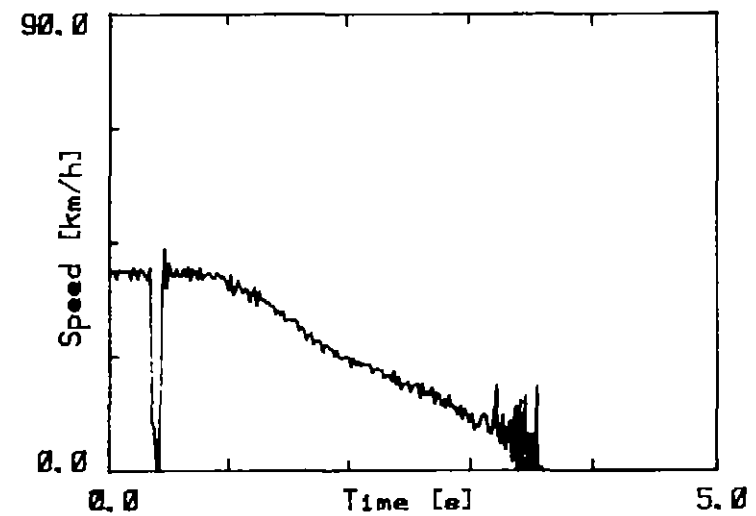


Figure 6.2 Example run to exhibit the various measures.



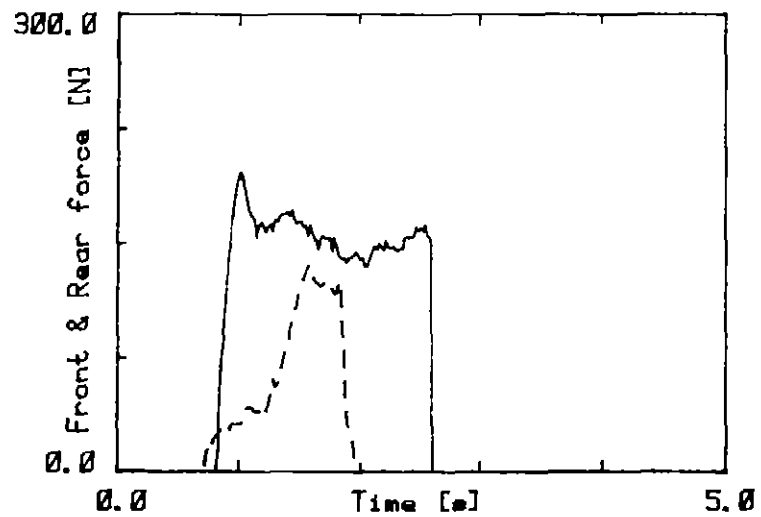
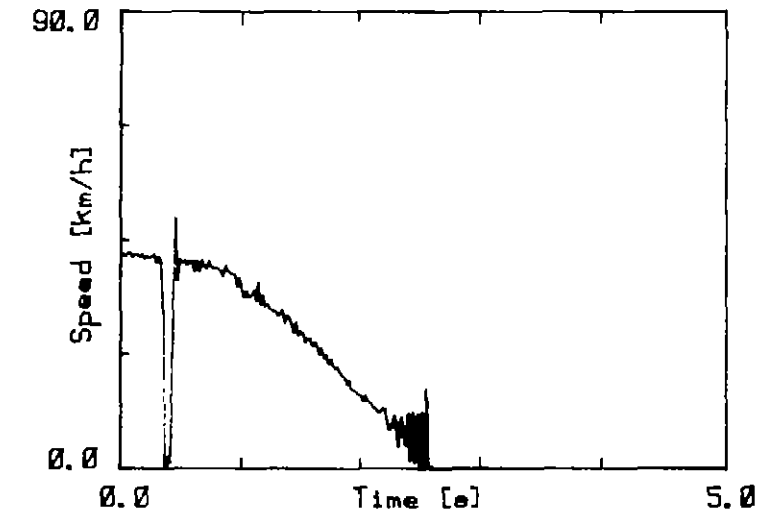


Figure 6.3 Example run to exhibit the various measures.

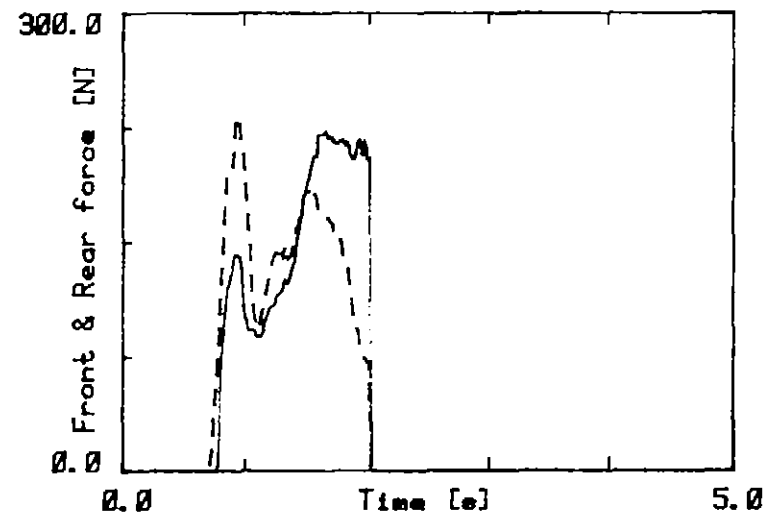
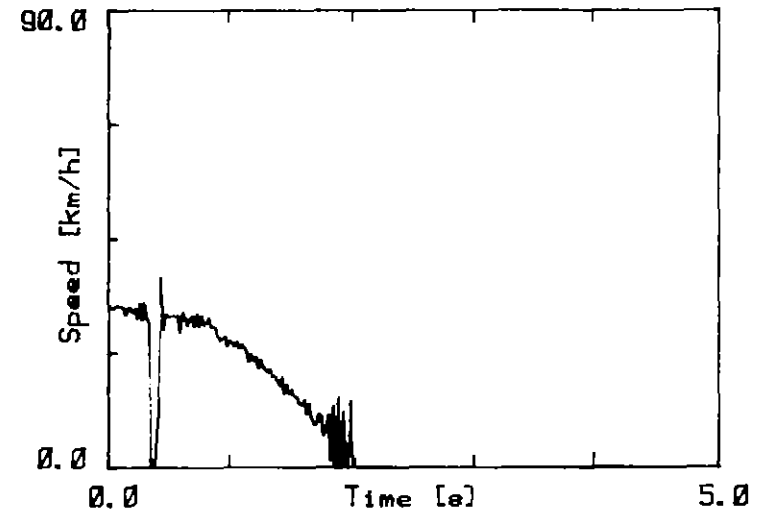


Figure 6.4 Example run to exhibit the various measures.

(11) FRONT/REAR RATIO - The front force mean (7) divided by the rear force mean (8), a measure of the proportioning of braking effort between the front and rear.

(12) FRONT-REAR CORRELATION - A simple correlation coefficient between the digitized data pairs of front and rear force levels, calculated for the time period during which both brakes were applied. This measure gives an indication of the degree of coupling between the rider's hand and foot brake force inputs. Contrasting examples are given in Figures 6.6 and 6.7.

### 6.2.3 Components of Skilled Performance

As indicated in the introduction to this chapter, the objective of the present analysis is to answer the question: What aspects of operator technique distinguish a skilled braking performance from a less-skilled one? The method adopted in an attempt to provide answers to this question was multiple linear regression. Several regressions were computed to determine the relationship between a measure of skill and those of the parameters described in the last section which characterize some aspect of operator technique.

The first measure of skill adopted was the rider's overall MOST score. Reflecting as it does performance in a variety of tasks, of which emergency braking was only one, the MOST score possibly provides the best general indication of the level of the rider's 'skill' in controlling a motorcycle.

It is possible, of course, that different skills are required for braking than for some of the other MOST tasks. The measure adopted to represent braking skill was average deceleration achieved. The other measure which might have been used, the measured stopping distance, suffers from the fact that it is sensitive to the initial speed of the bike and to the rider's reaction time, both of which are only partially within the rider's control.

TABLE 6.1

NUMERICAL VALUES OF MEASURES FOR DATA SHOWN IN FIGURES 6.1 TO 6.4

Measure	Figure			
	6.1	6.2	6.3	6.4
MOST score	25	24	19	7
Stopping dist. (m)	17.7	18.3	13.3	7.6
Reaction time (s)	0.479	0.459	0.371	0.381
Appl'n time diff. (s)	-0.508	-0.059	-0.098	-0.059
Average speed (km/h)	34.5	38.8	41.3	30.5
Ave deceleration (g)	0.38	0.40	0.62	0.66
Front force mean (N)	53.7	50.1	153.3	157.8
Front std dev (N)*	5.9	14.7	24.3	53.1
Front std-dev/mean	0.110	0.294	0.160	0.340
Rear force mean (N)	138.8	115.9	69.2	145.7
Rear std dev (N)*	33.8	37.8	43.5	46.2
Rear std-dev/mean	0.245	0.328	0.640	0.321
Front/rear ratio	0.39	0.43	2.22	1.08
Front-rear correlation	0.433	0.170	0.153	0.035

\* These measures are shown for comparison with the means and std-dev/mean ratios.

The following forward-selection strategy was adopted for the regression. The order of insertion of the independent variables into the equation was determined by using the partial correlation coefficient between the dependent and each independent variable as a measure of the importance of each variable not yet entered into the equation. The squared partial correlation coefficient of an independent variable may be understood as that proportion of the variance not estimated by the variables already in the equation which is associated with the given independent variable. The variable with the highest partial

correlation coefficient, which therefore explained the largest amount of the unexplained variance, was entered on each successive step. This procedure was varied if the variable in question was an interaction term (a 'product' of independent variables). In order for an interaction term to enter and remain in the equation, all of its constituent elements had to be already in the equation, whether or not they were significant. This was because an interaction term will be linearly correlated with each of its constituent elements, often quite substantially so. Not controlling for the constituent elements (or including them in the regression equation) would be to assume that all of the variance explained by the product of the two independent variables was due entirely to their interaction (Cohen and Cohen, 1975). Only after the constituent elements of the interaction term were controlled for, was the interaction term considered and its significance tested.

A partial F test was used to evaluate the significance of the variable most recently entered into the equation. If the variable did not make a significant contribution to the explained variance, the process was terminated (except for the case where an interaction term was being considered). The program for the multiple linear regression used the subroutine MULTR from Digital Equipment Corporation's Scientific Subroutine Package (SSP-11), version 1.2.

#### 6.2.4 Regression for MOST Score

Table 6.2 shows the measures associated with the dependent variable,  $Y$ , and the independent variables,  $X(i)$ ,  $i = 1, 2, \dots, 9$  for this regression, together with the means and standard deviations of the variables. Note that the sample size (49) is less than the total test group size (59) because the data traces for some subjects were too 'noisy' or, for some other reason, the measures could not be calculated from their data.

TABLE 6.2

## VARIABLES FOR MOST EMERGENCY BRAKING REGRESSION

Variable	Measure	Mean	Standard deviation
	(units)		
Y	MOST score	12.1	8.26
X(1)	Reaction time (s)	0.387	0.108
X(2)	Appl'n time diff. (s)	-0.004	0.253
X(3)	Average speed (km/h)	36.3	3.63
X(4)	Front force (N)	126.	55.6
X(5)	Rear force (N)	135.	35.4
X(6)	Front std dev/mean	0.241	0.0737
X(7)	Rear std dev/mean	0.304	0.0877
X(8)	Front/Rear ratio	1.01	0.537
X(9)	Front-Rear correl'n	0.352	0.424

Note: Sample size = 49

The mean for X(3) shows that the test speed was slightly higher than that which riders were required to maintain.

The simple correlation coefficients between variables are shown in Table 6.3. Variables which are highly correlated with the MOST Score are Front Force Mean (-0.655), Front/Rear Force Ratio (-0.465) and Reaction Time (0.449). These coefficients suggest that riders who (according to their test score) are skilled, react quicker, apply a larger amount of front brake force and proportion their braking effort more in favour of the front brake than the rear brake, than those who are less skilled. Note that any subsequent references to skilled and less-skilled imply, respectively, riders who scored well (low score), and riders who scored poorly (high score) on the MOST.

TABLE 6.3

SIMPLE CORRELATION COEFFICIENTS BETWEEN VARIABLES IN TABLE 6.2

Y	X(1)	X(2)	X(3)	X(4)	X(5)	X(6)	X(7)	X(8)
X(1)	0.449							
X(2)	-0.340	-0.199						
X(3)	-0.100	-0.322	-0.113					
X(4)	-0.655	-0.442	0.317	0.192				
X(5)	-0.142	0.108	-0.082	0.062	-0.007			
X(6)	0.029	-0.164	0.199	0.129	-0.039	0.186		
X(7)	-0.171	-0.164	0.211	0.077	0.273	-0.367	-0.119	
X(8)	-0.465	-0.429	0.321	0.188	0.828	-0.522	-0.138	0.491
X(9)	0.217	-0.284	-0.140	0.221	-0.102	0.116	0.000	-0.226
X(9)	-0.171							

For the independent variables, Front/Rear Ratio is highly correlated with the following independent variables - Front Force Mean (0.828), Rear Force Mean (-0.522) and Rear Std-Dev/Mean (0.491). Reaction Time is moderately correlated with Front Force Mean (0.442).

Using the regression strategy outlined earlier a regression was performed with the variables in Table 6.2. Interaction terms, which were considered up to third order, were found to be not significant when the constituent elements were controlled for. Tables 6.4 and 6.5 summarize the regression results. The order of inclusion has been preserved in the tables and the first variable for which the regression coefficient was not significant has also been included. Note that inclusion of this variable in the equation causes only a small change in the explained variance and the regression coefficient estimates for the significant variables.

TABLE 6.4

## REGRESSION RESULTS FOR MOST SCORE

Variable	R	R <sup>2</sup>	Estimate of population R <sup>2</sup>	$\Delta R^2$	Simple r	Overall significance of regression
Front force mean	0.654	0.428	0.417	0.428	-0.655	1%
Reaction time	0.678	0.460	0.437	0.032	0.449	1%
F-R correl'n	0.717	0.514	0.487	0.054	0.217	1%
Rear force mean	0.478	0.559	0.520	0.045	-0.142	1%
Appl'n time diff.	0.755	0.570	0.521	0.011	-0.340	1%

TABLE 6.5

## REGRESSION COEFFICENTS FOR MOST SCORE

Variable	Regression coefficient	Coefficient standard deviation	Significance of coefficient estimate
Front force mean	-0.0662	0.0175	1%
Reaction time	25.4	9.29	1%
F-R correl'n	5.38	2.13	5%
Rear force mean	-0.0517	0.0236	5%
Appl'n time diff.	-3.66	3.454	n.s.
CONSTANT	15.7	-	-

Note: Standard error of regression = 5.71

● Interpretation of regression for MOST score

The regression provides information on which of the measures for the emergency braking task differentiate between the skilled and less-skilled riders. The first variable to be entered into the equation is Front Force Mean, which explains 42.8% of the variance in MOST Score. The sign of the regression coefficient for this variable is such that large Front Force Mean leads to an improved score, i.e. skilled riders apply higher levels of front brake force than less-skilled riders. The variable Rear Brake Mean also appears in the regression equation; however its contribution to explained variance is much smaller (4.5%) and its regression coefficient is less significant than for Front Brake Mean. The sign of the regression coefficient indicates that use of the rear brake, as for the front brake, leads to an improved score.

The above results are consistent with observations made by Ervin, MacAdam and Watanabe (1977) during experiments in which three riders, classified by riding experience as professional, skilled and novice, performed braking tests as part of an investigation of a procedure for evaluation of motorcycle braking systems. They observed that the professional rider made greatest use of the front brake, whereas the skilled and novice riders preferred to use the rear brake, apparently because of a lack of confidence in controlling front-wheel braking.

A variable which does not appear in the regression equation and which correlates well with score ( $-0.465$ ) is Front/Rear Ratio. This is because Front/Rear Ratio is highly correlated with Front Force Mean ( $0.828$ ) and Rear Force Mean ( $-0.522$ ), and therefore accounts for approximately the same variance as front and rear force means. As a result, once Front Force Mean has been entered into the equation, Front/Rear Ratio explains only an insignificant proportion of the unexplained variance. This situation is generally referred to as the problem of multicollinearity (Cohen and Cohen, 1975).



Reaction Time was the second variable to enter the equation. The regression coefficient indicates that a short braking reaction time is associated with a generally skilled performance in the MOST. The fact that shorter reaction times were associated with better MOST scores may simply show that subjects with an inherently short 'simple reaction time' (McCormick, 1970) are likely to perform well in a variety of perceptual-motor tasks. However, 'complex reaction times' also reflect, in part, the 'uncertainty' associated with a task (McCormick, 1970), which is related to the number of decisions or choices to be made. In developing a skill, it seems that some of the task uncertainty is resolved, through practice, by encoding information into larger 'chunks' or units. Thus, for example, the unskilled sequence: "A stop is required - Which is the brake lever? - How hard do I press? - Foot brake versus hand brake? - How am I doing?..." may be replaced by the skilled sequence: "An emergency stop is required - Execute learned emergency braking sequence". The regression result that the more skilled riders in the MOST exhibited shorter braking reaction times is consistent with this interpretation.

Front-Rear Correlation was the third variable to enter the equation; its interpretation is a little more complicated. The range for this variable is from -1.0 to +1.0. Its regression coefficient indicates that a large positive value leads to an increased score, i.e., a less-skilled performance, and vice versa.

The importance of the sign of the correlation can be appreciated by referring to equation (6.1) on the following page, which gives the relationship between the ratio of the front and rear normal forces acting on the motorcycle tyres and the physical parameters and deceleration of the motorcycle. The simple relationship takes no account of suspension or tyre deflections, and assumes that the overall centre of mass remains in the same position relative to the wheel contact points.

$$\frac{N_f}{N_r} = \frac{(g.b + h.\ddot{x})}{(g.a - h.\ddot{x})} \quad (6.1)$$

where  $\ddot{x}$  = deceleration  
 $g$  = acceleration due to gravity  
 $a$  = distance from the front wheel contact point to the vertical projection of the overall motorcycle plus rider centre of mass onto the ground plane.  
 $b$  = distance from the rear wheel contact point to the vertical projection of the overall motorcycle plus rider centre of mass onto the ground plane.  
 $h$  = vertical distance from the ground plane to overall centre of mass.  
 $N_f$  = front wheel normal force  
 $N_r$  = rear wheel normal force

Equation (6.1) also represents the optimum ratio of the front and rear longitudinal forces at the tyre-road interface as a function of deceleration. That is, if this ratio is maintained, equal 'demands' on the available tyre/road friction coefficient will be made at the front and rear wheels. To relate this ratio to the front brake lever force, and rear brake pedal force, it is necessary to determine the lever-force / deceleration characteristics of the motorcycle. In Section 6.2.5 it is shown that the front and rear lever-force / deceleration characteristics were numerically very similar (i.e. a given lever force produced approximately the same deceleration, regardless of whether it was applied to the hand or foot brake). Since there was also very little zero-force deceleration offset, equation (6.1) represents a reasonable approximation (for this motorcycle) of the optimum front/rear lever-force input ratio as a function of deceleration.

The parameters required to evaluate the right side of equation (6.1) were measured for the motorcycle used in the experiments and are shown in Table 6.6. A platform scale was used to measure the front

and rear normal loads, from which the overall mass of the motorcycle, and the longitudinal position (a and b) of the centre of mass were estimated. To determine the vertical position of the centre of mass, the load on the 'side stand' was measured for two different roll angles. By measuring the cycle roll angle and the perpendicular distance, in the ground plane, from the side stand contact point to the line joining the two tyre contact points, it was possible to estimate 'h' with and without the rider. Figure 6.5 shows the calculated optimum ratio of front to rear lever force as a function of deceleration for the Honda CB400T. It is of interest to compare this optimum ratio with the ratios actually used by test riders.

TABLE 6.6

## PHYSICAL PARAMETERS FOR HONDA CB400T

	a (m)	b (m)	h (m)	m (kg)
cycle alone*	0.734	0.656	0.400	185
cycle + rider	0.803	0.587	0.661	258

\* This is the motorcycle as described in appendix A, i.e. with data acquisition system and transducers.

Figures 6.6 and 6.7 show data traces for two subjects. The first is for a subject with a high positive front-rear correlation (0.864); the second is for a subject with a high negative correlation (-0.766). According to the regression results, the data for the first figure would correspond to a less-skilled rider; that for the second a more-skilled rider. In fact, the MOST scores for these individuals were, respectively, 13 and 0. These examples are representative of the 'high correlation' runs.

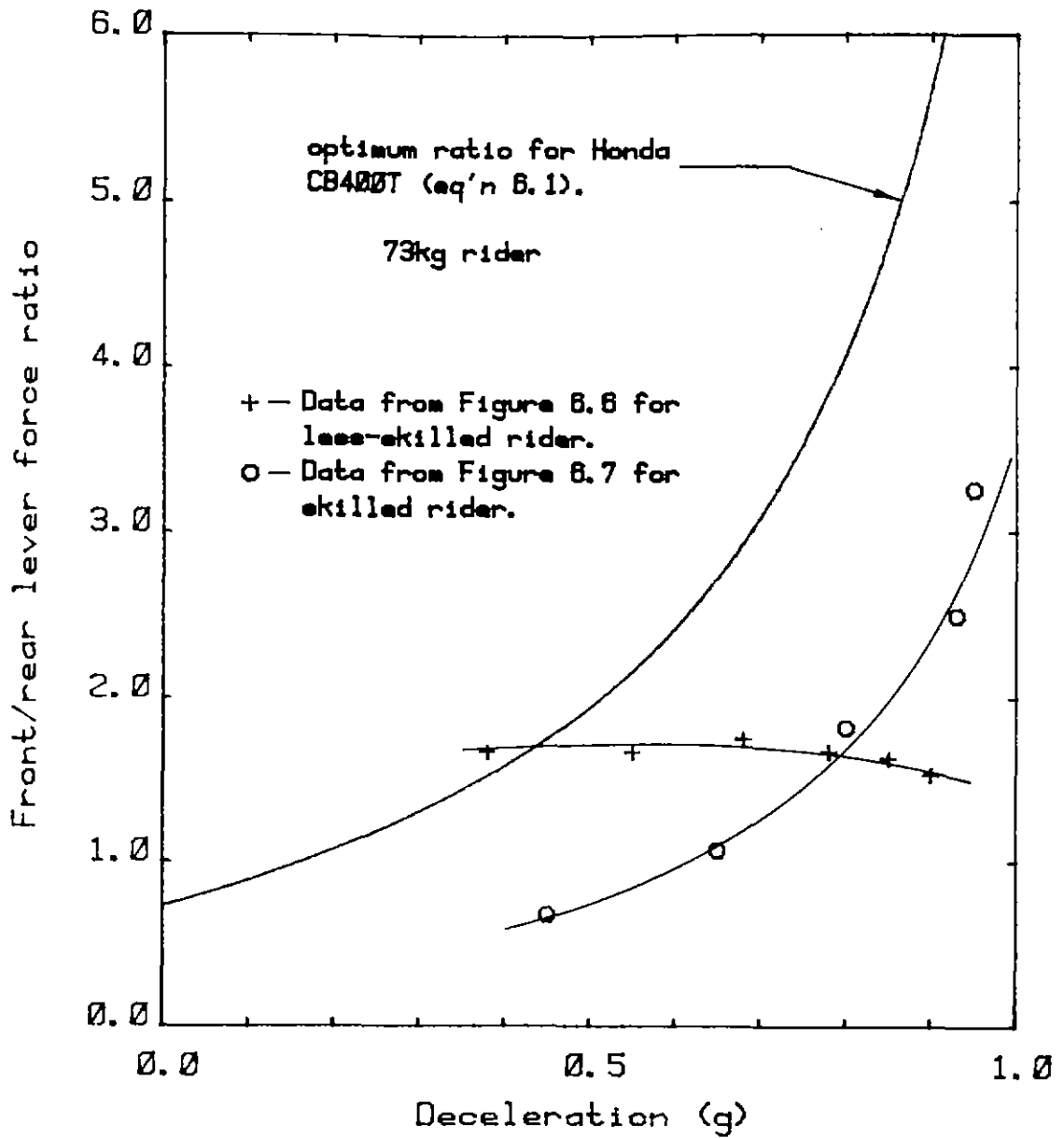


Figure 6.5 Ratio of front to rear brake lever force or tyre normal force against deceleration for the Honda CB400T.

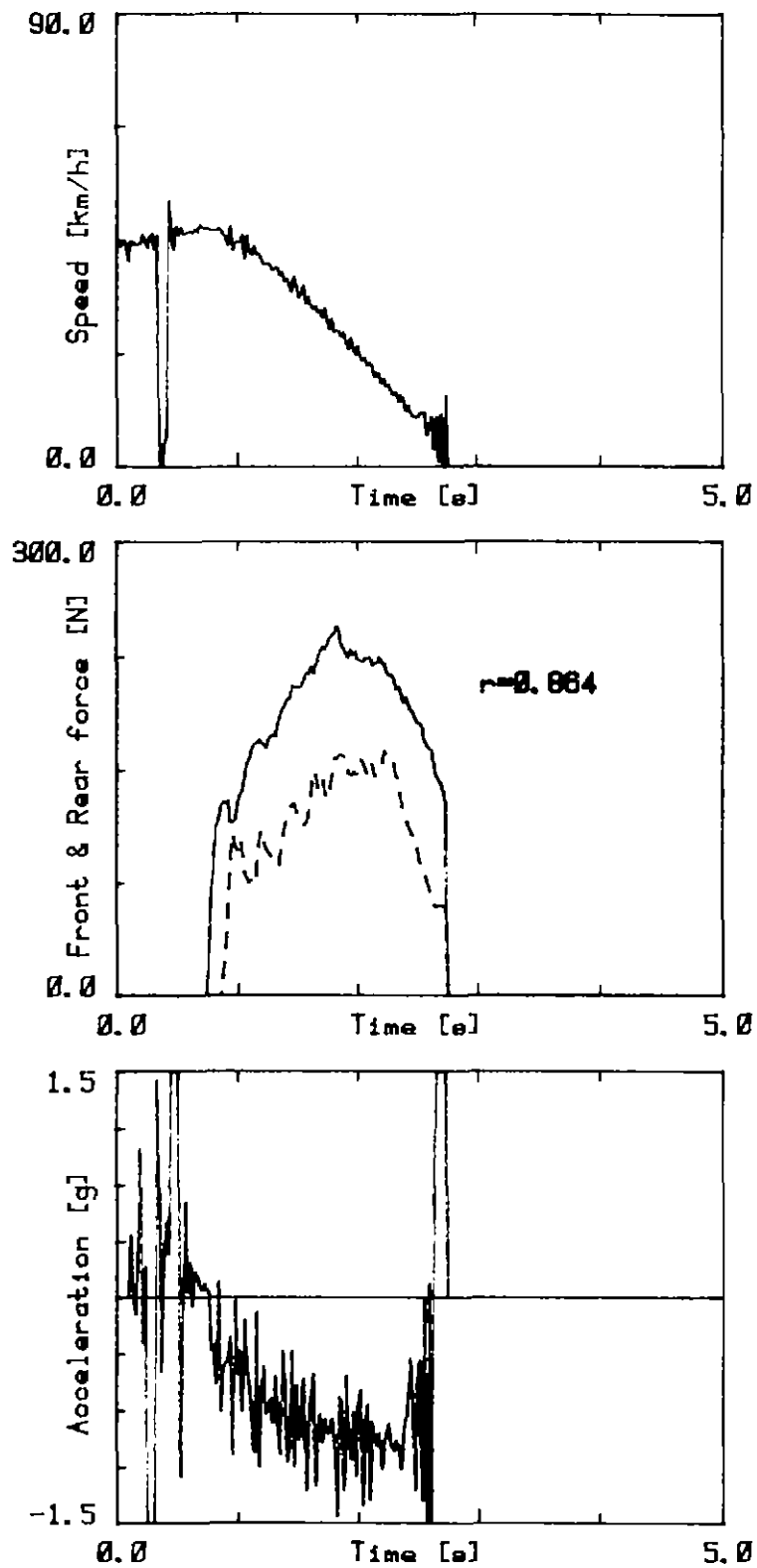


Figure 6.6 High positive front-rear correlation run (less-skilled rider).

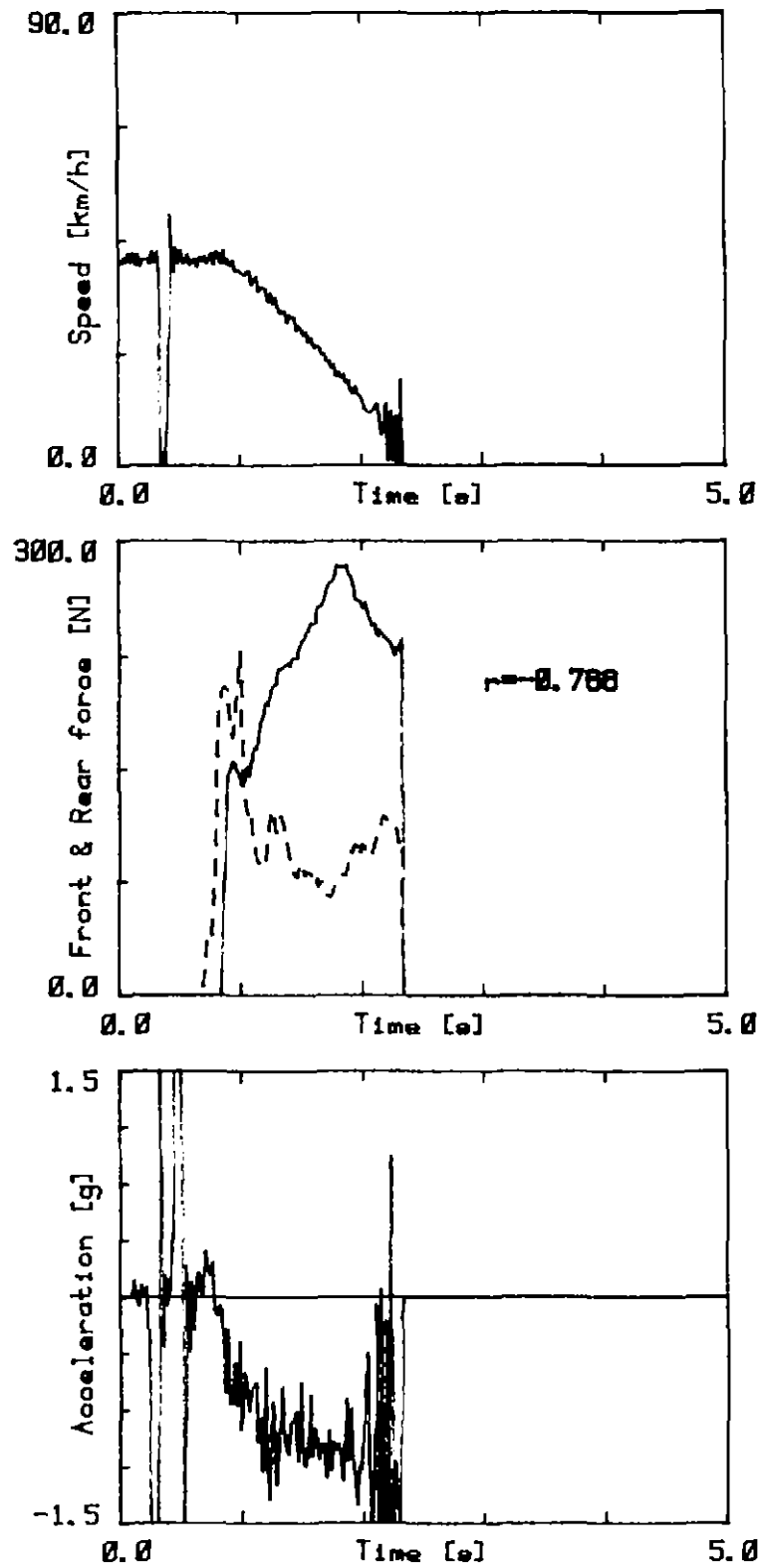


Figure 6.7 High negative front-rear correlation run (skilled rider).

Shown also in Figures 6.6 and 6.7 is the acceleration of the motorcycle obtained by differentiating the speed trace. The acceleration trace is quite 'noisy' since the speed trace from which it was calculated is noisy. The ratio of the measured front and rear forces was calculated for a number of points along the deceleration curves in Figures 6.6 and 6.7 (the traces were firstly smoothed) and plotted in Figure 6.5 for comparison with the theoretically determined optimum curve. The result for the skilled rider (data from Figure 6.7) shows that the subject increased the ratio of front to rear force as deceleration increased approximately in accord with the optimum curve. By contrast, the less-skilled rider (data from Figure 6.6) maintained an approximately constant ratio, regardless of deceleration.

The Front-Rear Correlation results suggest that skilled riders may be aware, at some level, of the 'weight transfer' which accompanies deceleration, and attempt to utilize this 'knowledge' by proportioning the braking effort to each wheel in an optimal manner. Applying the brakes as shown in Figure 6.6 would eventually result in a rear wheel lock-up, since the normal load on the rear wheel, and therefore the maximum available rear wheel longitudinal braking force, decreases with increasing deceleration. A rear wheel lock-up reduces the directional controllability of the motorcycle and may create a hazardous situation for the rider.

In summary, it appears that skilled riders are able to independently modulate their front and rear brake force inputs so that, as the motorcycle deceleration increases, the ratio of front to rear force increases in the manner required for optimum utilization of the available tyre/road friction.

Finally, although the estimate for the regression coefficient of the variable Application Time Difference was not significant, it is of interest to examine the data for this variable in detail. The sign of the regression coefficient for this variable indicates that riders who applied the front brake first were the more skilled riders. Table 6.7 provides a breakdown of scores and reaction times for the three possible outcomes for application time difference.

TABLE 6.7

## APPLICATION TIME DIFFERENCE DETAILS

	First brake application		
	Front	Together	Rear
No. of subjects	17	3	29
Appl'n time diff. (s)			
Mean	0.103	0.000	-0.115
Std. dev.	0.139	-	0.110
Reaction time (s)			
Mean	0.345	0.413	0.410
Std. dev.	0.095	0.181	0.105
MOST score			
Mean	9.24	15.67	13.83
Std. dev.	4.86	3.77	9.50

Approximately twice as many riders applied the rear brake first as applied the front brake first. The mean reaction time for the 'rear brake riders' was greater than for riders applying the front brake first, the difference being significant at the 5% level. The difference between the mean MOST scores for these two groups is also significant at the 5% level. These results indicate that, on average, the skilled riders reacted faster and applied the front brake first, whereas the unskilled riders took a longer time to react and applied the rear brake first. It is hypothesized that the skilled rider's strategy was to apply the most effective brake, for these conditions, as soon as possible to achieve the shortest stopping distance.



This result is not consistent with observations made by McKnight and Fitzgerald (1976) during straight line braking experiments involving two highly experienced riders. To record rider brake control inputs, a movie camera mounted on the motorcycle was used to capture the position of a set of pointers (connected to each control) displayed on a panel mounted behind the rider. They found that in most instances the rear brake was applied slightly before the front brake. This difference was attributed to the operator's and vehicle's control mechanisms rather than any attempt to apply one brake ahead of the other. The inconsistency with the present study is probably due to sample size differences (two compared to forty-nine), and simply reflects inter-rider variability. Further, it is difficult to assess the fidelity of the McKnight and Fitzgerald (1976) data, since details of the transducers used to measure the control inputs were not provided.

#### 6.2.5 Regression for Average Deceleration

The independent variables,  $X(i)$ , and their means and standard deviations shown in Table 6.2 apply also for the regression on Average Deceleration. For the dependent variable,  $Y$ , a mean value of 0.577g and a standard deviation of 0.109g were determined. Table 6.8 shows the correlation coefficients between Average Deceleration and the independent variables; the correlation coefficients between the independent variables are identical to those listed in Table 6.3.

Average Deceleration is highly correlated with Front Force Mean (0.886) and Front/Rear Ratio (0.652). The discussion in the previous section relating to correlated independent variables applies equally here. The results for this regression are summarized in Tables 6.9 and 6.10. Once again the order of inclusion of variables into the equation has been preserved in the tables and the first variable for which the regression coefficient was not significant has also been included.

TABLE 6.8

CORRELATION BETWEEN DECELERATION  
AND THE INDEPENDENT VARIABLES

Independent variable	Average deceleration
Reaction time	-0.336
Appl'n time diff.	0.218
Average speed	0.135
Front force mean	0.886
Rear force mean	0.169
Front std-dev/mean	-0.020
Rear std-dev/mean	0.159
Front/rear ratio	0.652
F-R correl'n coeff.	0.031

A very large proportion of the variance in average deceleration (78.5%) is explained by Front Force Mean level. The estimate for the regression coefficient for this variable is significant at the 1% level. By comparison, Rear Force Mean and Front-Rear Correlation together account for only 4.2% of the explained variance and the estimates for their regression coefficients are significant at the 5% level. The fourth variable which was not significant but was nevertheless included in the equation, was Reaction Time. The constant in the equation, 0.22g, reflects the amount of deceleration not accounted for by the selected independent variables and is assumed to be due to the effects of rolling resistance, aerodynamic drag and engine braking.

TABLE 6.9

## REGRESSION RESULTS FOR DECELERATION

Variable	R	$R^2$	Estimate of population $R^2$	$\Delta R^2$	Simple r	Overall significance of regression
Front force mean	0.886	0.785	0.781	0.785	0.886	1%
Rear force mean	0.903	0.816	0.808	0.031	0.169	1%
F-R correl'n	0.909	0.827	0.815	0.011	0.031	1%
Reaction time	0.913	0.834	0.820	0.007	-0.336	1%

TABLE 6.10

## REGRESSION COEFFICENTS FOR AVERAGE DECELERATION

Variable	Regression coefficient	Coefficient standard deviation	Significance of coefficient estimate
Front force mean	0.00185	0.000138	1%
Rear force mean	0.00045	0.000190	5%
F-R correl'n	0.0363	0.0170	5%
Reaction time	0.108	0.0745	n.s.
CONSTANT	0.219	-	-

Note: Standard error of regression = 0.049

- Interpretation of regression for average deceleration

The sign of the regression coefficients for Front Force Mean and Rear Force Mean indicates, as one would expect, that high front and rear force means lead to high decelerations. The sensitivity of the motorcycle to front brake force inputs is seen to be approximately four times that of the rear brake. As the regression coefficients for these two variables represent the front and rear brake lever-force / deceleration characteristics of the motorcycle, it is possible to check these estimates by referring to the work of Juniper (1982). A portion of Juniper's work was devoted to calibrating the CB400T brakes; i.e. he measured the brake lever-force / deceleration characteristics and brake lever-displacement / deceleration characteristics for the front and rear brakes independently. Note that the same transducers and data acquisition system were used for Juniper's work. Calibration of the cycle was achieved by the rider applying an approximately sinusoidal input of brake lever force while the motorcycle was travelling in a straight line. Juniper estimated the motorcycle's front and rear lever-force / deceleration sensitivity by fitting a first order regression equation to the data. The slope estimate obtained from the regression represented the required sensitivity. This estimate neglects the 'constant', or zero-force deceleration offset, which was found to be approximately zero for both brakes. Note that the test rider was required to disengage the engine prior to applying the brake. For the present study the constant in the regression equation would primarily result from engine braking because riders were required to ride in second gear and did not, in general, disengage the engine until the motorcycle was almost stationary. Table 6.11 shows a comparison of Juniper's results and those obtained in the present study using multiple regression analysis.

From the table it can be seen that the present study estimate for the sensitivity of the front brake is somewhat larger than Juniper's. Reasons which could account for the difference are as follows:

- The range of decelerations and speeds covered by the two tests was different: 0.3 to 1.0g and 0 to 40 km/h for the present study; 0.0 to 0.5g and 0 to 60 km/h for Juniper's work.

TABLE 6.11

## CB400T LEVER-FORCE/DECELERATION SENSITIVITIES

	Force sensitivities ( $\text{Ns}^2/\text{m}$ )	
	Front	Rear
Juniper (1982)	36.4	38.3
+1 std dev*	59.6	292
Present study <sup>+</sup>	55.1	226
-1 std dev	51.2	159

\* This refers to 1 standard deviation of the regression coefficient for the present study.

+ This is calculated from the coefficient for the linear term of the regression equation.

- Although riders were instructed to ride down the path in second gear some chose to ride in first gear.

The estimate for the rear brake is significantly larger than Juniper's. In addition to the reasons given above, the rear brake result can be explained as follows. During the conduct of the emergency braking test for the MOST, it was observed that many riders adopted the strategy of locking the rear wheel and controlling the application of the front brake. When the rear wheel is locked, any further increase in rear brake lever force does not produce a proportional increase in deceleration, i.e. the assumed 'linear' relationship between deceleration and rear brake force is no longer valid.

The braking strategy mentioned above is an interesting one and the work of McKnight and Fitzgerald (1976) highlights its importance. For their work, two highly experienced riders performed a series of straight line braking tasks. The following three braking techniques were used for applying the rear brake:

- (i) Locked - rear brake was applied so that the rear wheel remained locked.
- (ii) Controlled - the rear brake was applied as firmly as possible without locking the rear wheel.
- (iii) Modulated - the rear wheel was alternately locked and released.

The shortest stopping distance was achieved when the first technique was employed. McKnight and Fitzgerald (1976) attribute this to the fact that locking the rear wheel allows the operator to devote total attention to adjustment of the front brake. These results would suggest this to be a 'good' strategy for straight line braking. If the motorcycle is not travelling in a straight line, a rear wheel lock will cause the rear of the motorcycle to skid sideways with little control. This technique is therefore not recommended as it may become a habit.

The third variable to enter the equation was Front-Rear Correlation, for which the regression coefficient is positive. Recall from the MOST Score regression that the sign of the regression coefficient for this variable was negative. These results are not necessarily contradictory. The MOST score result indicates that skilled riders are able to proportion their braking effort in an optimal manner as deceleration changes, as discussed earlier. The present result indicates that a slightly higher mean deceleration can be achieved by maintaining a constant front to rear brake lever force ratio. Indeed to achieve the highest possible mean deceleration it would be necessary to make full use of the available tyre/road friction by maintaining the maximum possible deceleration level for the entire braking period. This can be achieved most efficiently by keeping both wheels on the verge of 'lockup', a condition which can be maintained by applying constant front and rear brake lever forces for the dura-

tion of the deceleration period (assuming that the braking system characteristics are independent of motorcycle speed).

Reaction time, which was not significant, was the final variable to be entered into the equation. The estimate for the regression coefficient is positive, and suggests that a longer braking reaction time leads to higher decelerations. One explanation for this curious result is as follows: The path which the riders were required to ride down was the same as for the immediately following obstacle avoidance exercise. The applicant instructions for the obstacle avoidance exercise indicate to the riders that the obstacle line is the 'target' for this exercise (see Appendix C). For the emergency braking exercise riders were told to come to a complete stop as quickly and as safely as possible; however, riders were not told to ignore the obstacle line. As a result of this omission the obstacle line may have represented a stopping target to riders. Riders with a longer reaction time would therefore have to brake harder to try to stop before the obstacle line. Juniper (1982) obtained the same result in emergency braking tasks in which the instructions given to the two riders tested were similar.

#### 6.2.6 Analysis of the Braking Measures for the AST

The measures devised for the MOST were used to describe the braking behaviour of riders in the AST. Two regressions were computed for each of the two measures of skill, namely, overall AST score and average deceleration. The first of each of the two regressions was performed with the level one data and the second regression with the level two data.

Of the four possible braking situations in the AST presented to the riders, only data for the two levels of the prescribed task were analysed. Furthermore, since riders were required to perform each task one or more times, where applicable the average of the numerical values for each measure was used. This was thought to represent each rider's braking behaviour more accurately than the measures of a single trial.

The data were examined and those runs from which the measures could not be extracted were not used. It is interesting to note that one particular rider applied the rear brake with such force, for all of his level one runs, that the output signal from the force transducer exceeded the maximum recordable level - which is about 300 N! Foot strength distribution data cited by Zellner (1980) for males applying automotive brakes and a machine foot bar, of which the latter, it would appear, is more akin to rear brake application on a motorcycle, indicate a fifth percentile point of about 230 N and a median, or fifty percentile point, of about 260 N. The brake force level which the present rider achieved is not known but the result indicates that it was significantly higher than the strength distribution data show.

From the sample of 18 riders, the data from the level one braking task was useable from 16 riders and from 15 riders for the level two task.

#### ● Regression for AST score

The measures used for the first two regressions on AST score are identical to those listed in Table 6.2 for the MOST and, with the exception of reaction time, speed, and AST score, the means and standard deviations of the variables are not very different to those listed in that table. A slightly longer average reaction time was determined for level one (0.520 s) and level two (0.499 s), and the test speed maintained by the subjects was lower (31.4 km/h), but closer to the specified test speed, for the AST than for the MOST. Note that the values shown in Table 6.2 are almost identical to those determined from the MOST data of the AST subjects, with the exception of Front Force Mean which was found to be somewhat less (98.9 N) than the value for the total MOST sample.

The values for the measures determined from the level one data were assigned to the independent variables and regressed on AST score using the regression strategy outlined in Section 6.2.3. The following independent variables explained 69.5% of the variance in AST score: Front Force Mean (50.4%), Application Time Difference (14.6%)



and Reaction Time (4.5%). Of these variables, the regression coefficient for the first two are significant at the 1% and 5% level, respectively, and the sign of the regression coefficients, for all three variables, are identical to those for the MOST listed in Table 6.5. The discussion pertaining to these variables presented in the MOST section applies equally here. The overall regression is significant at the 1% level. Note that the regression coefficient estimate for Application Time Difference is significant for the AST but was not significant for the MOST (see Table 6.5).

The values of the measures for the level two task were next assigned to the independent variables and the regression repeated. Front/Rear Ratio and Application Time Difference explained 68.2% of the variance in AST score. Of these two variables Front/Rear Ratio explained 61.42% of the variance in score and its regression coefficient is significant at the 1% level. The regression coefficient estimate for Application Time Difference is not significant but its sign is identical to the level one result for this variable. The overall regression is significant at the 1% level. The fact that Front/Rear Ratio appears in the regression equation and Front Force Mean does not is not inconsistent with the MOST or level one AST results. These two variables are not only highly correlated with score ( $-0.784$  for Front/Rear Ratio, and  $-0.749$  for Front Force Mean) but also with each other ( $0.925$ ). The problem of multicollinearity was discussed in Section 6.2.4 and that discussion is applicable here.

#### ● Regression for average deceleration

The measures used for the regression on Average Deceleration are identical to those used in the previous regressions and, although the sample was slightly different, the mean and standard deviations of the independent variables are almost identical. For the level one and two tasks, average decelerations of, respectively,  $0.549$  g and  $0.543$  g were calculated. These are slightly higher than the average deceleration achieved by the AST subjects in the MOST emergency braking ( $0.518$  g). Note that the two values of average deceleration in the AST are not very different, suggesting that the riders were braking to

their full capacity in the 'easier' level one task - as noted already in Chapter 5. This behaviour is examined in more detail in the next section.

The two regressions were computed and it was found that the level one and level two results were virtually identical. The following discussion applies equally to both regressions.

Front Force Mean was the first variable to be entered into the equation and it alone explained about 91% of the variance in Average Deceleration. With Front Force Mean in the equation, only a small amount of the variance in average deceleration was left for the eight variables and their interactions to explain. The regression was continued and a further ten variables, two of which were interactions, were entered into the equation. All of the variables explained only a small, but statistically not insignificant, amount of the remaining variance. Note that some variables in the equation were not statistically significant but were in the equation because they were the constituent element(s) of an interaction. Clearly because so much variance was explained by Front Force Mean, a remaining variable only need account for a small amount of the variance in Average Deceleration which was not accounted for by Front Force Mean for it to be significant. Furthermore, the number of parameters in the equation was getting close to saturation - that is, the number of observations - making the real significance of the new terms questionable (Draper and Smith, 1966). For these reasons only the relationship between Average Deceleration and Front Force Mean is believed to be accurately portrayed. The result for Front Force Mean is identical to the one obtained for the MOST.

#### 6.2.7 Learning Effect in the AST

Learning is characterized by a relatively permanent change in the performance of an individual which can be shown to be the result of experience (Fitts and Posner, 1967; McCormick 1970).

The AST was designed so that each subject performed a given task at least once. Because some riders were assigned a particular task more than once, in some cases six times (because task assignment was on a random basis), it was possible to determine whether or not there had been improvements in a subject's performance in the successive runs of a task.

Plots of stopping distance and average deceleration, which are used here as measures of performance, against trial number are shown in Figures 6.8 (a) and (b) for level one of the AST for subjects who received at least four repeated runs. Note that trial number zero refers to the MOST and successive trials on the plot need not correspond to consecutive runs in the test. Although there is a slight improvement over the subjects' MOST performance, in general, riders maintained a fairly constant level of performance. In fact, even those subjects who failed to stop before the obstacle line (11.6 m) appear to have maintained a constant level of performance.

Before one can determine whether or not learning has occurred, it is important to establish the nature of the performance and type of learning involved. Consider the conditions that contribute to learning: motivation, knowledge of results, distribution of training periods, and types of incentives used. Of these, knowledge of results is assumed to be the one of most importance in this situation for this reason: The braking task required that riders try to stop before the line representing the obstacle. If a rider satisfied this requirement in each run, then there would be no need in the next run to brake harder and try to stop in a shorter distance. As a consequence, one would not expect their level of performance to improve beyond that required to perform the task successfully. This was apparently not the case. The observation that riders appear to have maintained a constant level of performance is in accordance with the idea that individuals set themselves a performance level beyond which they do not 'push' themselves (Helson, 1964; McCormick, 1970). However, this is only one interpretation of the data and it is possible that the riders were all doing their best and could not improve their performance even if they wanted to.

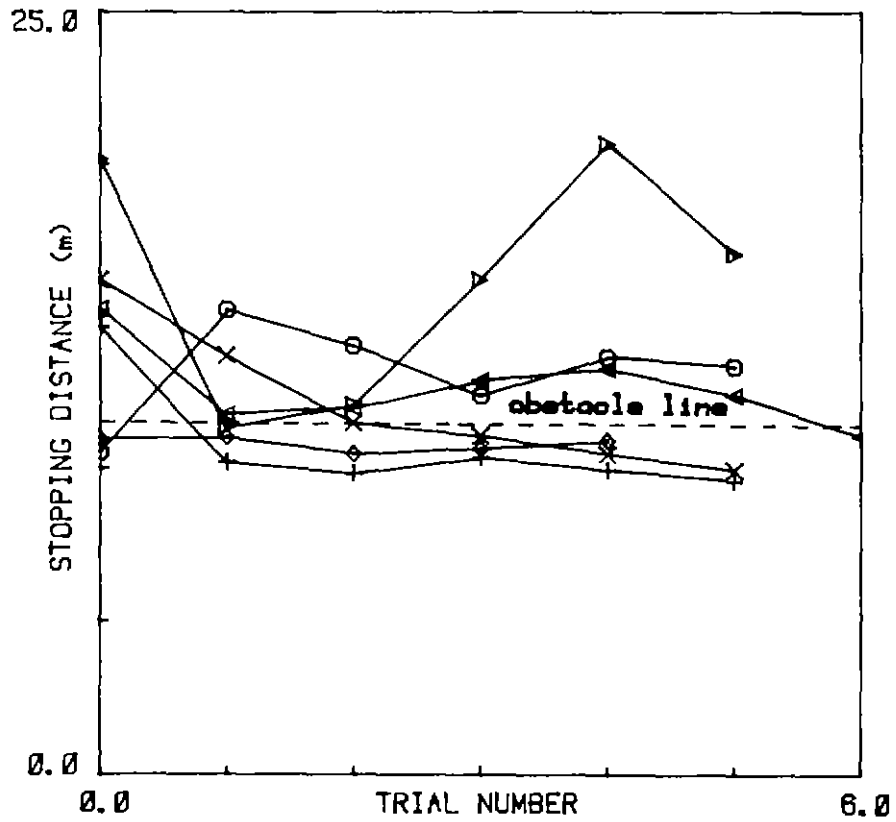


Figure 6.8 (a) Stopping distance achieved by a number of riders in the AST for repeated level one braking runs.

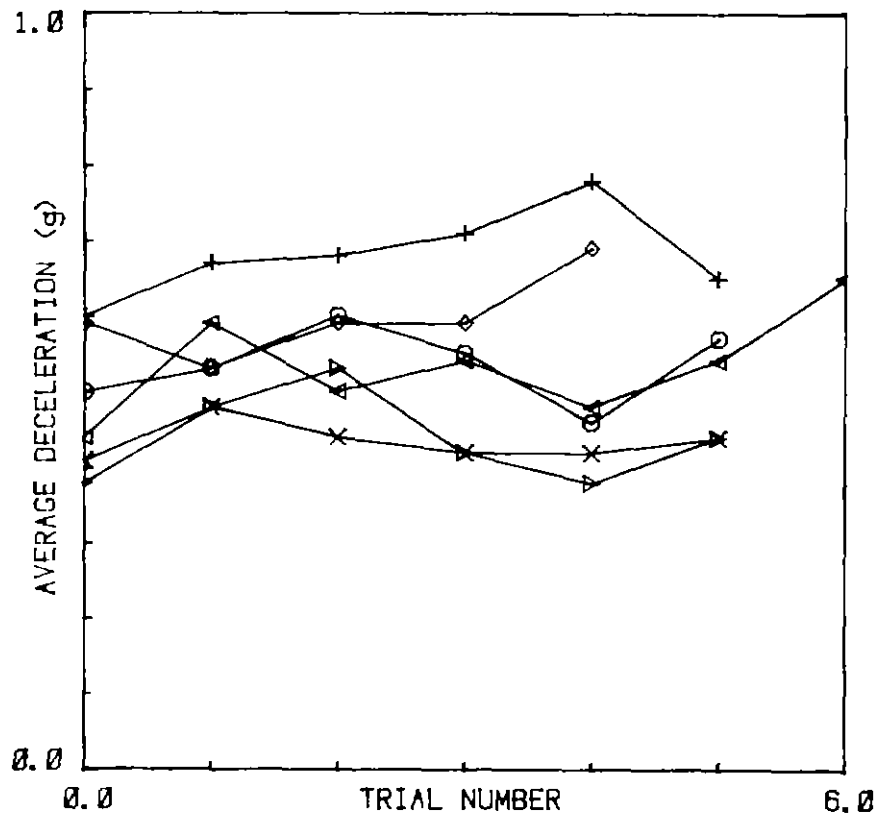


Figure 6.8 (b) Average deceleration achieved by riders in repeated level one braking runs.

It is interesting to observe in Figures 6.9 (a) and (b), which show front and rear force mean as a function of trial number, that the improved performance of riders in the AST over the MOST is apparently due to increased usage of the front brake. This result indicates that during the period between the tests riders improved their braking skills.

In summary, it appears that no learning has taken place during the AST and riders maintained a constant level of braking performance regardless of task difficulty; however, riders' braking skills appear to have improved since they were administered the MOST.

#### 6.2.8 Summary and Conclusions from Analysis of the MOST and AST Braking Data

Following is a summary of the findings from the analysis of the data collected on the instrumented motorcycle for the MOST and AST emergency braking exercise:

- (1) A multiple linear regression was performed with overall MOST score (taken as a measure of rider skill) as the dependent variable, and various measures extracted from the emergency braking data as the independent variables. Of the measures used, the most important were found to be: Front Force Mean, Reaction Time, Front-Rear Correlation and Rear Force Mean. These alone accounted for 57.0% of the variance in MOST Score. The overall regression was significant at the 1% level. The regression coefficients obtained from this regression indicate that the skilled riders, when compared with the less-skilled riders, apply larger front and rear brake forces, have shorter reaction times, and are able to independently modulate their front and rear brake force inputs so that, as the motorcycle deceleration increases, the ratio of front to rear force increases in the manner required for optimum utilization of the available tyre/road friction.

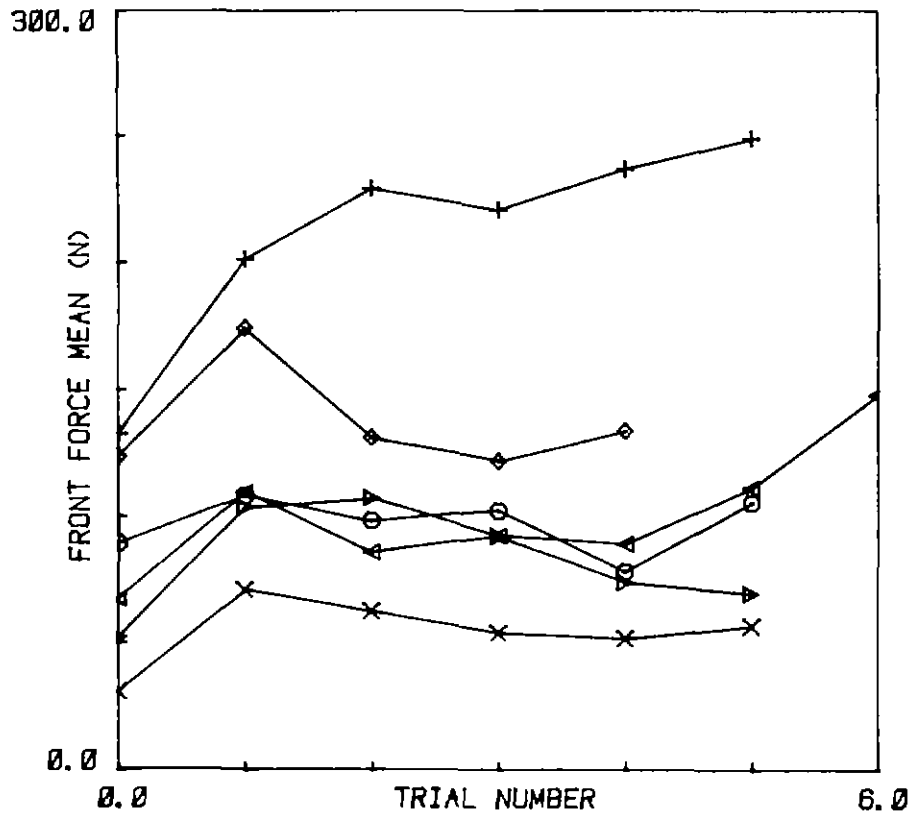


Figure 6.9 (a) Front force means for repeated runs.

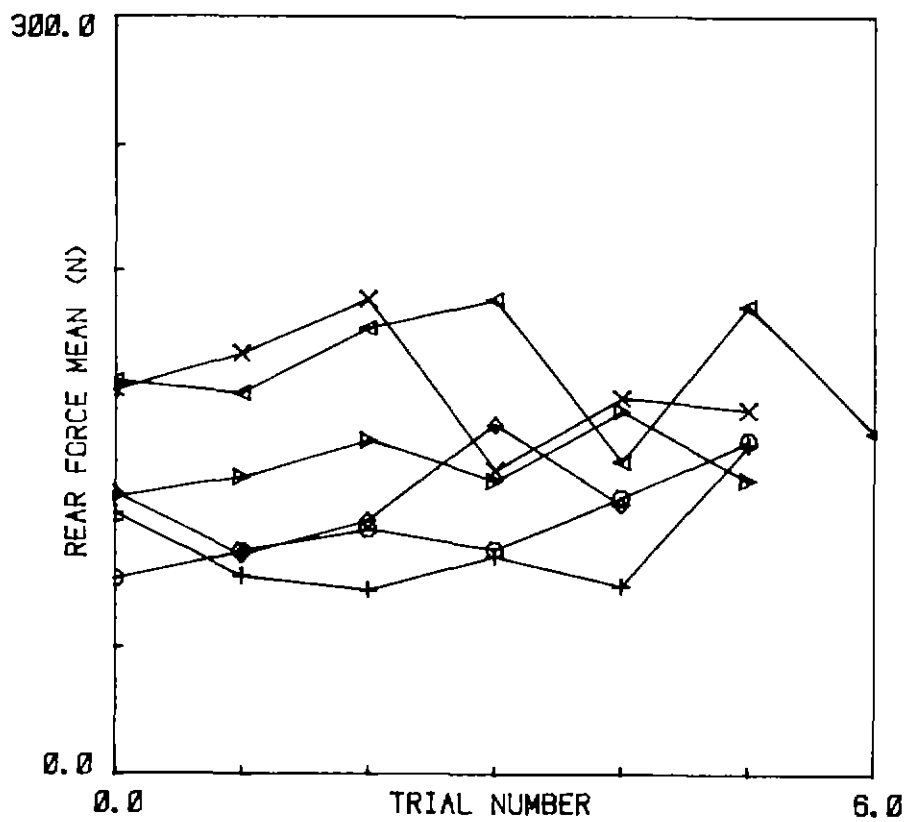


Figure 6.9 (b) Rear force means for repeated runs.

- (ii) An examination of the time difference between the application of the front and rear brakes indicates that the skilled riders applied the front brake first. By contrast, the less skilled riders applied the rear brake first. It is hypothesized that the skilled rider's strategy was to try to apply the most effective brake, for the given conditions, as soon as possible to achieve a shorter stopping distance. This finding is in direct contradiction to observations made by McPherson and Fitzgerald (1976), where for two skilled riders it was found that the rear brake was applied first in most instances.
- (iii) A second regression was performed to determine which of the measures are associated with average deceleration. Front Force Mean, Rear Force Mean and Front-Rear Correlation were the most important variables and accounted for approximately 83% of the variance in average deceleration. The regression coefficients for these variables indicate these features lead to improved decelerations: large front and rear force means and maintaining a constant front to rear brake lever force ratio.
- (iv) The estimate for the regression coefficient for front force mean compares reasonably well with that determined by Juniper (1982) for the same motorcycle using a different technique. For the rear brake the estimates for the present study are poor because many riders performing the test adopted the braking strategy of locking the rear wheel and devoting full attention to control of the front brake.
- (v) The regressions performed on the MOST data were repeated on the AST level one and two prescribed braking task data and similar results were obtained.
- (vi) Examination of the data for the repeated prescribed braking trials in the AST revealed that no learning had taken place and riders maintained a constant level of performance regardless of task difficulty. However, riders' braking skills appear to have improved since they were administered the MOST.

## 6.3 OBSTACLE AVOIDANCE TASK

### 6.3.1 Data Analysis

The analysis of the data in this section deals primarily with the obstacle avoidance task of the MOST and AST. Several analysis techniques were used and these are discussed subsequently. Where appropriate, analysis of the data for some of the less critical MOST exercises are presented.

Although the data collected for the obstacle avoidance task were quite good, a number of the runs could not be used because problems occurred with some of the transducers during the conduct of the experiments. For example, the steer torque transducer failed suddenly three times, the first two times for no apparent reason and the third time when the motorcycle was dropped by a subject during a test exercise. The data for the steer torque variable was therefore not available for 16 of the subjects administered the MOST and for 5 of the subjects administered the AST. Furthermore, the rate gyroscopes used initially were found to be adequate during moderate manoeuvres; however, during the more severe manoeuvres, and for the more aggressive riders, these were found to be too sensitive. In order to capture the maximum roll and yaw velocities achieved by these riders, it was necessary to use less sensitive gyros (see Appendix A). It took some time for the new gyros to arrive from overseas during which the experiments continued using the more sensitive ones. For those riders tested with the more sensitive gyros there were some runs where the roll and yaw rate data traces were 'clipped' because of transducer saturation, i.e. the transducers were subjected to motions which were beyond their sensing range. Approximately half of the MOST sample was tested with the less sensitive gyros.



The approaches which were used to examine the data for this task consisted of the following:

- Multiple Linear Regression - Various measures were devised and extracted from the data traces and analysed using multiple linear regression to determine what aspects of operator technique distinguish a skilled performance from a less-skilled one.
- Ensemble Averaging - The responses of riders of similar 'skill' level were averaged in an attempt to uncover characteristic patterns of behaviour and sequencing of control inputs associated with a particular 'skill' group.
- Data Traces and Two-Variable Plots - The data traces for each subject were examined to determine whether any other differences exist between their control and response parameters which were not revealed in the regression analysis or ensemble averages. Further, two-variable plots were explored as an alternative form of data presentation. This method of presenting the data was first used by Rice (1978) who suggests that cross-plots, or control diagrams, generated by expert riders may be useful as a training aid by using the expert's diagram as a reference to instruct trainees.

### 6.3.2 Interpretation of Typical Data Traces

Figure 6.10 shows the recorded data traces for a skilled rider performing a left obstacle avoidance manoeuvre. For this task the instrumentation recorded the rider's steer torque ( $T$ ), steer angle ( $\delta$ ) and body lean control ( $\phi_R$ ) inputs, and roll rate ( $\dot{\phi}$ ) and yaw rate ( $r$ ) responses of the motorcycle as shown. Roll angle ( $\phi$ ) of the motorcycle, which is also shown, was obtained by integrating the roll rate data. Speed was constant at about 30 km/h. The sign convention for the transducer outputs used here was defined in Section 3.3.2.

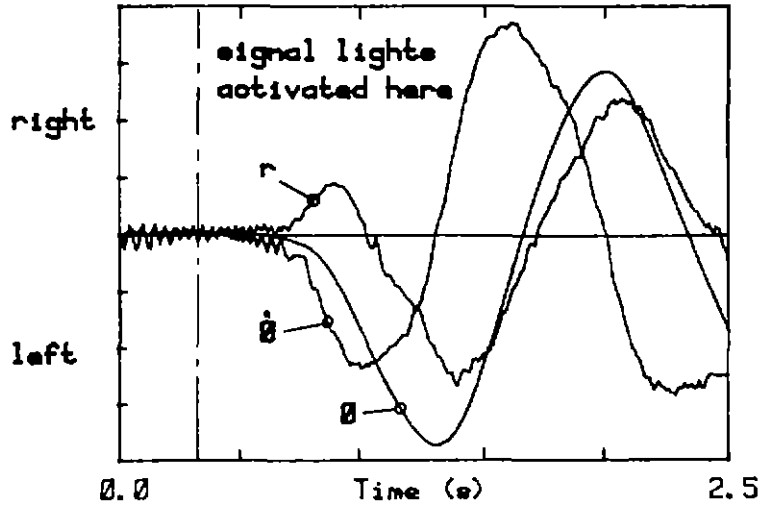
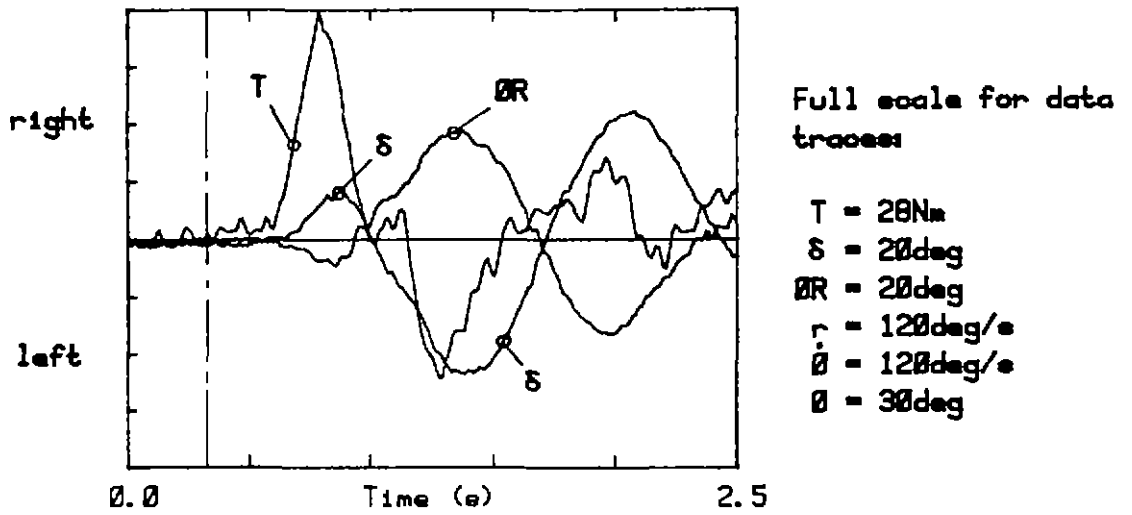


Figure 6.10 Data traces for a skilled rider performing an obstacle avoidance manoeuvre to the left.

The task required that the rider turn left or right from a straight path to avoid an 'obstacle', the direction of turn being indicated by signal lights. As well as avoiding the obstacle - a transverse line painted on the path - the rider was required to avoid encroaching the furthest lateral boundary of the adjoining traffic lane (see Appendix C for more details).

The data traces show that the rider initiated the turn by applying a steering torque to the right, in a direction opposite to that of the intended turn. The front wheel tracked to the right and the outward inertia force caused the cycle to roll to the left (shown on the roll rate trace). During this phase of the manoeuvre the cycle yaw rate was positive, i.e., the cycle was turning to the right away from the intended turn direction. The cycle continued to roll further to the left until the front wheel was caused to track to the left by reducing the applied steering torque (0.8s to 1.0s mark). Maximum roll velocity to the left was achieved when the steering assembly was in the plane of symmetry of the motorcycle, i.e. straight ahead. As the steering assembly was turned to the left (beyond the 1.0s time mark), the roll velocity began to decrease as the inertia force acting on the cycle worked 'against' the gravitational force. At this point the cycle was moving in the required direction - to the left. Prior to passing the obstacle, and in order to avoid crossing the outer left-hand boundary on the course, the steering assembly was turned further to the left (1.25 to 1.5s time period) by applying a rapid steering torque in that direction, which increased the outward inertia force and caused the cycle to roll towards and beyond the upright position, around the obstacle line (at approximately the 1.5s mark) and away from the outer boundary (2.0s mark). During the entire manoeuvre, the rider lean trace indicates the rider's upper torso remained closer to the vertical than the motorcycle main frame. Further, the data traces for steer angle and rider lean are closely coupled for the duration of the manoeuvre. Interpretation of this behaviour is deferred to a later section. Note that there may be some error in the measured rider lean trace (see Appendix J).

### 6.3.3 Multiple Linear Regression

#### (a) Measures for the obstacle avoidance task

An identical regression strategy to that outlined in Section 6.2.3 for the emergency braking was used to compare the obstacle avoidance performance and technique of different riders. Measures which were sensible were again devised to 'describe' different features of the data traces which characterize the rider, the rider's control inputs and the cycle's response.

Following is a list of the obstacle avoidance task measures. The quantitative significance of the measures can be appreciated by referring to Figures 6.11 and 6.12, which show examples of two obstacle avoidance behaviours, and Table 6.12 which provides the numerical values of the measures associated with each of the examples.

(1) TEST SCORE - This is the overall MOST score (the number of penalty points assigned) and is assumed to be directly related to rider skill level.

(2) TURN SUCCESS - Whether or not a rider managed to successfully manoeuvre to avoid the 'obstacle'. Success and failure are denoted by, respectively, 1 and 0.

(3) REACTION TIME - The time period measured from when the signal lights were activated to when the steer torque transducer registered a significant deviation of steer torque from zero. This transducer provided the best indication of when the rider reacted.

(4) REVERSE STEER TORQUE SLOPE - The rate of change of steer torque immediately after the rider reacted. This is a measure of the 'aggressiveness' of the rider.

(5) REVERSE STEER PERIOD - The time period after the initial reaction during which the steering assembly is displaced away from the intended turn direction.

(6) MAXIMUM REVERSE STEER ANGLE - The maximum magnitude of the steer angle during the reverse steer angle period.

(7) TURN STEER PERIOD - The time period during which the steering assembly is displaced towards the intended turn direction.

(8) MAXIMUM TURN STEER ANGLE - The maximum magnitude of the steer angle during the turn steer period.

(9) TIME TO MAXIMUM TURN STEER ANGLE - The time period measured from when the rider reacted to when peak turn steer angle occurred.

(10) INITIAL ROLL ACCELERATION - The magnitude of roll acceleration at the beginning of the reverse steer phase. The slope of the roll velocity trace was estimated from the data traces.

(11) TIME TO MAXIMUM ROLL ANGLE - The time period measured from when the rider reacted to when the first zero crossing of the roll velocity trace occurred.

(12) ROLL ACCELERATION AT MAXIMUM ROLL ANGLE - The magnitude of roll acceleration when maximum roll angle occurs. The slope of the roll velocity trace measured at the point where it first crosses the zero axis after the rider reacted.

(13) MAXIMUM LEAN ANGLE - The maximum magnitude of the lean angle trace.

(14) TIME TO MAXIMUM LEAN ANGLE - The time period measured from when the rider reacted to when maximum lean angle occurred.

(15) AVERAGE SPEED - The average speed of the motorcycle when the signal lights were activated.

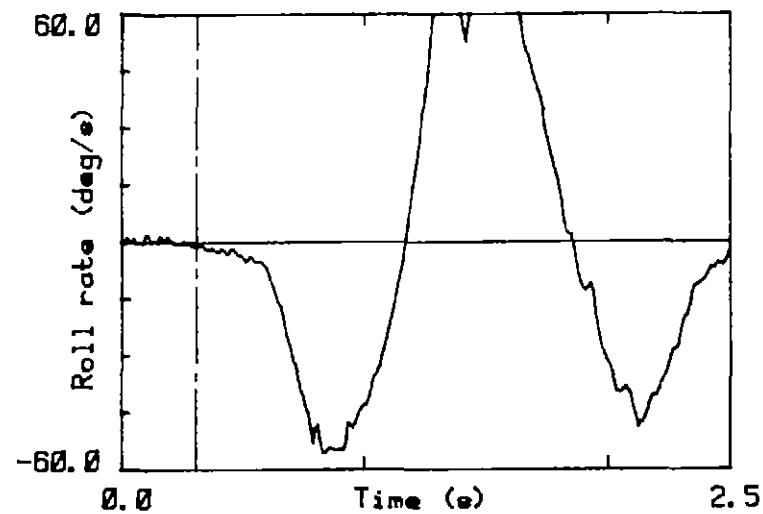
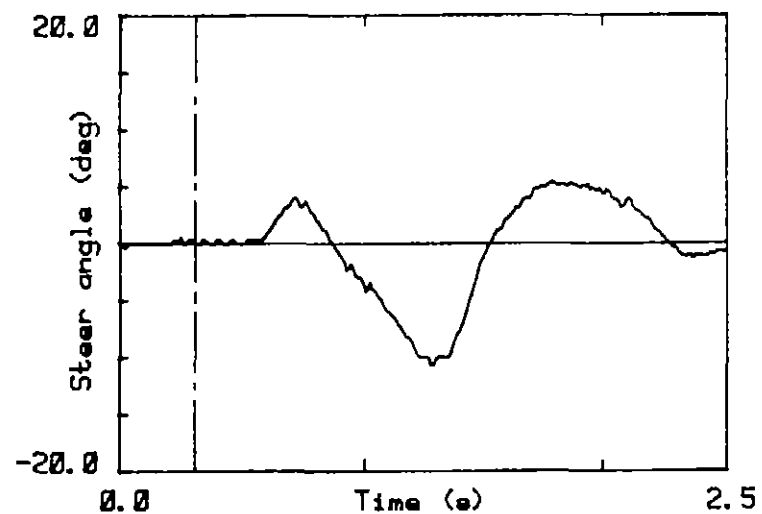
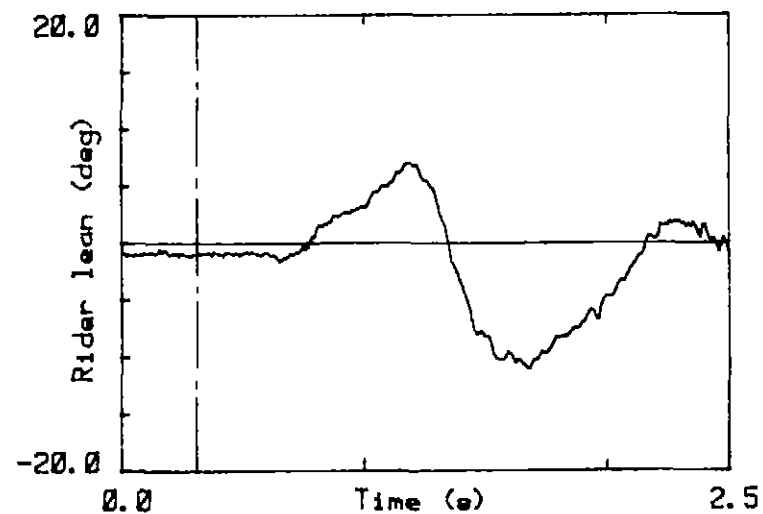
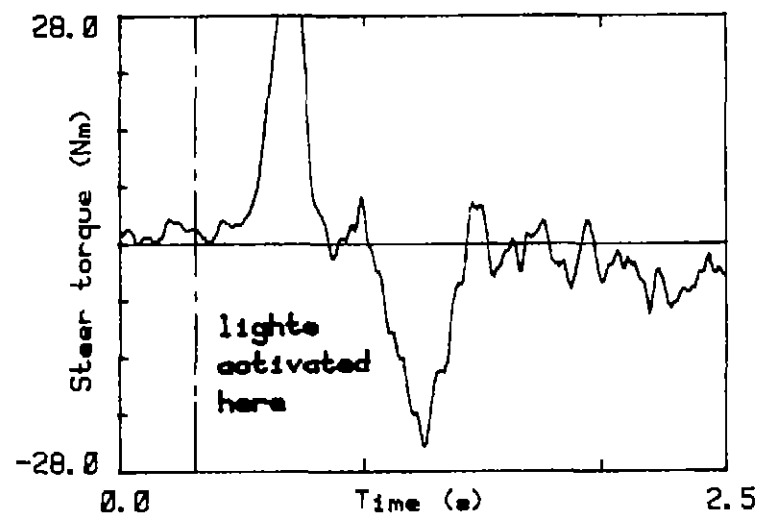


Figure 6.11 Example run to exhibit the various obstacle avoidance task measures.

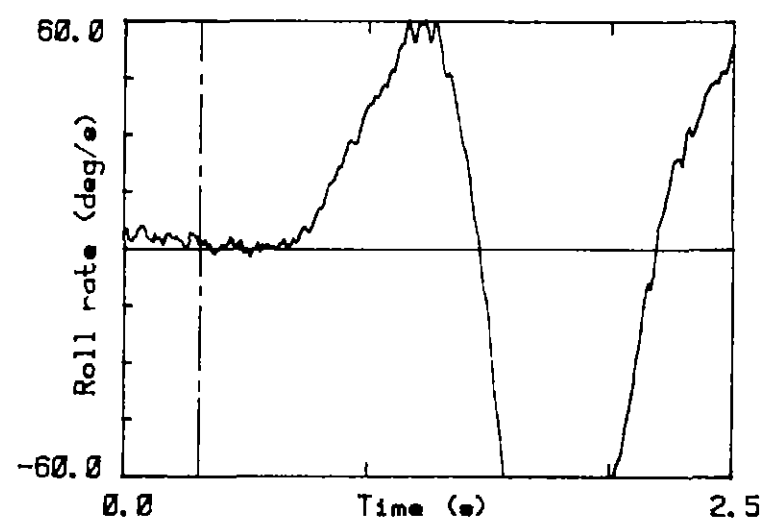
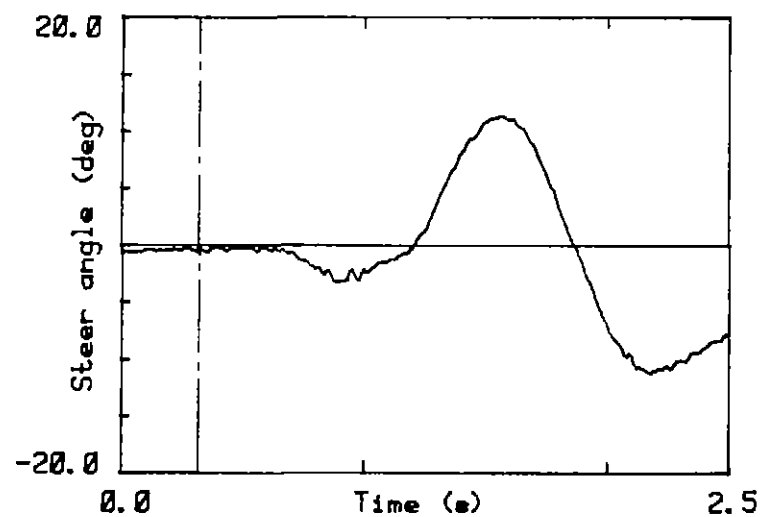
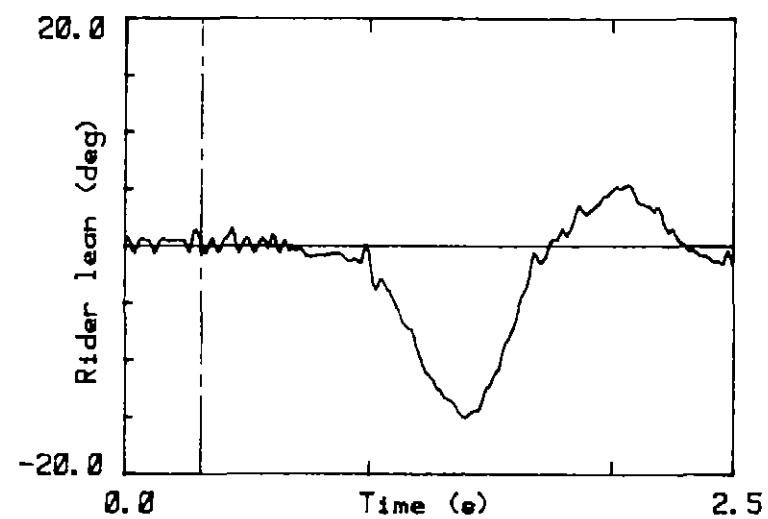
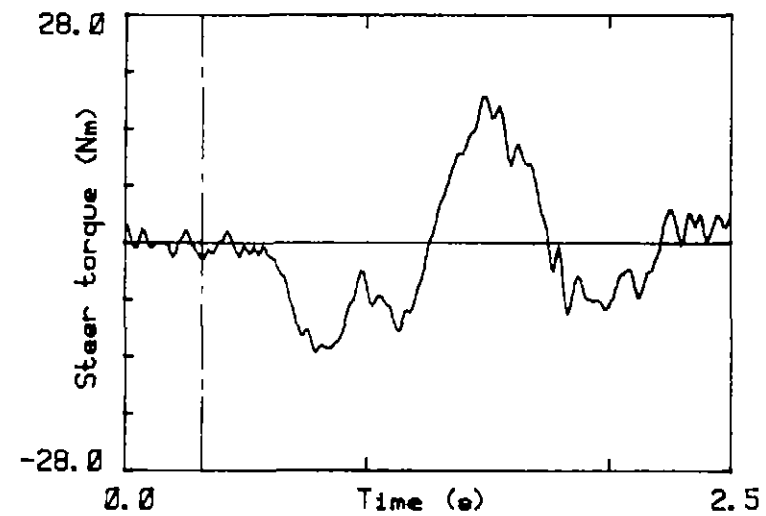


Figure 6.12 Example run to exhibit the various obstacle avoidance task measures.

TABLE 6.12

NUMERICAL VALUES OF MEASURES FOR DATA SHOWN IN FIGURES 6.11 AND 6.12

Measure	Figure	
	6.11	6.12
MOST score	3	13
Turn success	1	1
Reaction time (s)	0.216	0.256
Reverse steer torque slope (Nm/s)	280.	78.0
Reverse steer period (s)	0.296	0.630
Maximum reverse steer angle (deg)	3.6	2.8
Turn steer period (s)	0.656	0.670
Maximum turn steer angle (deg)	10.2	11.2
Time to maximum turn steer angle (s)	0.746	1.00
Initial roll acceleration ( $\text{deg/s}^2$ )	224.	125.
Time to maximum roll angle (s)	0.630	0.880
Roll accel'n at max. roll angle ( $\text{deg/s}^2$ )	400.	500.
Maximum lean angle (deg)	6.8	14.8
Time to maximum lean angle (s)	0.650	0.826
Average speed (km/h)	31.6	28.1

Various other measures were considered, for example peak reverse steer torque and peak roll angle, but these could not be extracted from many of the data traces because of 'clipping'. Had these measures been used the size of the sample would have been severely reduced. Note also that there are no measures related to yaw rate. From the data in Figure 6.10 it can be seen that the yaw rate trace follows exactly the steer angle trace. In Chapter 3 it was shown that the steady state yaw rate to steer angle gain for this motorcycle for a given speed was quite insensitive to lateral acceleration. It appears from the data of Figure 6.10, and from the data for other rid-



ers, that for the time varying input of steer angle required to perform the obstacle avoidance manoeuvre under these test conditions, the yaw rate to steer angle gain remains constant. The measures devised for steer angle are therefore proportional to equivalent ones for yaw rate.

Of the 59 riders tested, data for 16 of the riders could not be used because steer torque data were not available. Of the remaining 43 riders, data for 17 of them had to be rejected because of the way the manoeuvre was performed. For example, of those riders who successfully avoided the 'obstacle', several guessed the turn direction and actually initiated the turn well before the signal lights were activated. Of those failing, a number made no attempt at manoeuvring to avoid the obstacle and continued travelling in a straight line. Others turned in a direction opposite to that indicated by the signal lights, aborting the attempt once they had realized they were travelling in the wrong direction. For some the initial control inputs were for a turn direction opposite to that indicated by the signal lights - it appears they tried to guess the turn direction - but subsequent control inputs caused the cycle to alter course and move in the signalled direction. For these riders it was not possible to extract the measures successfully.

As for the emergency braking analysis, two regressions were computed to determine the relationship between a measure of skill and those of the parameters described earlier which characterize some aspect of operator technique. The measures of skill adopted were overall MOST score, which reflects the riders' performance in a variety of tasks of which obstacle avoidance was only one, and turn success which was chosen to represent the riders' obstacle avoidance skill.

## (b) Regression for MOST score

Table 6.13 shows the measures associated with the dependent variable,  $Y$ , and the independent variables,  $X(i)$ ,  $i=1,2,\dots,13$ , for this regression, together with the means and standard deviations of the variables. Note that the sample size was reduced to 21 because the peak lean angle for 5 of the riders was greater than 20 degrees which was beyond the sensing range of the lean transducer. A regression was performed with the variables omitted for which there were missing data and the same variables were found to be significant.

TABLE 6.13

## VARIABLES FOR MOST OBSTACLE AVOIDANCE REGRESSION

Variable	Measure (units)	Standard	
		Mean	deviation
Y	MOST score	10.3	7.84
X(1)	Reaction time (s)	0.288	0.0673
X(2)	Steer torque grad. (Nm/s)	228.	145.
X(3)	Reverse steer period (s)	0.358	0.0865
X(4)	Max. reverse steer angle (deg)	3.78	1.98
X(5)	Turn steer period (s)	0.740	0.124
X(6)	Max. turn steer angle (deg)	10.0	3.12
X(7)	Time to max. turn steer angle (s)	0.802	0.156
X(8)	Initial roll accel'n (deg/s <sup>2</sup> )	243.	107.
X(9)	Time to max. roll angle (s)	0.706	0.115
X(10)	Roll accel'n at max. roll angle (deg/s <sup>2</sup> )	432.	210.
X(11)	Max. lean angle (deg)	12.1	4.62
X(12)	Time to max. lean angle (deg)	0.732	0.169
X(13)	Average speed (km/h)	33.5	2.63

Note: Sample size = 21

The mean for X(13) shows that riders maintained the required test speed of 32 km/h quite well. The mean initial roll acceleration is seen to be approximately half that achieved at maximum roll angle. Peak roll angle occurs, on average, before maximum lean angle which occurs before peak steer angle. For the average test speed of 33.5 km/h, about 23% of the total manoeuvre length was required by the riders before the turn was initiated and, a further 29% before the cycle actually began to turn in the desired direction.

The correlation coefficients between variables are shown in Table 6.14. Variables which are highly correlated with MOST score are Reaction Time (0.530) and Maximum Turn Steer Angle (-0.515). These coefficients suggest that riders who (according to their test score) are skilled, react quicker and apply a larger maximum turn steer angle during the turn phase than those who are less skilled.

For the independent variables, Maximum Reverse Steer Angle is highly correlated with Initial Roll Acceleration (0.886). Time To Maximum Turn Steer Angle is highly correlated with Time To Maximum Roll Angle (0.921) and Time To Maximum Lean Angle (0.756), and Time To Maximum Roll Angle is highly correlated with Time To Maximum Lean Angle (0.813). This indicates that these three events, maximum roll angle, maximum turn steer angle and maximum lean angle occur at approximately the same point in time for all of the riders. A large number of the independent variables are moderately correlated with each other.

As for the emergency braking regression, interaction terms, which were considered up to third order, were found to be not significant when the constituent elements were controlled for. Tables 6.15 and 6.16 summarize the regression results. As before, the order of inclusion has been preserved in the tables and the first variable for which the regression coefficient was not significant has also been included. Note that inclusion of this variable in the equation causes only a small change in the explained variance and the regression coefficient estimates for the significant variables.

TABLE 6.14

CORRELATION COEFFICIENTS BETWEEN VARIABLES IN TABLE 6.13

	Y	X(1)	X(2)	X(3)	X(4)	X(5)	X(6)	X(7)	X(8)
X(1)	-0.530								
X(2)	-0.051	0.454							
X(3)	0.278	-0.206	-0.520						
X(4)	-0.053	0.329	0.611	-0.080					
X(5)	-0.034	-0.077	-0.136	-0.019	-0.297				
X(6)	-0.515	-0.235	0.216	0.113	0.471	-0.278			
X(7)	-0.196	-0.242	-0.137	0.364	-0.167	0.577	0.330		
X(8)	-0.169	0.238	0.651	-0.345	0.886	-0.412	0.413	-0.416	
X(9)	-0.056	-0.330	-0.345	0.536	-0.220	0.590	0.247	0.921	-0.456
X(10)	-0.227	-0.304	0.024	0.141	0.451	-0.562	0.583	-0.296	0.577
X(11)	-0.024	-0.151	0.231	0.101	0.387	-0.001	0.354	0.068	0.453
X(12)	-0.003	-0.306	-0.506	0.372	-0.581	0.570	-0.006	0.756	-0.696
X(13)	0.013	-0.055	-0.014	-0.260	-0.166	0.063	-0.030	-0.324	0.066

	X(9)	X(10)	X(11)	X(12)
X(10)	-0.172			
X(11)	0.218	0.538		
X(12)	0.813	-0.283	-0.048	
X(13)	-0.200	0.312	0.207	0.062

TABLE 6.15

## REGRESSION RESULTS FOR MOST SCORE

Variable	R	R <sup>2</sup>	Estimate of population R <sup>2</sup>	$\Delta R^2$	Simple r	Overall significance of regression
Reaction time	0.530	0.280	0.243	0.280	0.530	5%
Max. turn steer angle	0.665	0.442	0.380	0.162	-0.515	1%
Reverse steer period	0.788	0.622	0.555	0.181	0.278	1%
Max. lean angle	0.809	0.654	0.567	0.031	-0.024	1%

TABLE 6.16

## REGRESSION COEFFICIENTS FOR MOST SCORE

Variable	Regression coefficient	Coefficient standard deviation	Significance of coefficient estimate
Reaction time	61.4	18.0	1%
Max. turn steer angle	-1.28	0.403	1%
Reverse steer period	38.5	13.7	5%
Max. lean angle	0.327	0.268	n.s.
CONSTANT	-12.33	-	-

Note: Standard error of regression = 5.16

● Interpretation of regression for MOST score

The regression provides information on which of the measures for the obstacle avoidance task differentiate between the skilled and less-skilled riders. The first variable to be entered into the equation is Reaction Time, which explains 28.0% of the variance in MOST score. The sign of the regression coefficient indicates that a short obstacle avoidance reaction time is associated with a generally skilled performance on the MOST. The regression computed for the emergency braking task showed that an identical relationship exists between braking reaction time and MOST score. The discussion in Section 6.2.4 pertaining to reaction time applies equally here.

Maximum Turn Steer Angle was the second variable to enter the equation. Its regression coefficient indicates that a large maximum turn steer angle leads to a reduced score, i.e., a skilled performance, and vice versa. For the period during which the maximum turn steer angle occurs, the cycle is travelling in the desired direction. In order to come out of the turn it is necessary for the rider to turn the steering assembly further into the turn. The larger the maximum turn steer angle the faster will be the motion of the motorcycle towards the upright position. The correlation between maximum turn steer angle and roll acceleration at maximum roll angle (0.583) indicates this to be the case. By achieving a larger maximum turn steer angle the skilled riders can reduce the roll angle of the cycle quicker than the less-skilled riders.

The third variable to enter in the equation was reverse steer period, which explains 18.1% of the variance in MOST score. The regression coefficient indicates that a short reverse steer period is associated with a skilled performance in the MOST. It appears that skilled riders are able to achieve the desired vehicle response during the critical initial phase of the manoeuvre in a shorter time than the less-skilled riders. One advantage of this behaviour is that less time is spent, and hence less distance is covered, going in the 'wrong' direction.

Maximum Lean Angle, which was not significant, was the final variable to be entered into the equation. The estimate for the regression coefficient is positive and suggests that riders who maintain a small lean angle, i.e. keep their upper-torso in the plane of symmetry of the motorcycle, are skilled.

(c) Regression for turn success

The independent variables,  $X(i)$ , and their mean and standard deviations shown in Table 6.12 apply also for the regression for Turn Success. For the dependent variable,  $Y$ , a mean value of 0.667 was determined, indicating that two-thirds of the sample of 21 riders successfully manoeuvred around the obstacle. Table 6.17 shows the correlation coefficients between turn success and the independent variables; the correlation coefficients between the independent variables are identical to those listed in Table 6.14.

Turn Success has the highest correlation with Reaction Time ( $-0.511$ ). The discussion in the previous section relating to correlated independent variables applies equally here. The results for this regression are summarized in Tables 6.18 and 6.19.

The first variable to enter in the equation is Reaction Time, which explains 26.1% of the variance in Turn Success. The estimate for the regression coefficient suggests that riders with a short reaction time are more likely to succeed than those with a long reaction time. Clearly, the shorter the reaction time the longer the manoeuvre length available to the rider.

Maximum Lean Angle, which was not significant, was the second variable to be entered into the equation. The sign of the regression coefficient indicates that riders who maintain their upper-torso in the plane of symmetry of the motorcycle are more likely to succeed than those who do not.

Repeating the regression with the missing data variables omitted leads to a similar result for the significant variable.

TABLE 6.17

CORRELATION BETWEEN TURN SUCCESS  
AND THE INDEPENDENT VARIABLES

Independent variable	Turn success
Reaction time	-0.511
Steer torque gradient	-0.285
Reverse steer period	-0.137
Max. reverse steer angle	-0.300
Turn steer period	0.048
Max. turn steer angle	0.256
Time to max. turn steer angle	0.200
Initial roll accel'n	-0.213
Time to max. roll angle	0.057
Roll accel'n at max. roll angle	0.077
Max. lean angle	-0.242
Time to max. lean angle	0.138
Average speed	-0.102

TABLE 6.18

REGRESSION RESULTS FOR TURN SUCCESS

Variable	R	$R^2$	Estimate of population $R^2$	$\Delta R^2$	Simple r	Overall significance of regression
Reaction time	0.511	0.261	0.222	0.261	-0.511	5%
Max. lean angle	0.604	0.365	0.294	0.104	-0.242	5%



TABLE 6.19

## REGRESSION COEFFICIENTS FOR TURN SUCCESS

Variable	Regression coefficient	Coefficient standard deviation	Significance of coefficient estimate
Reaction time	-4.02	1.36	1%
Max. lean angle	-0.0341	0.0199	n.s.
CONSTANT	2.24	-	-

Note: Standard error of regression = 0.406

With the exception of Reaction Time, it appears that none of the other measures are strongly related to turn success. Indeed, upon close examination of the data traces there appear to be no apparent differences in control actions between those who failed and those who succeeded which can be associated with the unsuccessful attempts. Evidence to support this statement will be presented shortly. These results and observations are not inconsistent with those of Rice and Kunkel (1976). A part of their work was devoted to detecting differences in riding technique in a lane change task of three riders with different riding experience. Approach speed for the test, which was nominally 60 km/h, was varied at the discretion of the rider. The turn was always to the left and the course was delineated by cones. Striking a cone(s) constituted an unsuccessful run. According to Rice and Kunkel (1976):

"Failures to perform the manoeuvre are not directly identifiable from the data traces. That is, unsuccessful runs are not marked by readily discernible variations in control input patterns. In general, incorrect timing of the chosen action is seen as the principal cause of failure in this manoeuvre..."

This conclusion is not surprising when ones examines the difference in the path of travel of the cycle between a successful and unsuccessful run. For the present study, a failure is when the cycle either crosses the obstacle line or the line representing the adjacent traffic lane, and for Rice and Kunkel's test a failure occurred when a cone was struck. In both cases the difference in the lateral displacement of the cycle need only be a few centimetres!

#### 6.3.4 Ensemble Averaging

In the previous section an unsuccessful attempt was made to find quantitative measures of rider control performance which would differentiate between a skilled and a less-skilled obstacle avoidance performance. A further attempt was made to ascertain how the sequencing and form of the control and response parameters differed for riders in different 'skill' groups. This required that the runs be examined in their entirety. Ensemble averaging of the data of riders arranged into 'skill' groups was a measure used to examine the average rider control input and cycle output response.

In addition to the ensemble means, 90% confidence intervals for the mean were calculated for each data channel to give an idea of intra-group variability. It was expected that less variability (tighter confidence intervals) would be observed for the more skilled riders, consistent with the manoeuvres being executed in a more learned, uniform manner.

#### (a) Exercises 2 and 3 of the MOST

Exercises 2 and 3 of the MOST were the first tasks to be examined using this method. The analysis produced some interesting results and illustrates some important general motorcycle handling skills which are worthy of discussion. For the comparison, overall MOST score was adopted as the measure of skill. Several score groups were established and the data of the riders in these groups were averaged. A typical data trace for steer torque, steer angle and roll angle of the motorcycle for a skilled rider performing exercises 2 and 3 of the

MOST is shown in Figure 6.13. Figure 6.14 shows the path which the rider had to follow. The times at which points A and F on the path was reached are indicated in Figure 6.13. The rider was required to start from rest at A, negotiate the sharp right hand turn from B to C and then accelerate in the larger radius turn D-E, reaching approximately 32 km/h at point F. The speed trace for this particular rider (not shown) revealed a uniformly increasing speed, reaching 40 km/h at F. Other traces recorded but not shown in this example are roll rate, yaw rate, rider lean relative to the motorcycle, rear brake force and front brake force.

If the rider is to achieve the positive roll angle (to the right) necessary for tracking the right turn, the initial steering displacement must be negative (anti-clockwise). This initial steering displacement, seen on the trace to be opposite that of the intended turn direction, causes the front wheel to track to the left and the motorcycle to roll to the right. As the equilibrium roll angle for the turn is approached the rider must provide a positive steer displacement, into the turn, to match the equilibrium turn conditions. This process can be seen on the traces between 0.0 and 2.5 seconds. The test motorcycle has a handling characteristic at this speed such that, if the cycle has a positive roll angle, the steering assembly tends to fall into the turn, causing the cycle to reduce its roll angle and return to the vertical position. Thus, if the rider is to maintain a constant roll angle through the sharp right-hand turn, a constant negative steer torque must be applied. In Figure 6.13, the positive steer angle, roll angle and negative steer torque for the right-hand turn can be seen occurring during the time interval 1.0 to 3.0 seconds. In order to return the cycle to the upright position to negotiate the first straight section on the course (C to D), the rider simply reduces the applied steer torque allowing the front wheel to track further to the right and the cycle as a result approach the vertical position. The rider's next task is to accelerate to 32 km/h whilst following the long right-hand curve. As the motorcycle's speed is increased in the curve two changes occur: Firstly the inertia forces acting laterally on the motorcycle increase; secondly the handling characteristics of the motorcycle change.

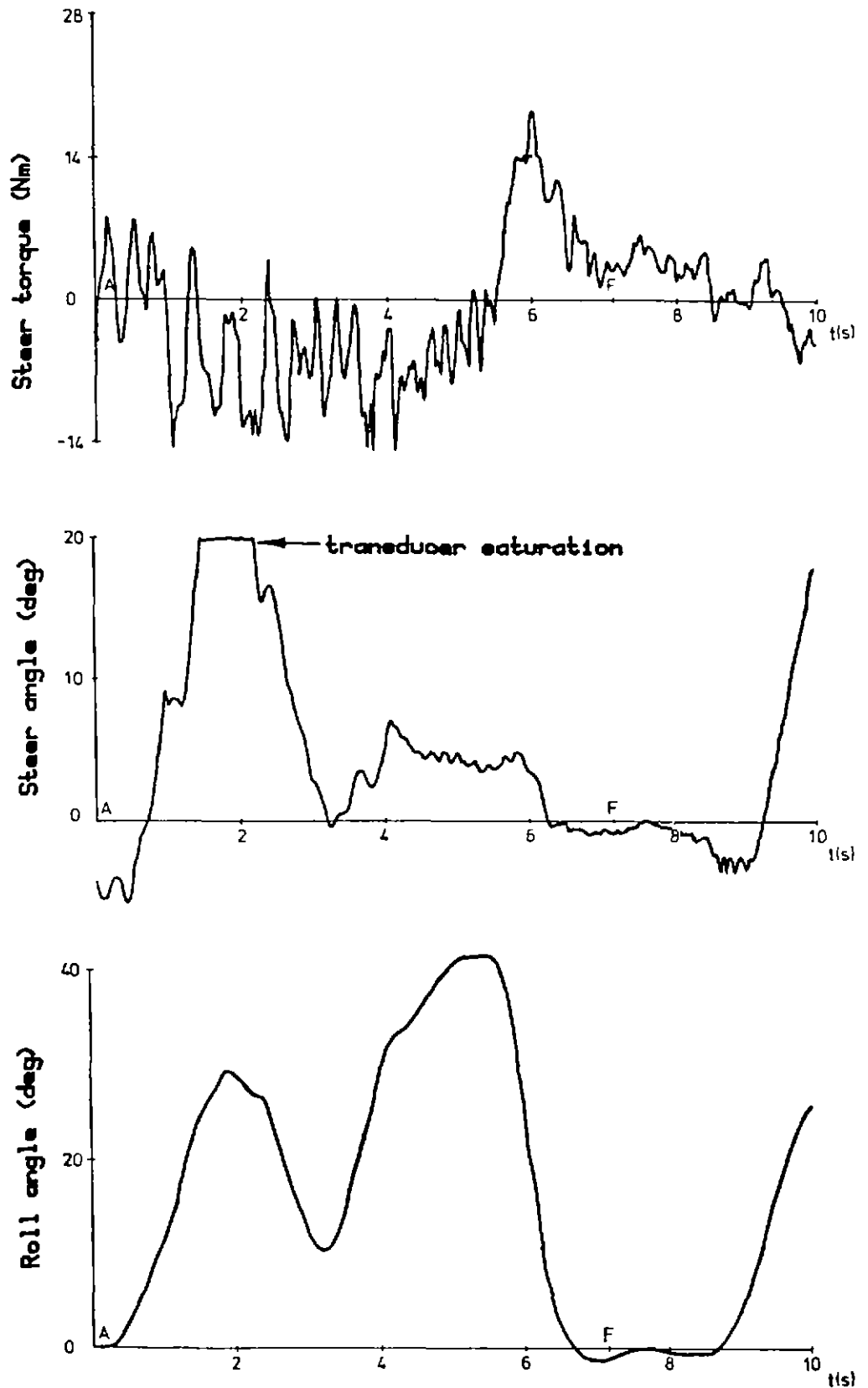


Figure 6.13 Steer torque, steer angle and roll angle data traces as a function of time for a highly skilled rider; exercises 2 and 3.

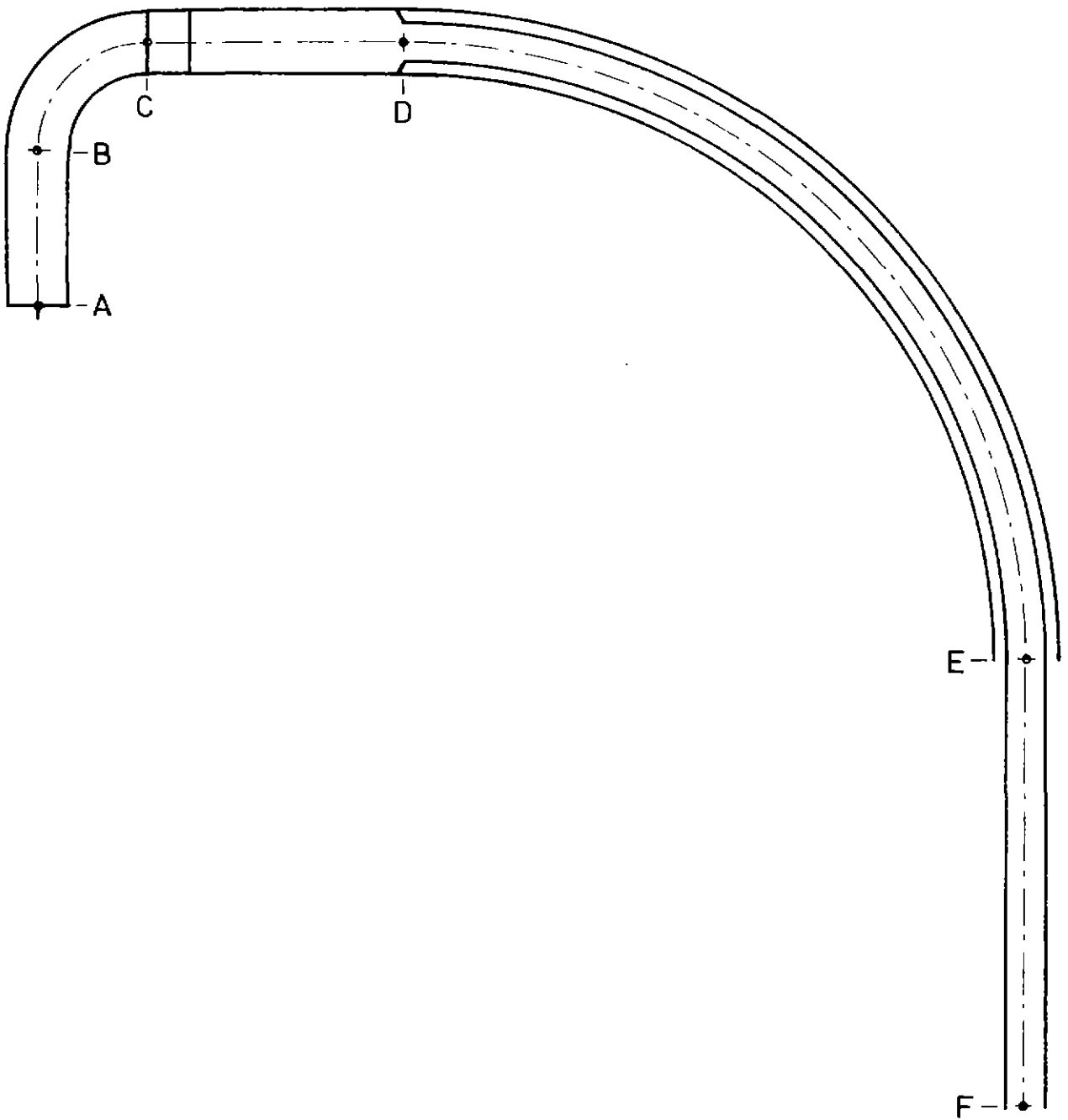


Figure 6.14 Schematic of course for exercises 2, 3, 4 and 5 showing the position of points A to F on the path centreline.

The rider must compensate for the changing equilibrium conditions and motorcycle characteristics by providing control inputs to increase the roll angle. From Figure 6.13 it can be seen that as the rider accelerates in the turn (beyond the 4.0 second time point) both steer torque and steer angle control inputs are decreasing. This is consistent with the data of Figure 3.7 in Section 3.3.3 (a) which shows that the steer torque requirement per degree of roll angle decreases as speed and lateral acceleration increase for this speed range. Note that the data of Figure 3.7 correspond to steady state conditions and only approximate the time varying behaviour of the variables in Figure 6.13.

As the rider approaches the straight section EF the cycle must return to the upright position. This is accomplished by this particular rider very rapidly by applying a large reverse steer torque at the 5.5 s mark. This produces an increase in steering displacement causing the front wheel to track quickly to the right. A very rapid reduction in roll angle results, closely followed by a reduction in steer displacement, as required for the final straight section of the course. It will be seen subsequently that the reverse steer torque control input used by this rider to come out of the turn at E is not typical of all riders.

The data traces were first averaged over time. However, by averaging in this manner much information is lost since riders perform the manoeuvres at differing speeds and are on different parts of the course at different points in time. Therefore in this particular case averaging over time yields little information regarding averaged performance of the group.

A more realistic representation was obtained by transforming the data from being a function of time to being a function of position on the course (distance). This means that comparisons would be made between riders when at the same point on the course.

For exercises 2 and 3, and 4 and 5, times were recorded for performing the manoeuvre (a normal part of the MOST). For exercises 2 and 3 the time taken to travel from point A to F (see Figure 6.14) was recorded, and for exercises 4 and 5 the time to travel from F to C. This manoeuvre time was used in a transformation program to establish the beginning and ending point for the manoeuvre. To transform the data the speed trace occurring between these two points was integrated, divided into equi-distant intervals, and the data for each channel corresponding to each distance point determined. For exercises 2 and 3 a data point was determined for approximately every 5 cm on the manoeuvre path. Using the exercise time to demarcate the beginning and end of the manoeuvre meant that deviations due to some riders covering more distance between A-F were reduced. The run shown in Figure 6.13 for exercises 2 and 3 is shown transformed in Figure 6.15, points A to F being indicated on the distance axis. The transformed run gives a 'better picture' of what is occurring on the course.

A comparison of the results for the best (0 to 3 penalty points assigned) and worst (greater than 20 penalty points assigned) scoring groups is shown in Figures 6.16 (a) through 6.16 (g). Each group is composed of the data of 9 subjects. Several points of interest are noteworthy from the data in the figures:

#### Steer Torque Plots (Figure 6.16(a)) -

- The 90% confidence band for the >20 group is wider, indicating more inter-rider variability, in particular for the B to D interval; i.e. in the sharp right-hand turn. The 0 to 3 group therefore exhibit a more precisely co-ordinated and consistent performance.
- There is a marked difference in the steer torque control input between groups around point E on the course. Group 0 to 3 show a definite reverse steer torque application. The >20 group tend to reduce the applied steer torque gradually. What this means is that the 0 to 3 group apply the appropriate steering inputs for the desired manoeuvre that will make the motorcycle respond most quickly. The >20 group, by reducing the applied steer torque allow this

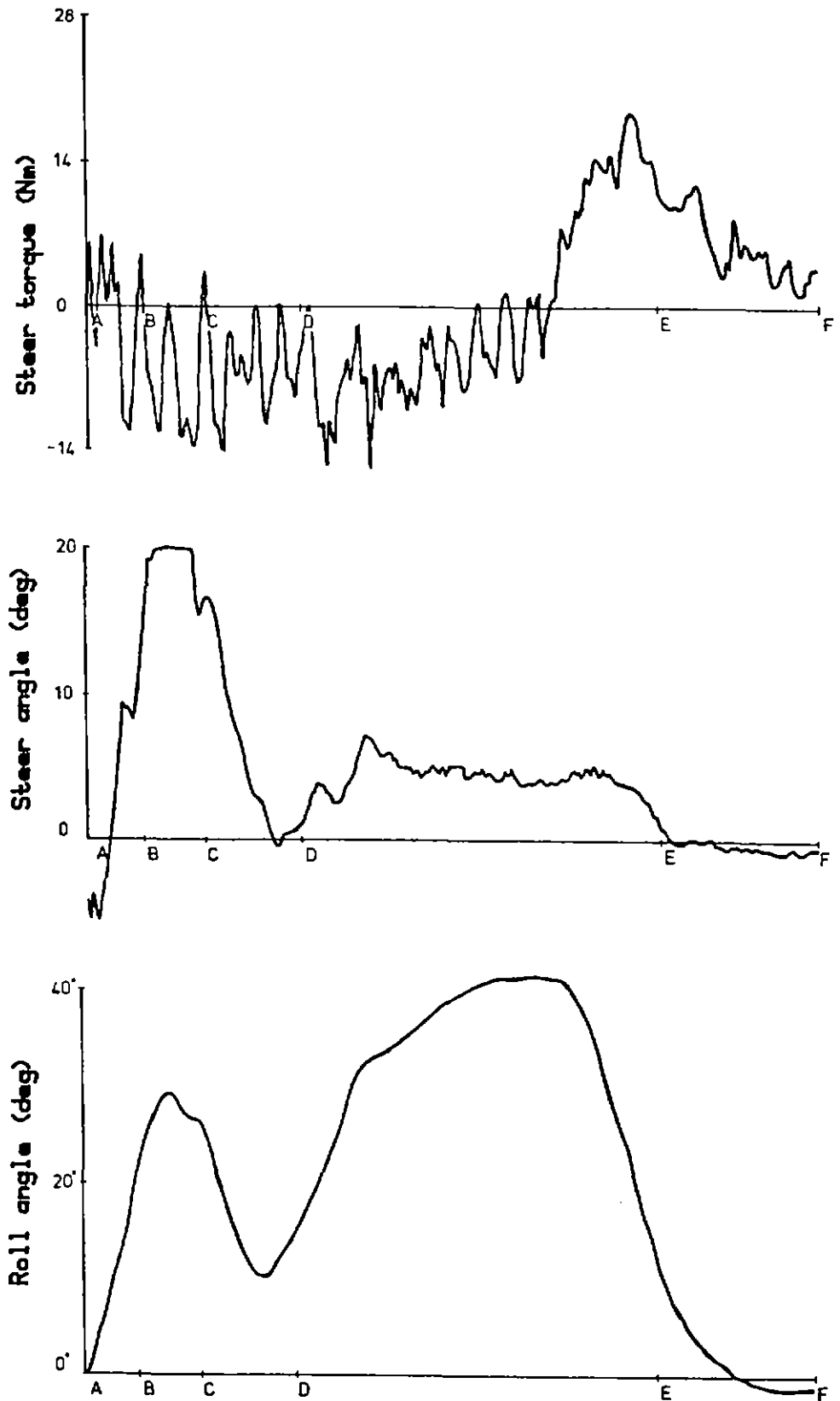


Figure 6.15 Traces shown in figure 6.13 transformed to being a function of distance.



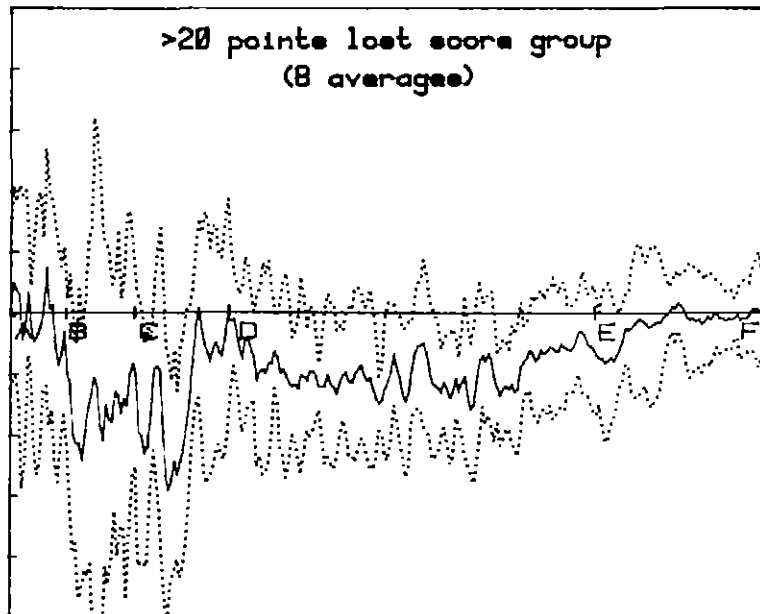
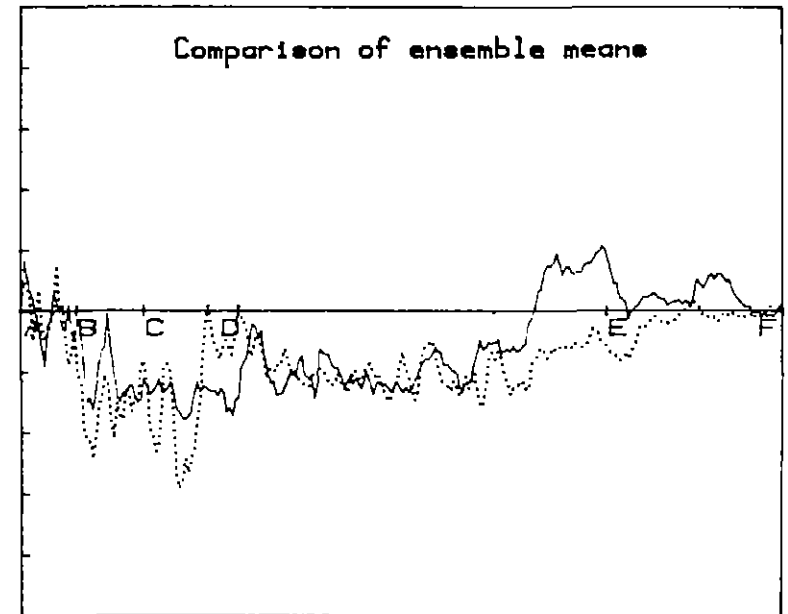
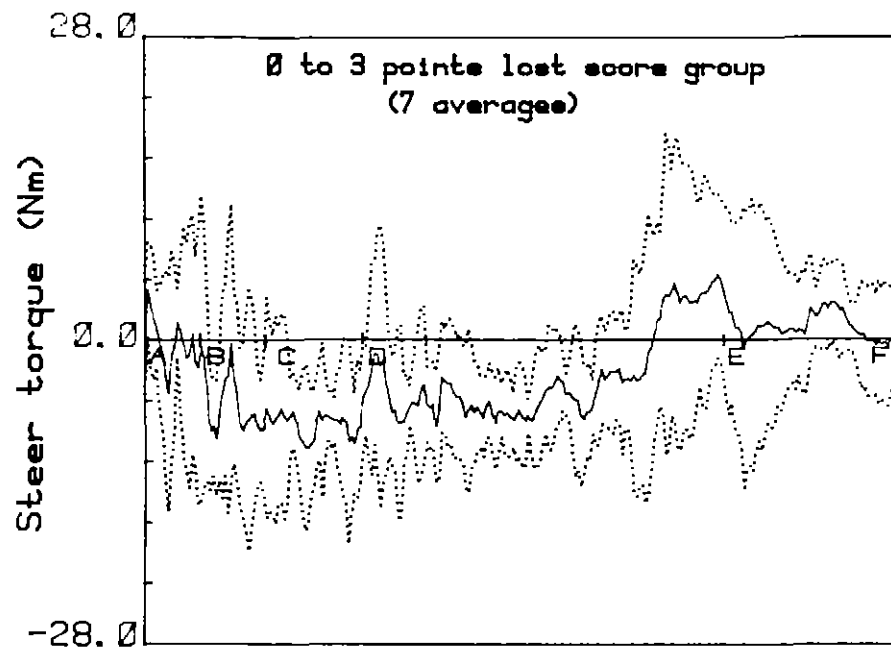


Figure 6.16 (a) Comparison of steer torque ensemble averages of two score groups for exercises 2 and 3 in the MOST.

particular motorcycle to do what it would naturally tend to do: i.e. turn the steering assembly further into the turn and hence reduce the motorcycle's roll angle. The better group are therefore aware, at some level, of how to make the motorcycle respond more quickly by applying a reverse steer input.

#### Steer Angle Plots (Figure 6.16(b)) -

- Smoother transition between C-D for the 0 to 3 group.
- More rapid steering input at point E for 0 to 3 group due to large reverse steer torque input.

#### Roll Rate Plots (Figure 6.16(c)) -

- Amplitudes much larger and overall performance smoother for 0 to 3 group.
- Peak at E twice as large for 0 to 3 group.
- Roll rate sign positive over longer distance between D-E for 0 to 3 group.

#### Yaw Rate Plots (Figure 6.16(d)) -

- Generally higher yaw rate values for 0 to 3 group.

#### Measured Rider Lean Plots (Figure 6.16(e)) -

- Lean angles for the 0 to 3 group are larger over the distance between B and D. Behaviour is different near point E. Note that there may be some error in the measured lean trace (see Appendix J).

#### Roll Angle (Figure 6.16(f)) -

- Much larger for 0 to 3 group.

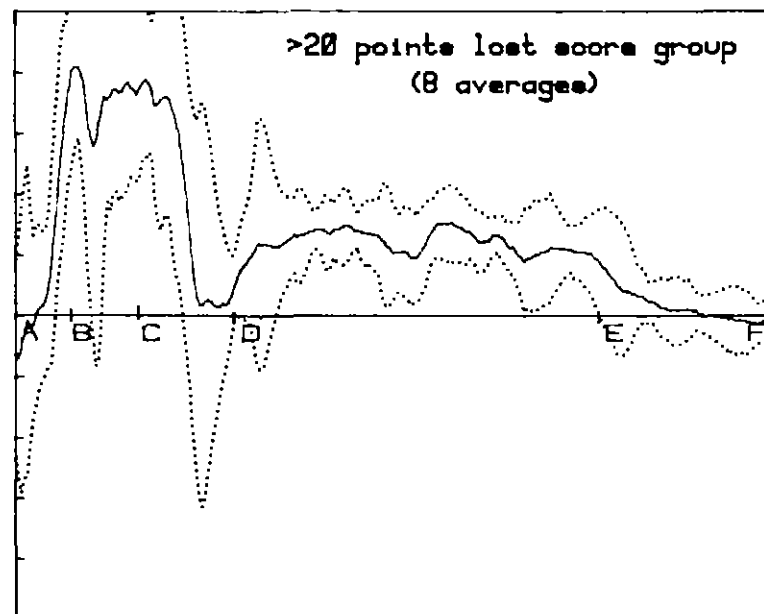
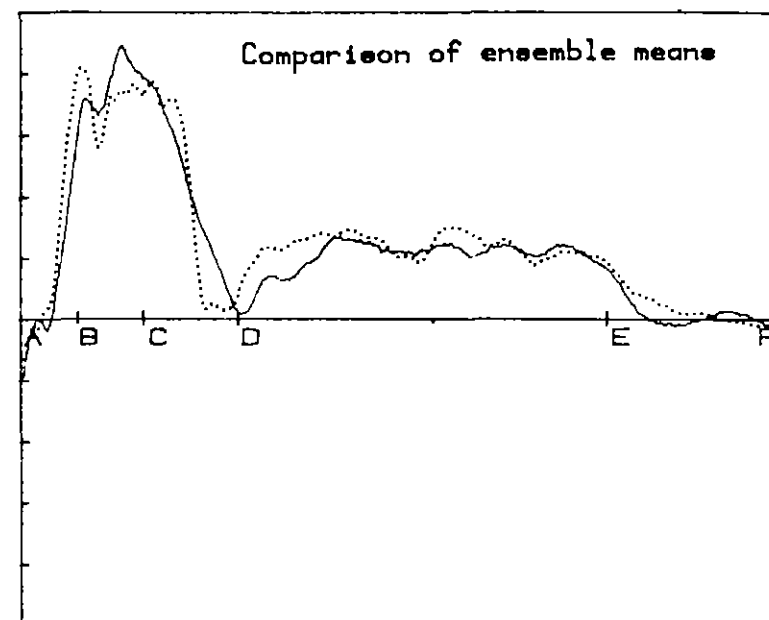
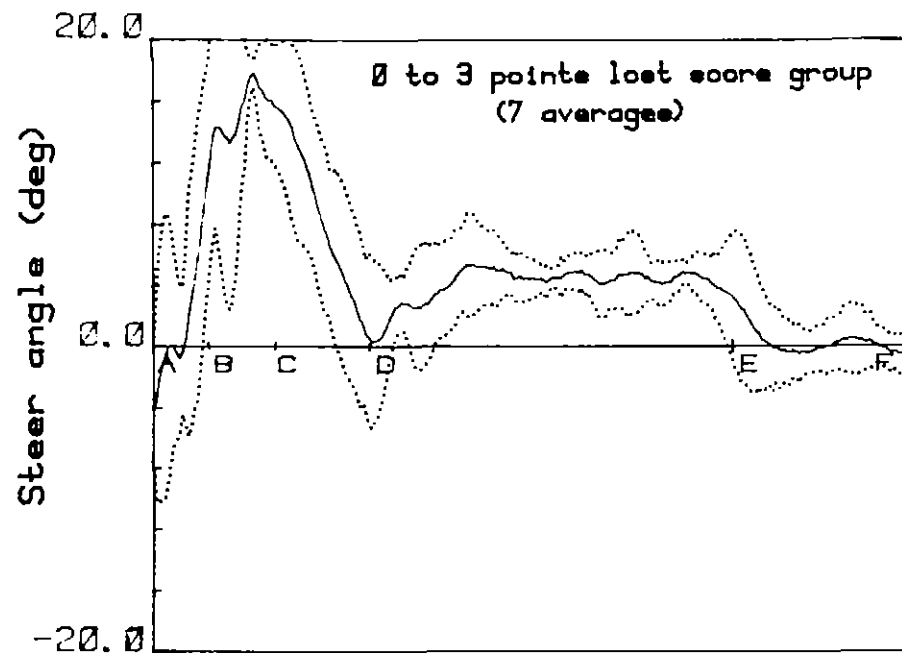


Figure 6.16 (b) Comparison of steer angle ensemble averages of two score groups for exercises 2 and 3 in the MOST.

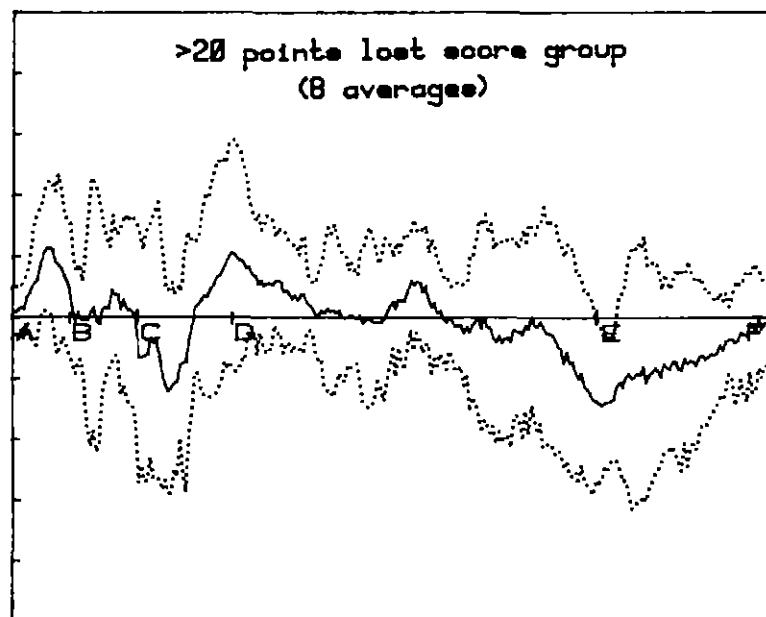
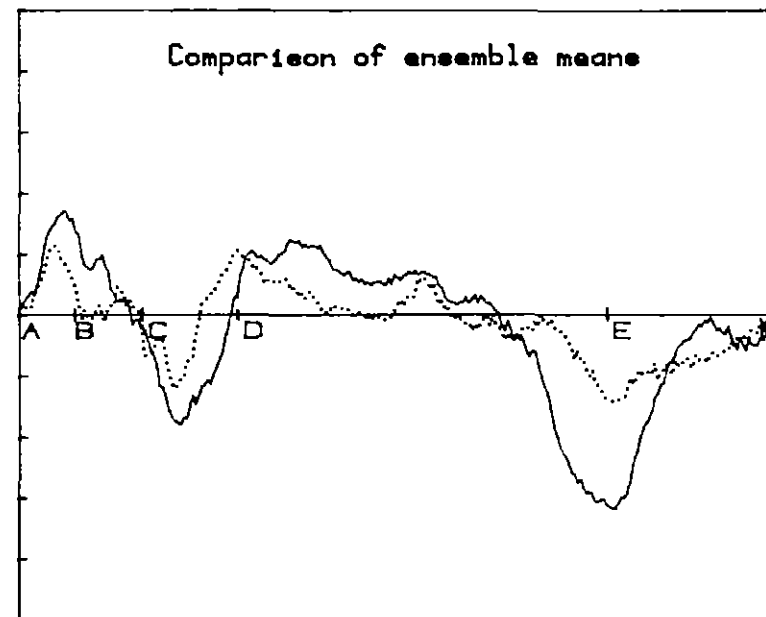
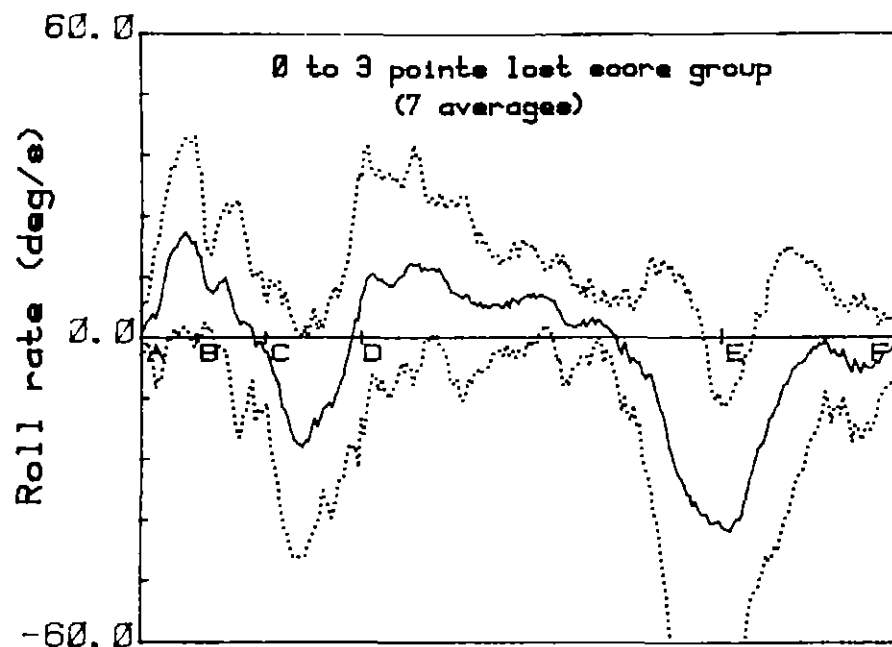


Figure 6.16 (c) Comparison of roll rate ensemble averages of two score groups for exercises 2 and 3 in the MOST.

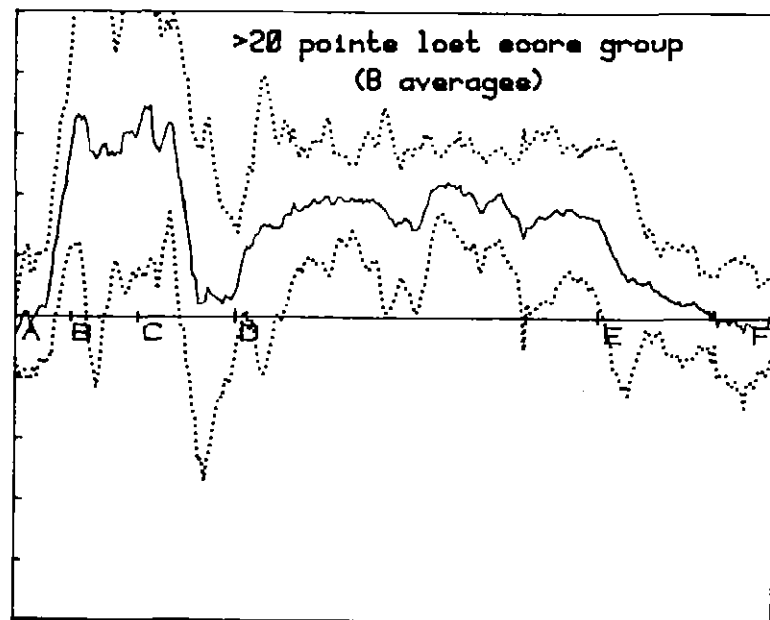
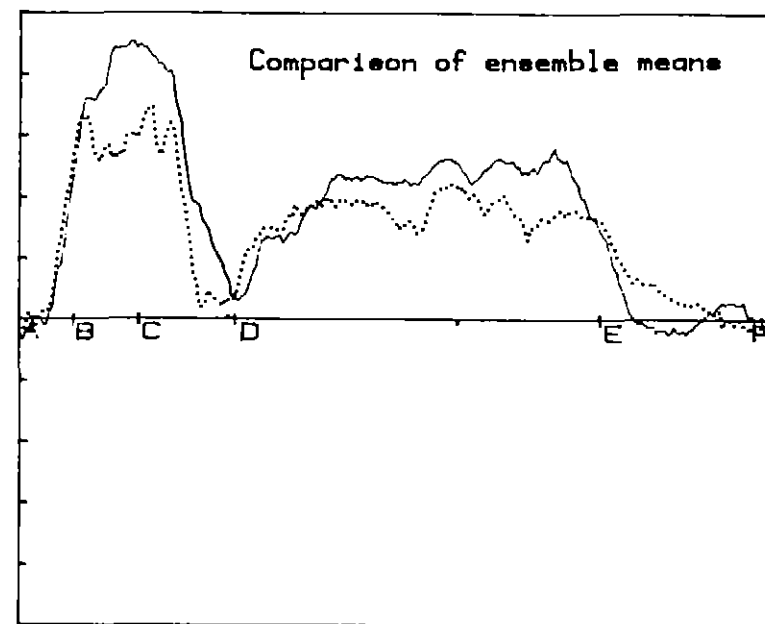
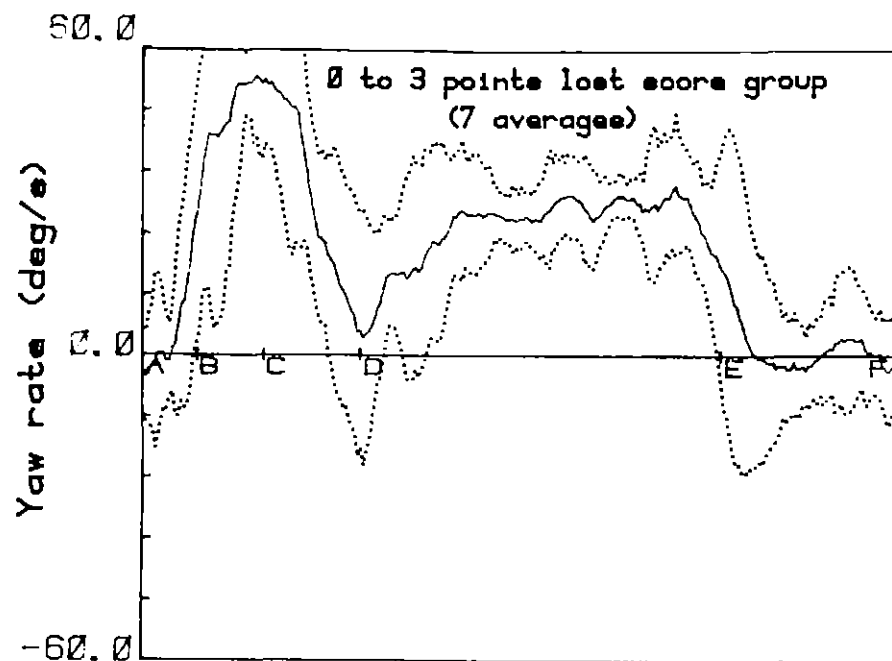


Figure 6.16 (d) Comparison of yaw rate ensemble averages of two score groups for exercises 2 and 3 in the MOST.

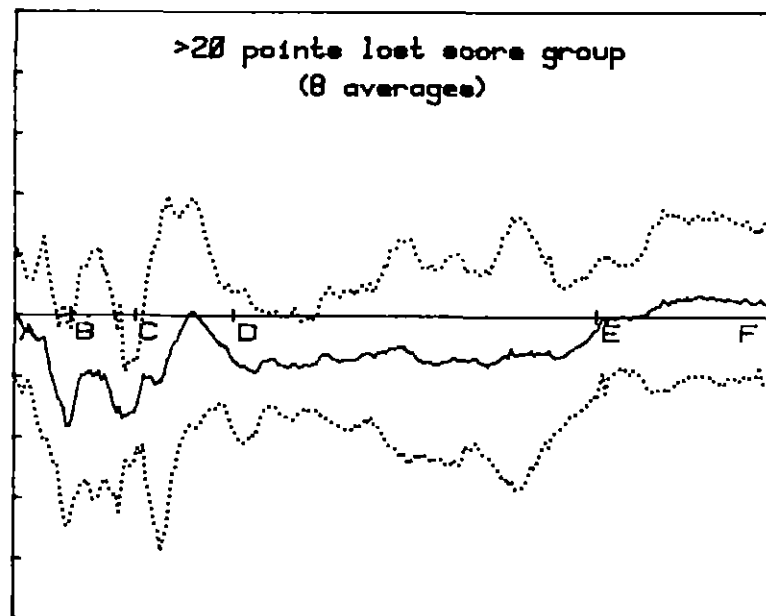
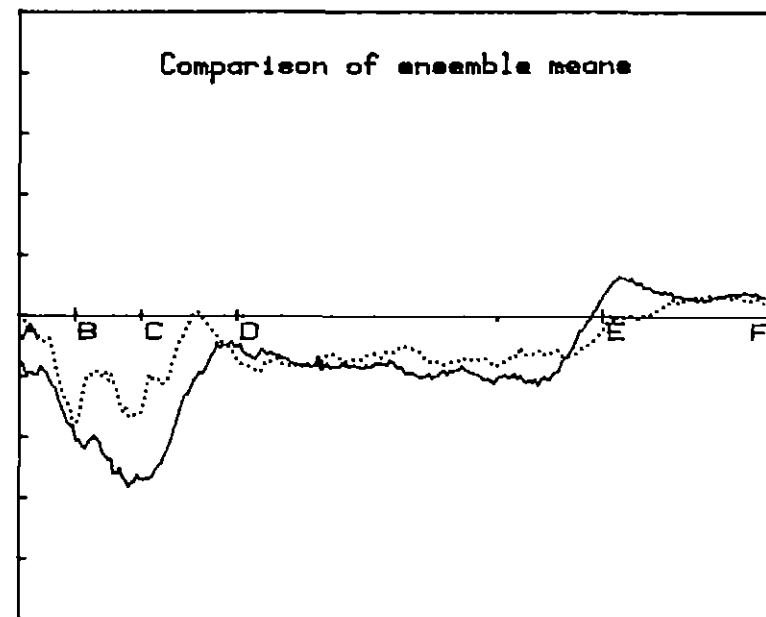
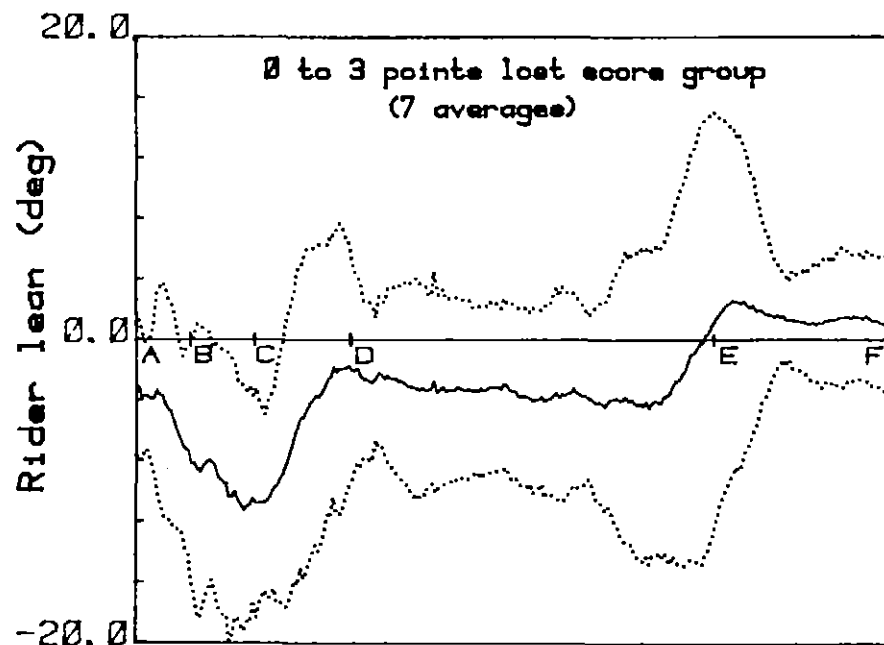


Figure 6.16 (e) Comparison of rider lean ensemble averages of two score groups for exercises 2 and 3 in the MOST.

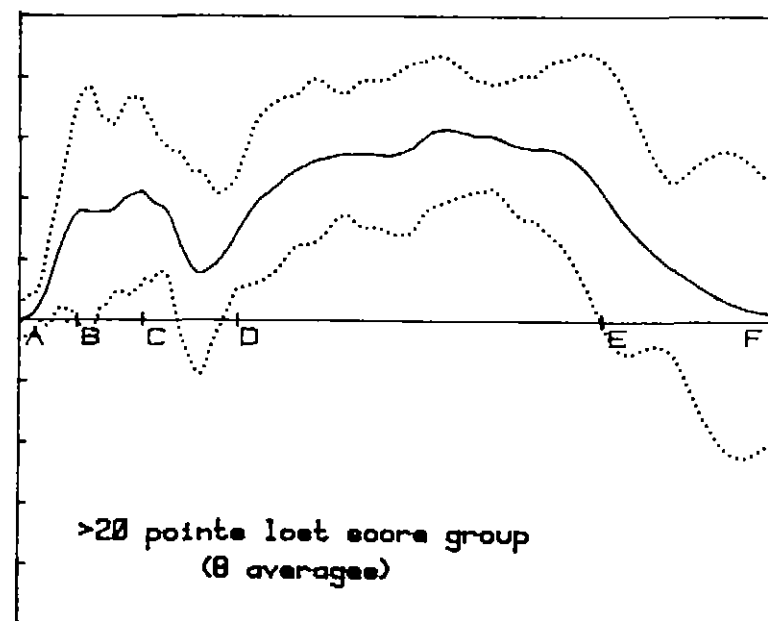
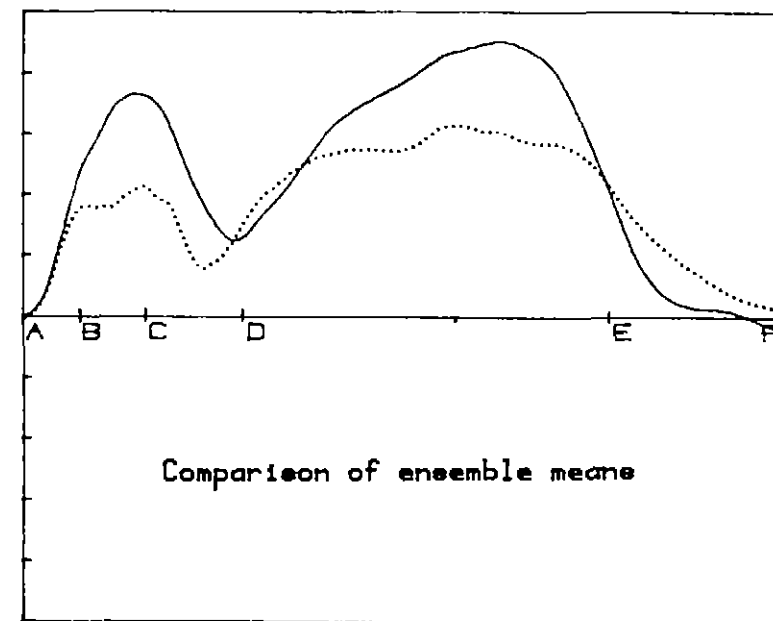
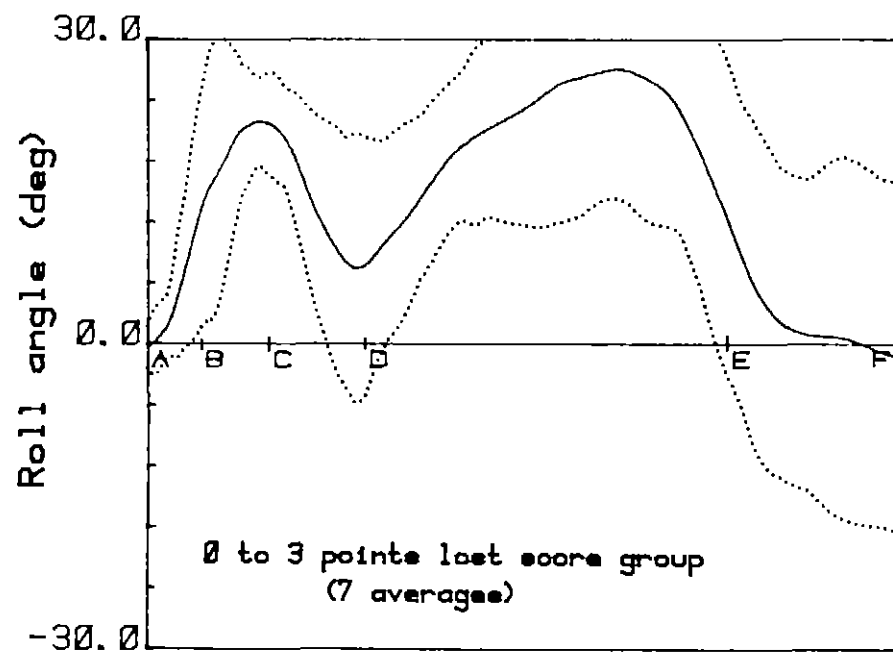


Figure 6.16 (f) Comparison of roll angle ensemble averages of two score groups for exercises 2 and 3 in the MOST.

Speed (Figure 6.16(g)) -

- Higher for the 0 to 3 group.

Making similar comparisons for the other groups does not reveal a consistent trend between the behaviours of the least- and most-skilled groups. Rather, the largest difference seems to be between the poorest group (>20) and the rest. Generally it can be said that the more skilled riders generated larger motion quantities, and more rapidly. In part, they achieved this through the application of definite 'reverse steer' inputs at the appropriate times.

(b) Obstacle avoidance exercise

The data for the sample of 21 riders used in the regression analysis of Section 6.3.3 (a) were used for comparing the averaged behaviour of riders for this task. Data for other riders were not used for reasons identical to those given in that section. The same two measures of skill described earlier, namely overall MOST score and Turn Success, were used and the sample was divided into two groups for each measure. The averaged control and response parameters of the two groups for each measure were then compared.

For the first comparison riders were divided by MOST score into the following two groups; those assigned 10 penalty points or less formed the first group (the assumed more-skilled group) and the remaining riders formed the second group. A score of 10 was chosen because it is the mean score for the sample. As the runs for the sample of riders are composed of both left and right turn data, it was necessary to invert either the right or left turn data to increase the sample size of each group. The right turn data traces were inverted to have the same form as the left turn data. It is assumed that there is little difference between riders performing a left- and right-hand obstacle turn. Recall from Chapter 4 that it was shown, for the present sample of riders, that the difference between the success rates for the two turn directions was statistically not significant.



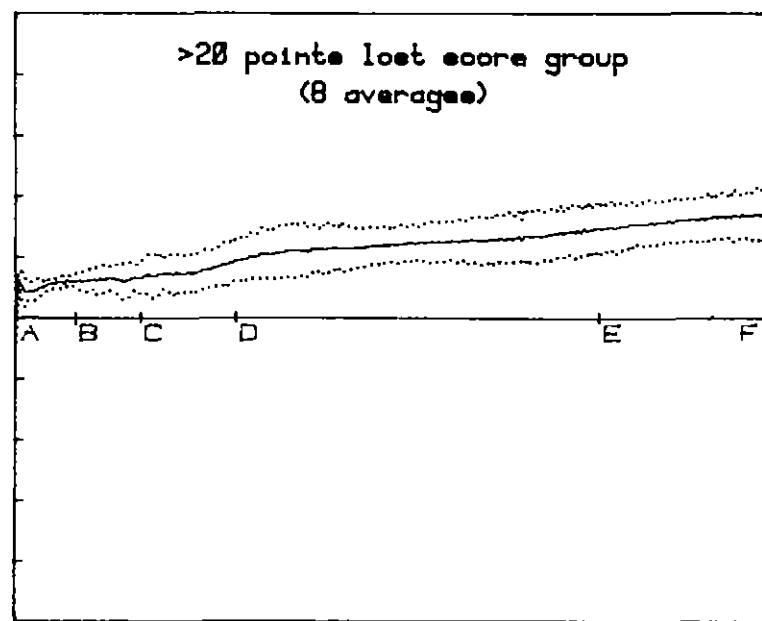
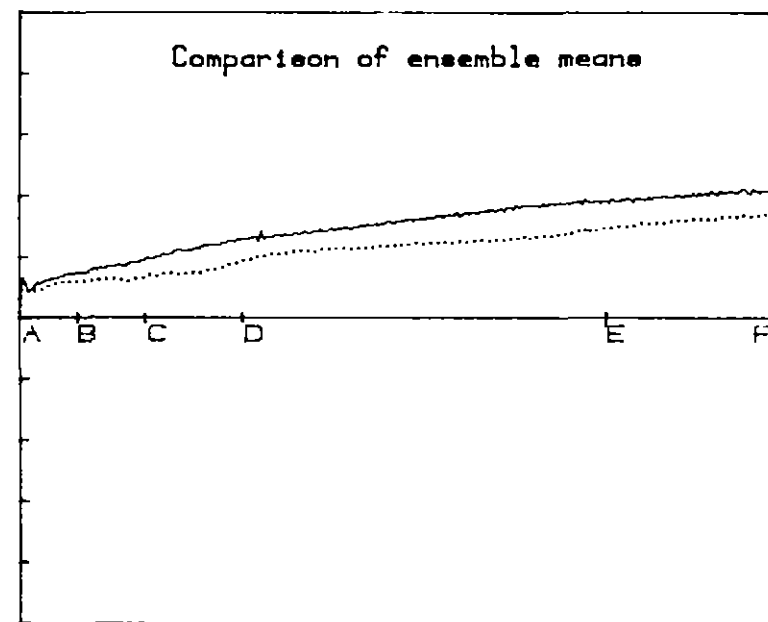
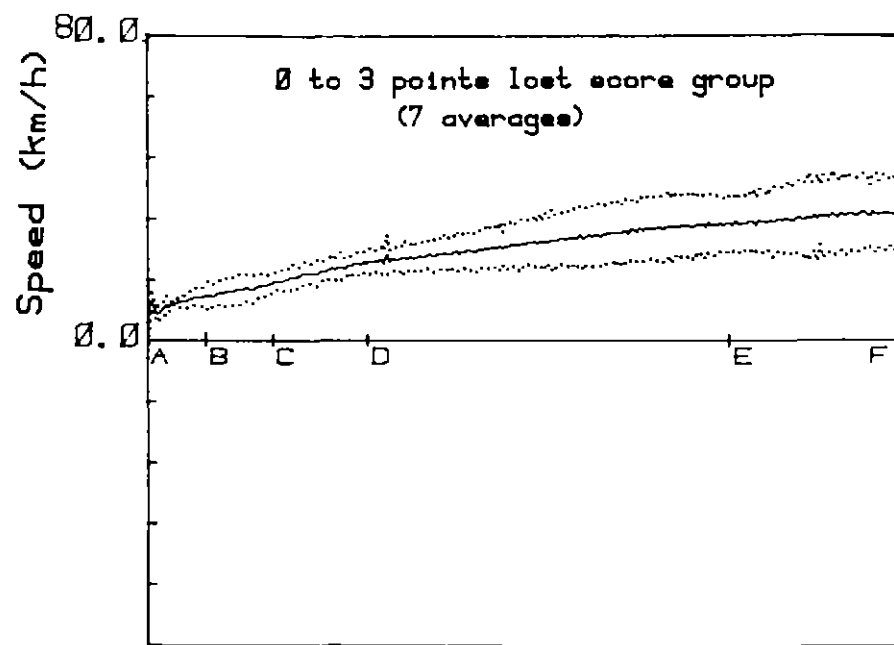


Figure 6.16 (g) Comparison of speed ensemble averages of two score groups for exercises 2 and 3 in the MOST.

For similar reasons to those given in the previous section the data were transformed to being a function of distance. The data were transformed from the data point corresponding to where, on the course, the signal lights were activated, to where the motorcycle had moved a distance of 18 m (60 ft) along the path of travel. This is the section of the course over which the manoeuvre is performed (see Appendix D). Note that the path of travel for any two riders is not the same and hence the position of the cycle after 18 m of travel will be different. However, because the maximum lateral displacement of the cycle is small (3 m) compared to its longitudinal displacement (18 m), the difference in final position of the cycle for different travel paths will, in general, be minimal.

Figures 6.17 and 6.18 show the ensemble averages and 90% confidence intervals for the mean of the various data traces of the two score groups. Note that the ensemble data for the roll and yaw rate traces are inaccurate around the maxima because, as mentioned earlier, for some of the runs the motion quantities were beyond the sensing range of the transducers. The ensemble data for roll angle is therefore not shown because it is derived from the roll rate data.

The confidence intervals for the two groups indicate that there is as much variation between the control and response parameters of the riders in the skilled group as for those in the less-skilled group. It is of interest to compare how the variation in the control and response variables for a group of riders differs from the variation in these parameters for successive runs of a single rider, i.e. is there as much variation between different riders as there is between the runs of a single rider? Figure 6.19 shows the ensemble average and 90% confidence interval of the various data traces for 5 left-hand obstacle turns, for a single rider, performed as part of the AST. The rider was classified as skilled by MOST and AST scores. The traces in Figure 6.19 show that there is very little difference between the magnitude and timing of the control and response parameters for the successive runs of the rider. By contrast, averaged data for a less-skilled rider, not shown, indicates that there is as much variation in these parameters between runs as there is in the runs of

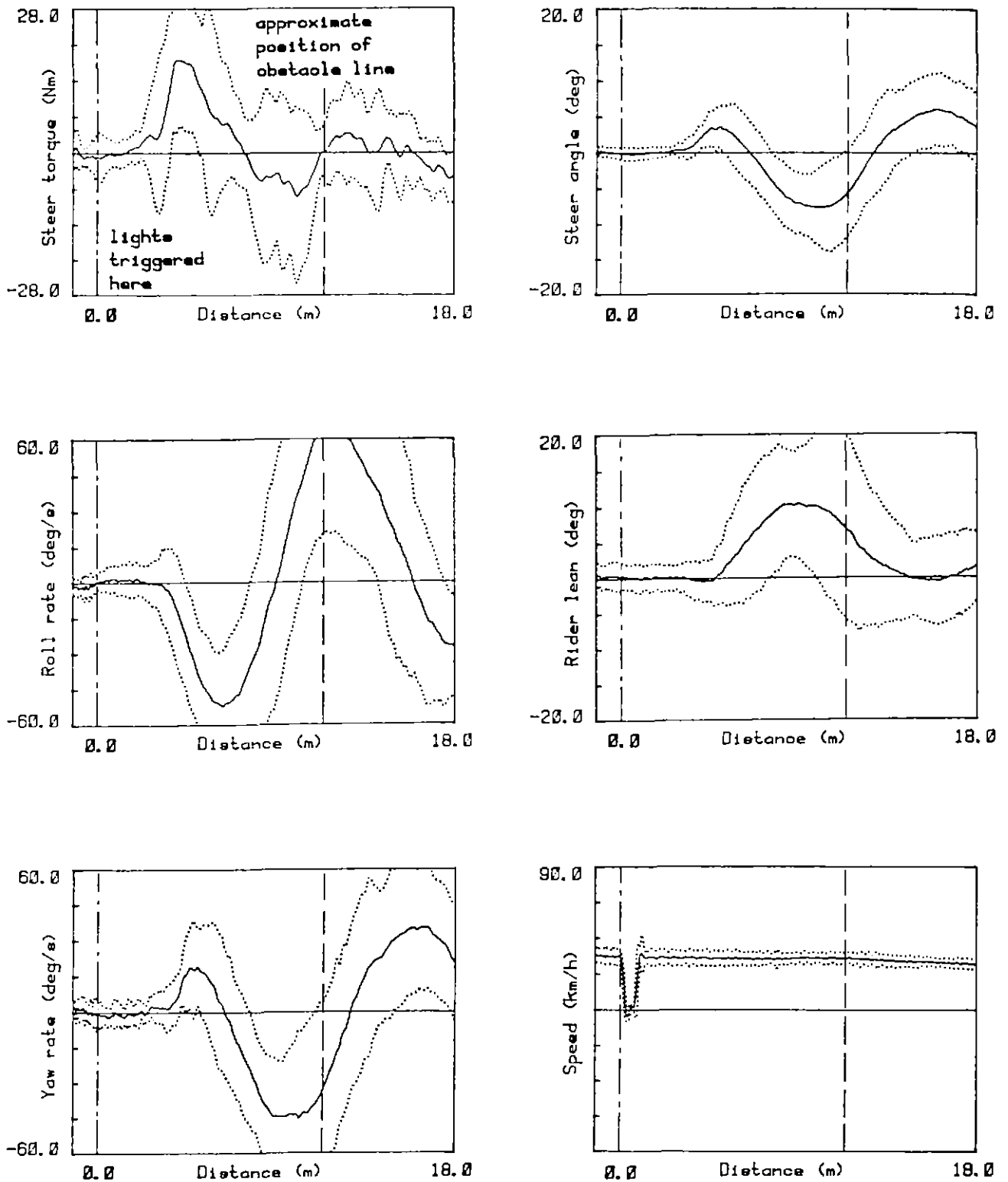


Figure 6.17 Ensemble averages for the obstacle avoidance task of the data traces of riders assigned more than 10 penalty points (9 averages).

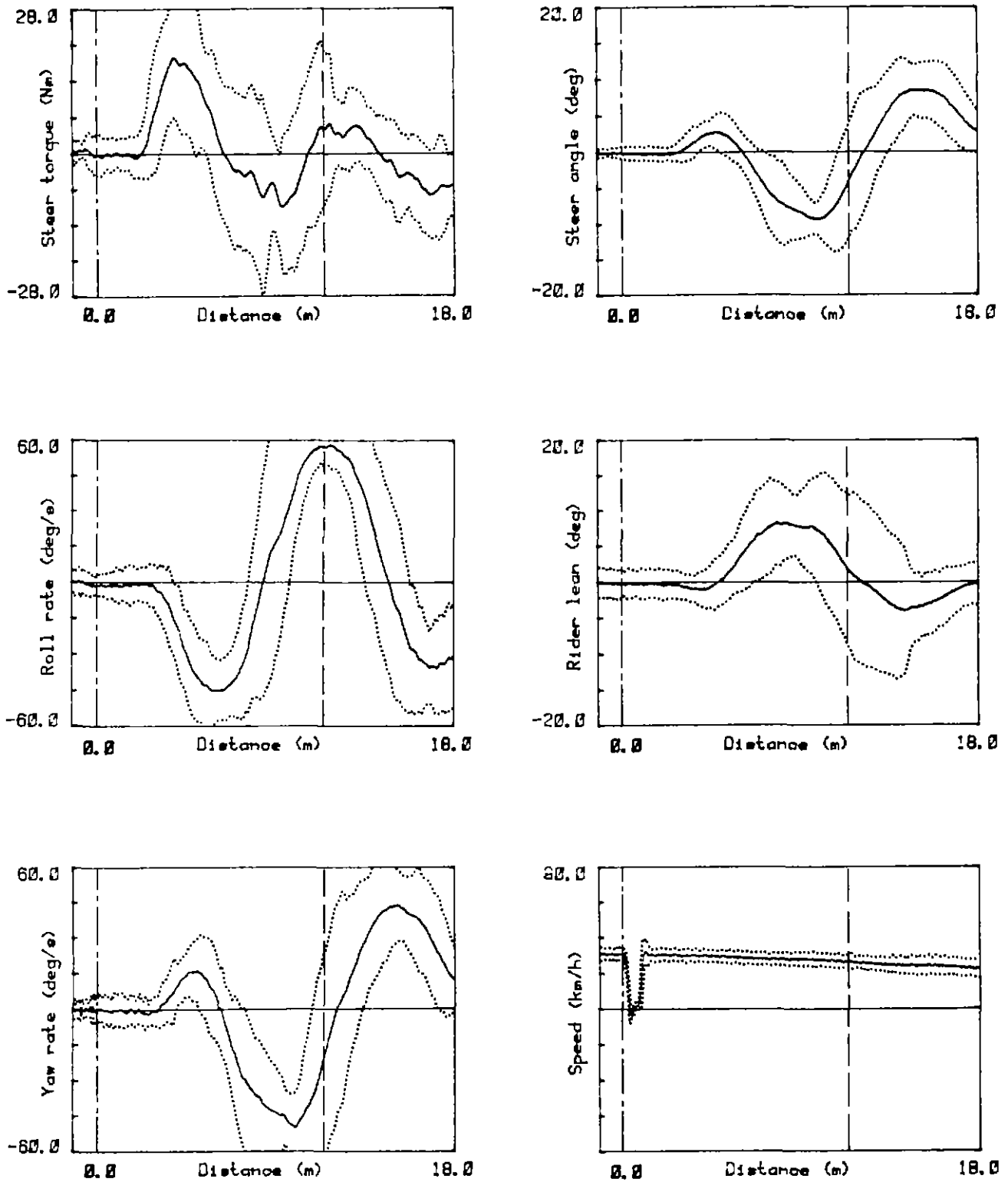


Figure 6.18 Ensemble averages for the obstacle avoidance task of the data traces of riders assigned 10 or less penalty points (12 averages).

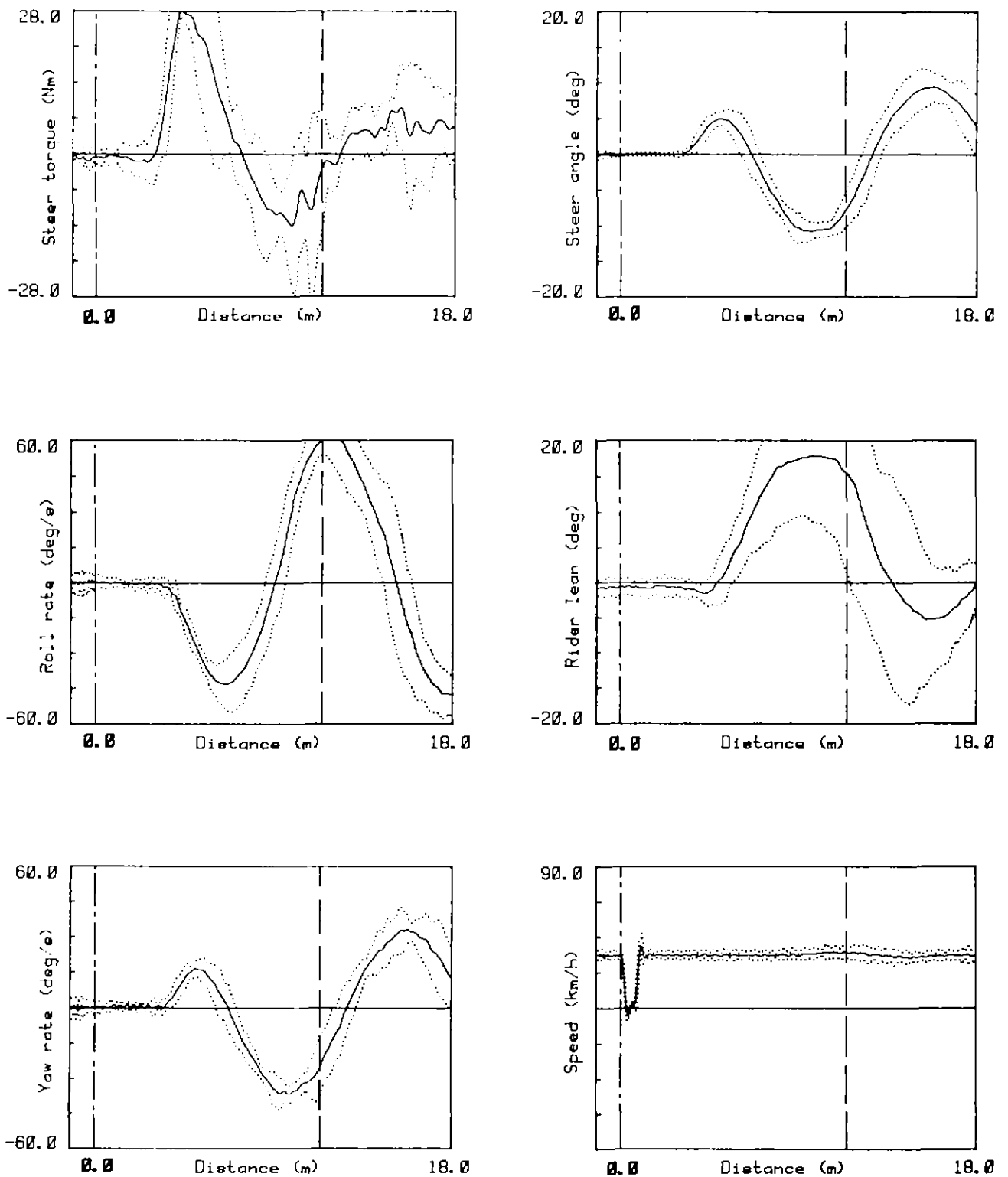


Figure 6.19 Ensemble averages and 90% confidence intervals of the obstacle avoidance data traces of a skilled rider.

riders of the two groups shown in Figures 6.17 and 6.18. The fact that the variation in the control and response parameters of the most skilled group is no different to that of the less-skilled group is not inconsistent with the above observation. When one considers the sources of variation between riders, such as reaction time, tolerance on manoeuvre path (the path width between the obstacle line and adjacent boundary line is about 1.8 m), and the likelihood of riders using different skilled strategies to achieve the same end, it is not unlikely that the manoeuvring paths of a group of skilled riders, the riders of which each have small inter-run variability, will differ.

Figure 6.20 shows a comparison of the ensemble means for the two score groups. Shown also in the figures is the approximate position of the obstacle line. The traces show that the skilled riders reacted slightly quicker than the less-skilled ones. The general form of the traces is identical and there are only small differences in the amplitude of the control and response quantities. The significance of these differences was discussed in the regression section, Section 6.3.3 (b). The position of the zero crossings for all of the variables reveals that the skilled riders performed the manoeuvre in a shorter distance than the less-skilled ones.

The sequencing of the control inputs, namely steer torque and angle and rider lean, are next examined by way of Figures 6.21(a) and (b) which show the ensemble means of these variables superposed. One of the interesting features of the data is the phasing between the three variables. Rider lean and steer torque are almost exactly out of phase for both the skilled and less-skilled riders. Leaning relative to the motorcycle, to the right say, is accompanied by an anticlockwise steering torque, and vice versa. Similarly, rider lean and steer angle are also out-of-phase but rider lean is seen to lead steer angle. This behaviour is examined in more detail in Section 6.3.5 where it is shown that the coupling between rider lean and steer torque is stronger for the less-skilled riders.

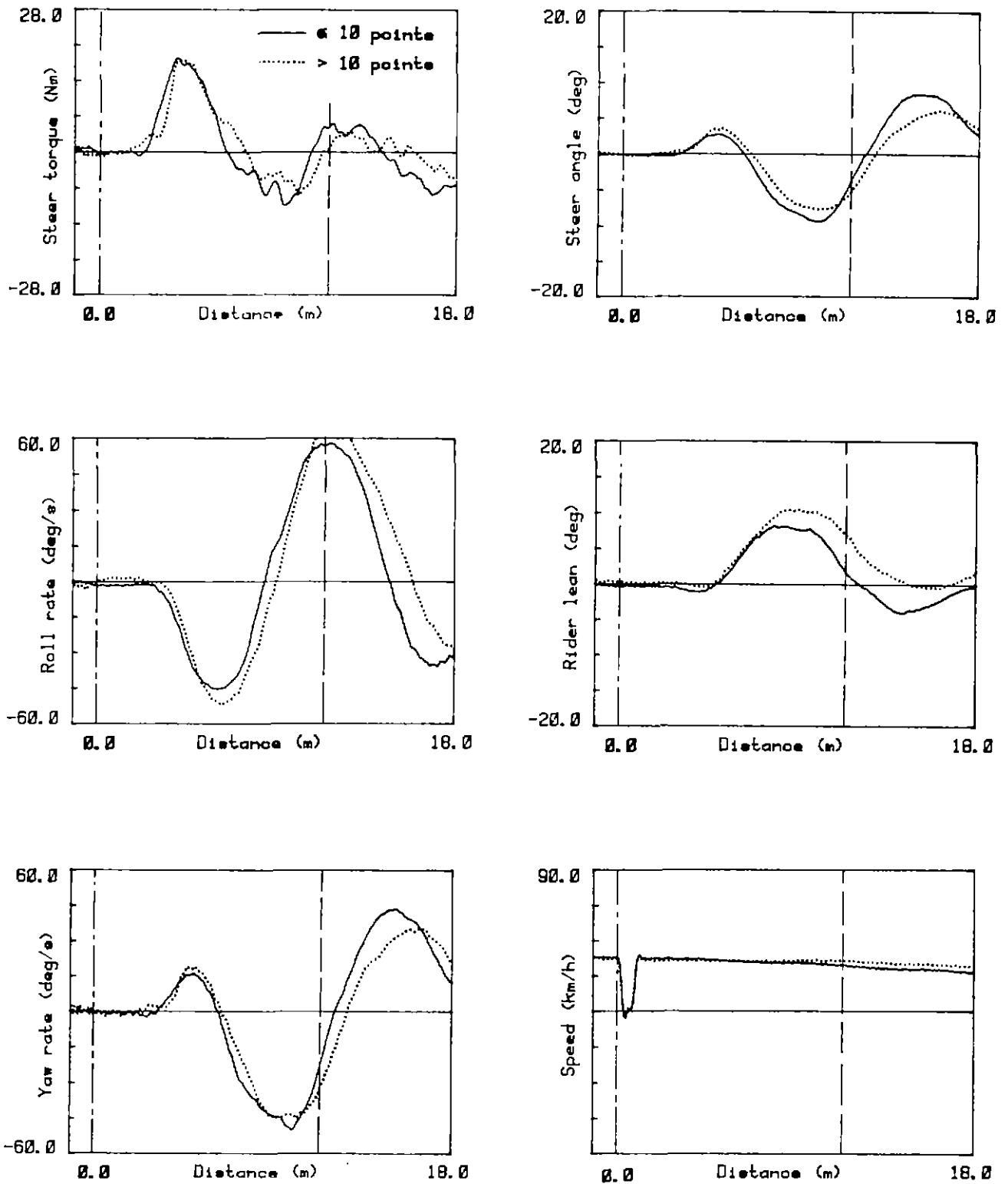


Figure 6.20 Comparison of the ensemble means of the two score groups shown in figures 6.17 and 6.18.

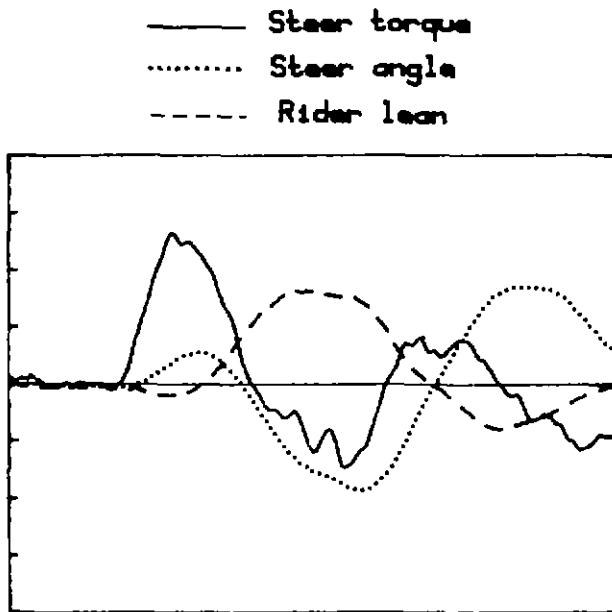


Figure 6.21 (a) Comparison of steer torque and angle, and rider lean averages for the riders who were assigned 10 or less penalty points.

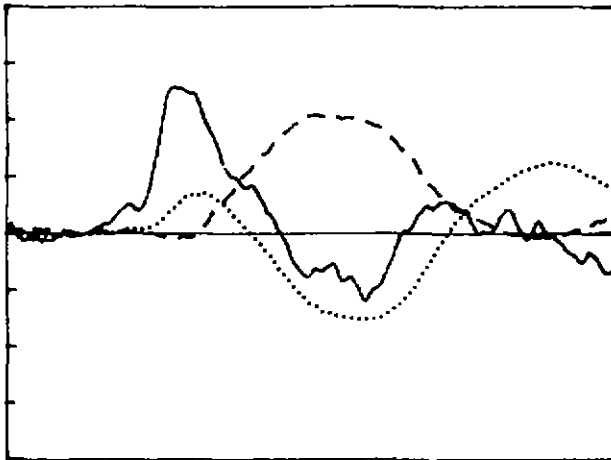


Figure 6.21 (b) Comparison for the riders assigned more than 10 penalty points.



The second comparison was between the ensemble averages of those riders who succeeded and those who failed to avoid the obstacle. Figures 6.22 and 6.23 show the data traces for these two groups and Figure 6.24 a comparison of the ensemble means. Once again there is no apparent difference between the width of the confidence intervals for all of the data traces with the exception of rider lean. For the unsuccessful group the mean rider lean input is larger and there is more variation in the leaning behaviour between riders. The similarity in the sequencing and form of the control inputs, apart from the rider lean difference, for the two groups is remarkable. In fact the only difference between success and failure seems to be that those riders who failed took longer to react. Note that this is consistent with the regression result of Section 6.3.3 (c).

#### 6.3.5 Data Traces and Two-Variable Plots

##### (a) Rider data traces

The steer torque and rider lean traces were first examined to see how riders differ in their utilization of these two control means to initiate the obstacle turn. A large number of the riders attempting the manoeuvre commenced the turn with a steering torque input which was applied independently of body lean. The data in Figure 6.25 is presented as an example of this behaviour. A smaller number of riders leaned their upper body into the turn and simultaneously applied a steer torque input. This behaviour is exemplified in the data of Figure 6.26. The data in this figure show that leaning to the right is accompanied by an anti-clockwise application of steer torque. There was not a single case where the turn was initiated by lean alone. The data shown in Figure 6.25 are for a rider who, on the basis of his MOST score, was classified as skilled. His attempt at manoeuvring to avoid the obstacle was successful. The data in Figure 6.26 is for a less-skilled rider whose attempt was unsuccessful. The traces presented in Figure 6.25 are typical of those for the skilled riders tested. For the less-skilled riders the data in the two figures represent extremes of behaviour.

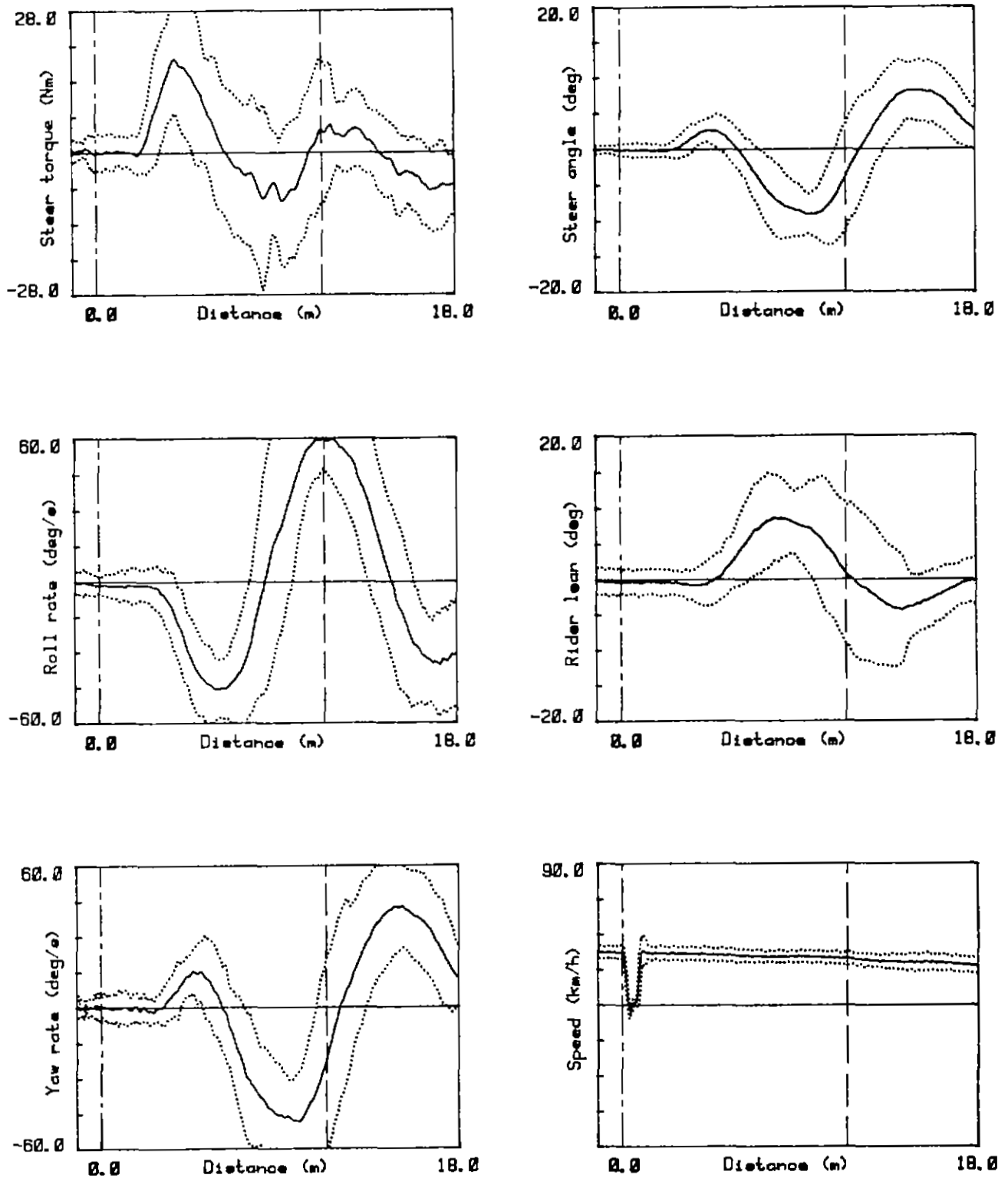


Figure 6.22 Ensemble averages for the obstacle avoidance task of the data traces of those riders who successfully manoeuvred around the 'obstacle' (14 averages).

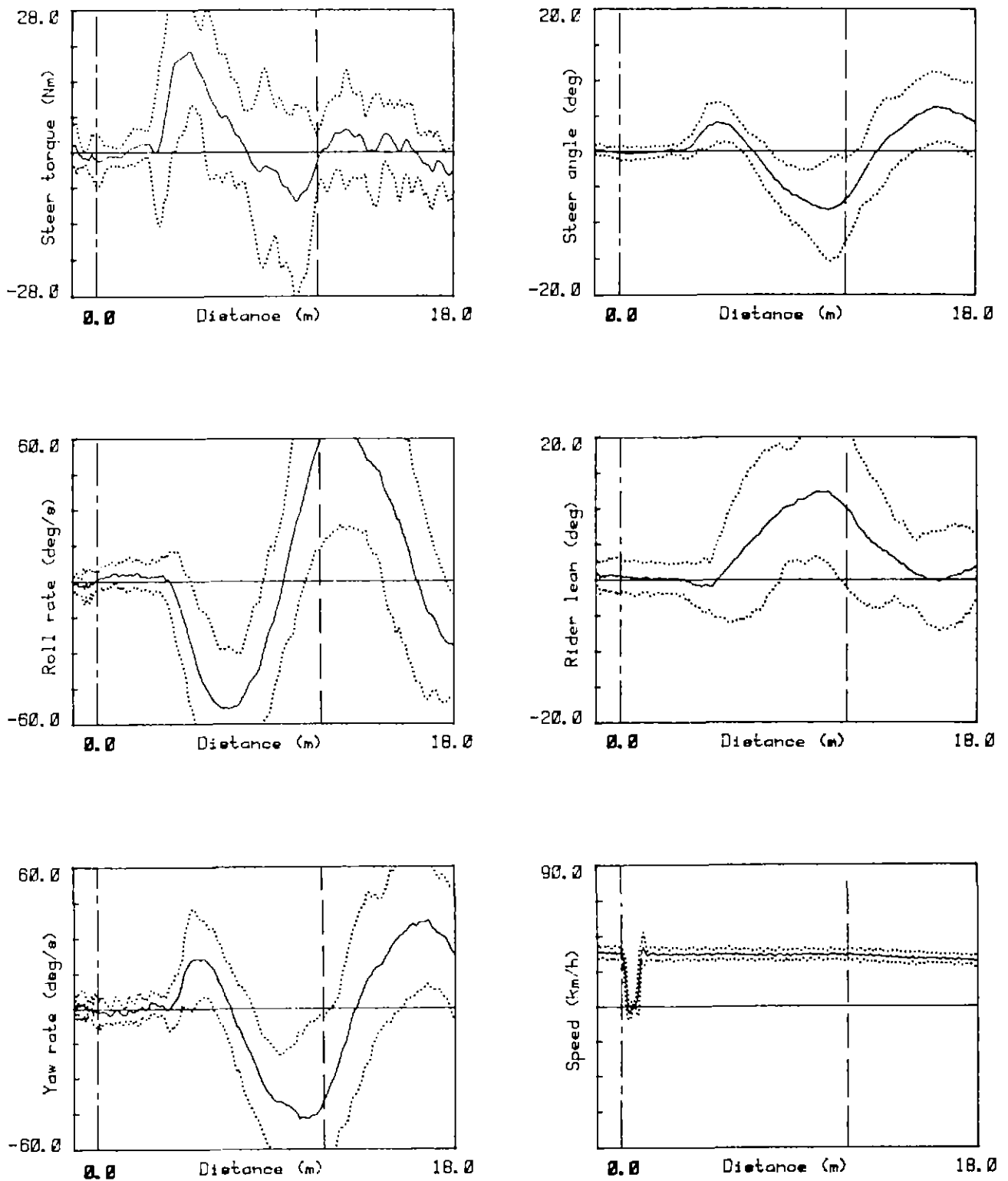


Figure 6.23 Data traces of those riders who were unsuccessful in manoeuvring to avoid the 'obstacle' (7 averages).

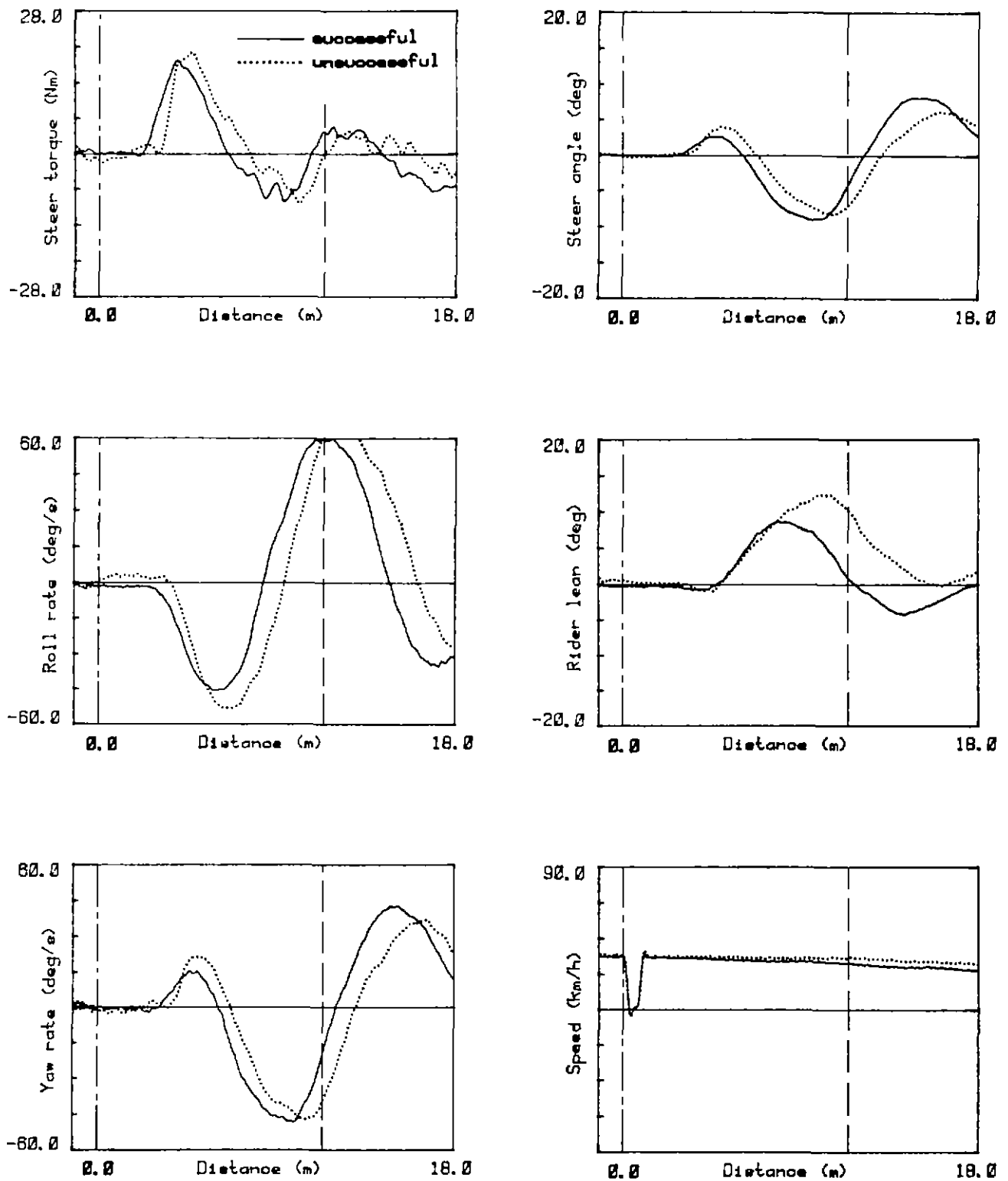


Figure 6.24 Comparison of ensemble means of the successful and unsuccessful obstacle avoidance groups.

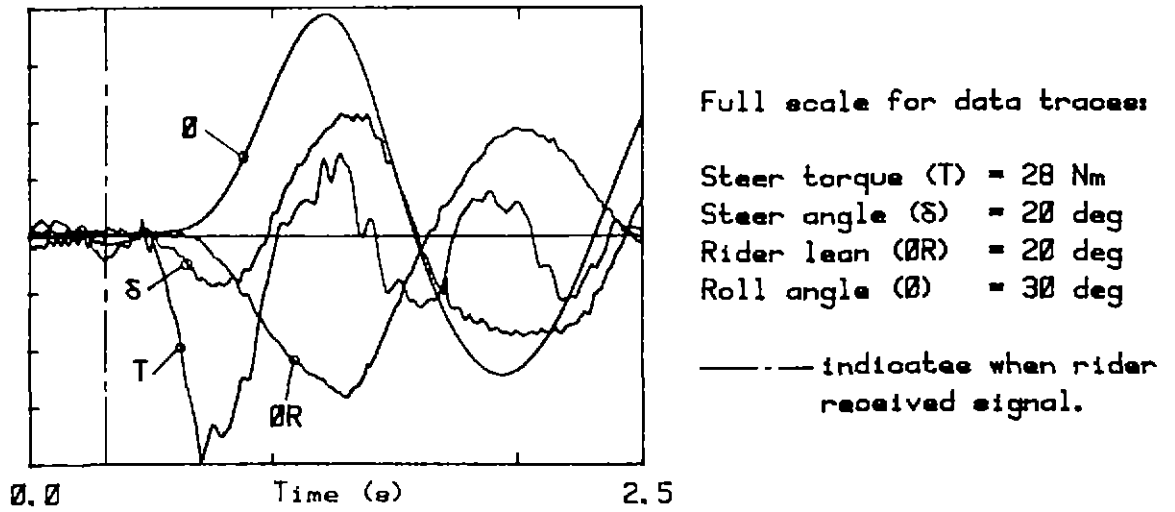


Figure 6.25 Obstacle avoidance data traces for a skilled rider.

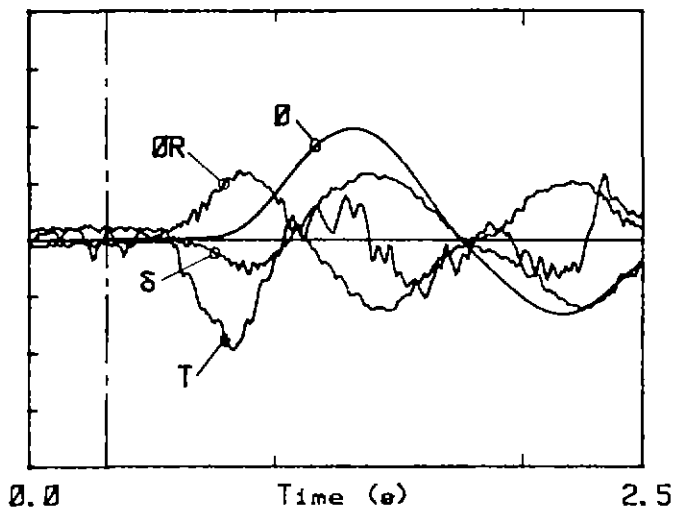


Figure 6.26 Obstacle avoidance data traces for a less-skilled rider.

Similar observations were made by Rice and Kunkel (1976) and their comments are pertinent to this discussion:

"One of the interesting features of these [novice rider] runs, however, is the phasing between applied steer torque and rider lean angle - each torque application is accompanied by an opposing lean motion. This phasing apparently brings the steering deflection more closely in phase with steer torque than is indicated in the data traces of the more experienced riders."

Following the initial control inputs, for the two examples shown, steer angle and rider lean remain closely coupled, and opposite in sign for the duration of the manoeuvre. Steer torque takes a slightly different course. The steer torque transducer was mounted between the handlebar and steering assembly and thereby measured the resultant of the torques applied by the rider and those due to the inertia forces and external forces acting on the steering assembly. These forces change as the roll angle of the motorcycle changes.

To demonstrate the assertion that a stronger coupling between the leaning and steering inputs is associated with less-skilled riders, two measures of coupling between leaning and steering inputs were devised and their relationship to MOST score was examined. The first measure was a correlation coefficient between the digitized rider lean and steer angle data pairs, the second a correlation coefficient between rider lean and steer torque. The data for the sample of 21 riders were available for the first measure, whereas the data for only 14 riders were available for the second measure because of clipping of the steer torque signal. Correlation coefficients between the first and second measures and MOST score were calculated as, respectively, -0.056 and -0.537. The second measure, i.e. lean-torque coupling, is seen to be more strongly related to MOST score. Its sign indicates that a large negative correlation coefficient, that is strong coupling, is associated with a less-skilled performance, and a value close to zero (as the range for the lean-torque coupling correlation coefficient for subjects varies from 0.029 to -0.665) is associated

with a skilled performance on the MOST. Multiple regressions were computed to check the relationship between overall MOST score and the measures listed in Table 6.13 with each of the two measures included separately. The results indicate that lean-torque coupling is a significant variable (the overall regression and the estimate for the regression coefficient being significant at the 5% level of significance) and the direction of the relationship with MOST score is as indicated above. Two other variables were also in the equation, however the estimates for their regression coefficients were not significant. Note that lean-torque coupling and reaction time, which are both moderately correlated with MOST score, are also moderately correlated with each other ( $-0.515$ ) and, once either of these two variables is entered into the equation the other will not appear in the equation because it only explains an insignificant proportion of the unexplained variance (see Section 6.2.4 on the problem of multicollinearity). Rider lean and steer angle coupling, on the other hand, was found to not be a significant variable when it was used as a predictor of MOST score together with the other variables. It is interesting to note that the coupling between rider lean and steer angle was quite high for all of the subjects with correlation coefficients in the range  $-0.343$  to  $-0.911$  and a mean value of  $-0.767$ .

This result indicates that a coupling exists between the less-skilled riders' leaning motion and steer torque inputs as suggested earlier. A mechanism is proposed in Section 6.3.8 which provides an explanation for this behaviour.

#### (b) Cross-plots

The data for all of the riders (MOST and AST) were next plotted in two-variable format and examined. A cross-plot of control parameters, such as steer torque and rider lean, provides information on the phasing between the control variables. Plots of control and response parameters give information on the phasing of inputs with respect to vehicle motion. Both are a means of comparing rider behaviour in a specific task (Rice, 1978).

The data shown in Figures 6.25 and 6.26 are examples which, it is believed, contain the important features of the obstacle turn data observed in most of the subject runs. Cross-plots of the control and response variable from these two examples are given in Figures 6.27(a), (b) and (c), and 6.28(a), (b) and (c). The time parameter is indicated in each plot by the arrows and numbers. Note that these numbers indicate the direction of increasing time and are only used as points of reference for the subsequent discussion; they are not equal intervals of time. Attention is drawn to the following features of these plots:

- Rider lean versus steer torque (Figures 6.27(a) and 6.28(a))

The two methods of initiating the turn discussed earlier are clearly visible in the cross-plots (points 0,1 and 2). Except for differences in the control variable magnitudes, the remaining portion of the two plots are similar. Note that for the more difficult obstacle turns, e.g. level 2 of the AST, steer torque was found to be, in general, larger in magnitude.

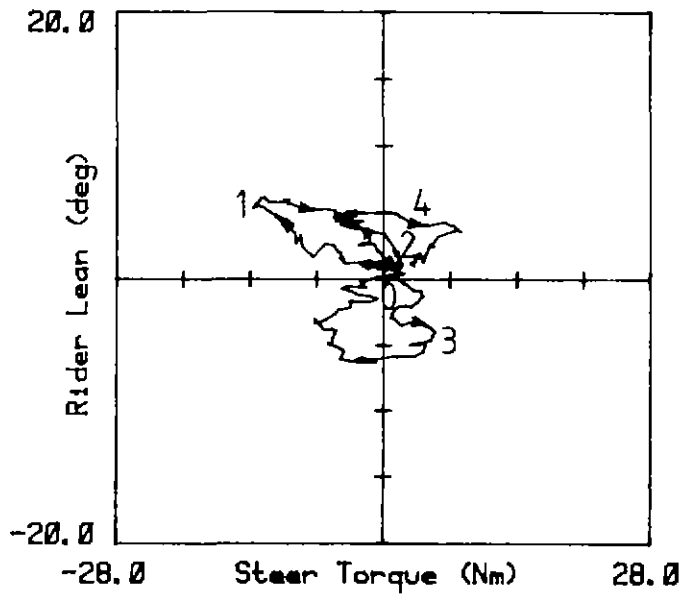
- Rider lean versus steer angle (Figures 6.27(b) and 6.28(b))

Steer angle is seen to be proportional to rider lean for the entire manoeuvre. Leaning to the right is accompanied by an anti-clockwise steer displacement, and vice versa. The two variables were found to be 180 degrees out of phase with some variation in this phase angle between riders. Further, the ratio between rider lean and steer angle was not the same for all riders and hence the slope of this line on the cross-plot varied.

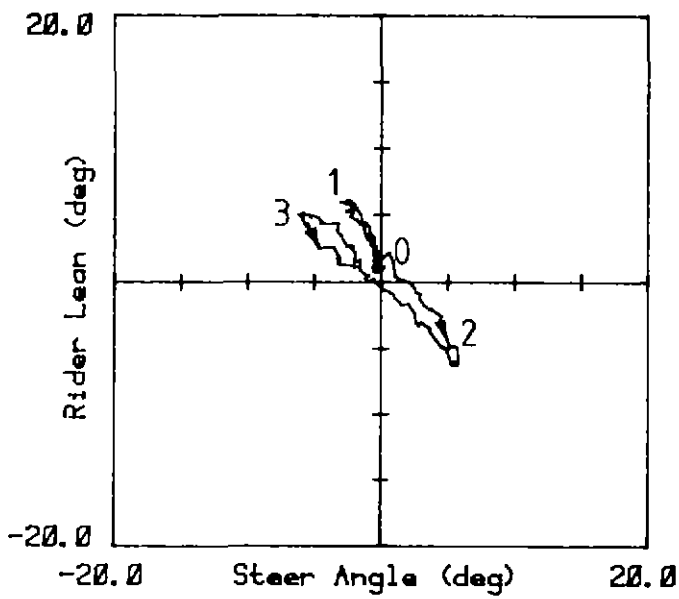
- Rider lean versus roll angle (Figures 6.27(c) and 6.28(c))

These plots indicate that the riders tried to maintain their upper body close to the vertical regardless of the roll angle of the motorcycle. This behaviour was observed in the data traces of all of the riders and is consistent with the observations of Rice (1978). Note that, as for the ratio between rider lean and steer angle, the ratio of these two variables also varied between riders.

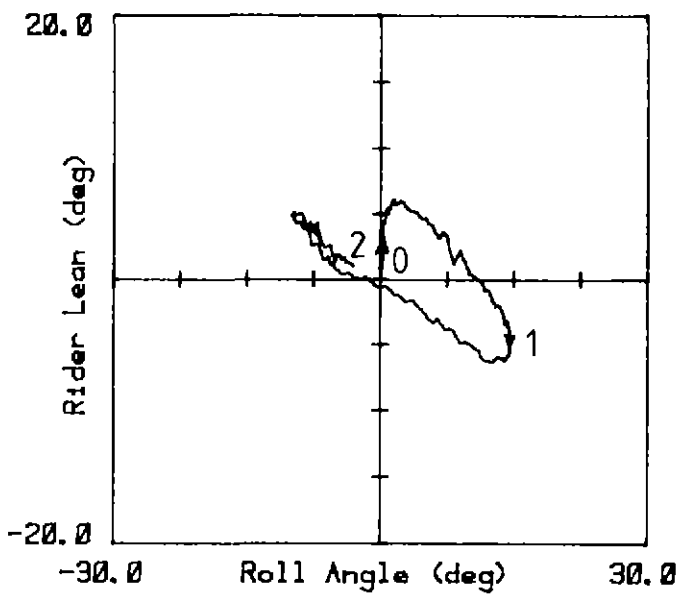




(a)

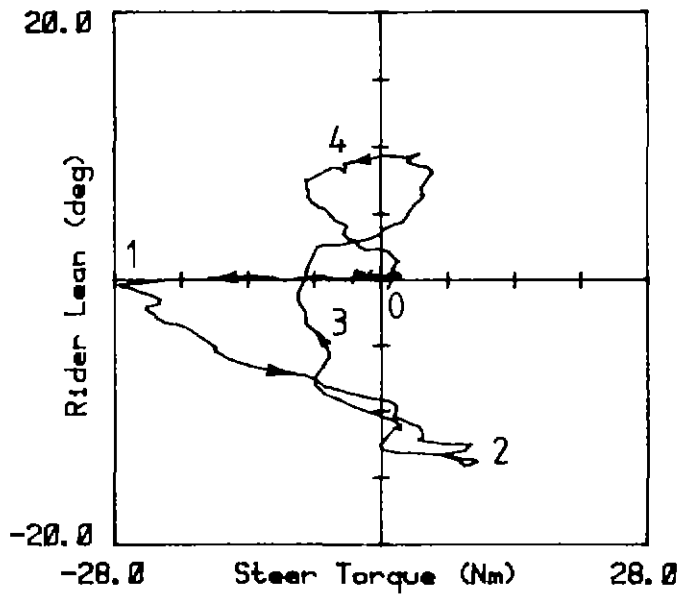


(b)

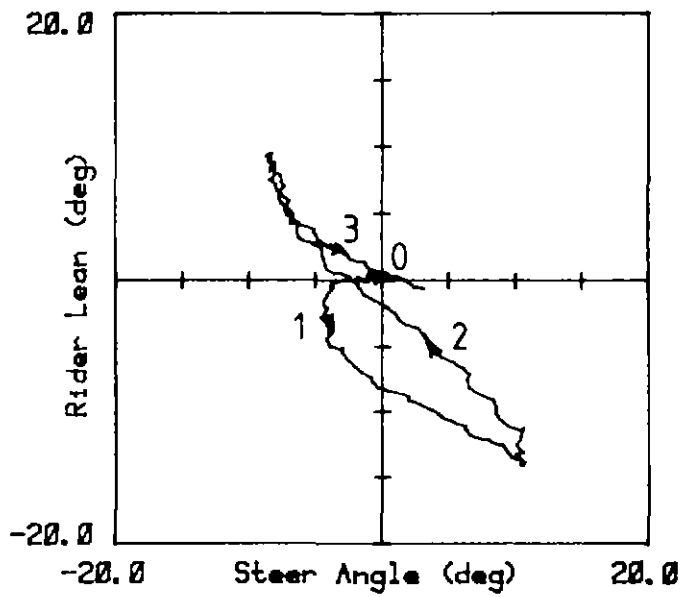


(c)

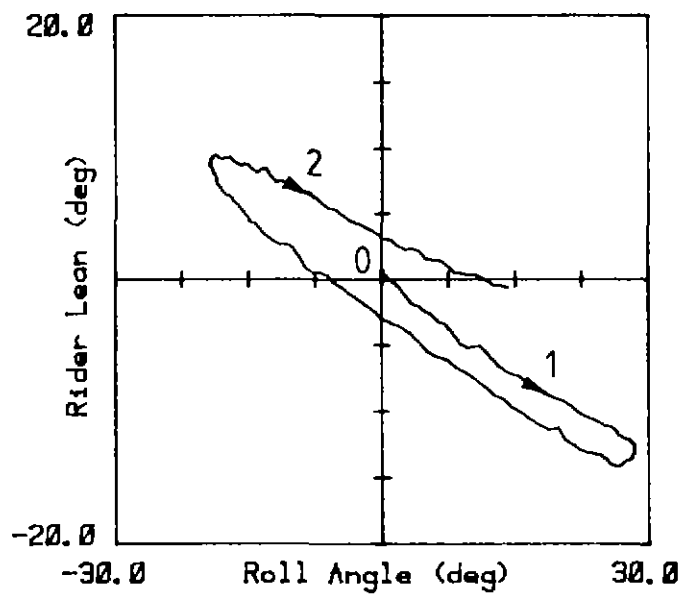
Figure 6.27 Cross-plots of the various control and response parameters of the data for the less-skilled rider of figure 6.26.



(a)



(b)



(c)

Figure 6.28 Cross-plots for the data of figure 6.25 of the skilled rider.

As rider lean and steer angle, and rider lean and roll angle were found to be 180 degrees out of phase and similar in form for all of the riders, plots of steer torque against roll angle or steer angle did not reveal any other significant differences.

It appears that the crossplots are useful in the sense that they provide a 'better picture' of the phasing between variables and show more clearly differences in the control strategies of riders for initiating a turn than do the time histories.

#### 6.3.6 Proposed Rider-Lean Steering Mechanism

The data presented in the previous section have indicated that a coupling exists between the rider's upper body lean and steer torque inputs. This coupling is stronger for less-skilled riders than for the skilled ones. This observation, together with reports from the subject riders about how they controlled their machine have led to the proposed steering mechanism described in this section. A detailed analysis of the proposed mechanism has been carried out in Chapter 7.

##### (a) The mechanism

It has generally been accepted that the two primary control means available to the rider are the application of torques to the steering assembly through the handlebars, and to the main frame by leaning the upper body relative to the motorcycle. It is proposed here that, because of the physical linkage provided by the rider's stiffly-held arms, it is possible for the rider to apply appropriate steer torques while actively controlling upper-body lean only.

According to the proposed mechanism, if the rider wants to turn left, say, the rider simply has to lean in that direction. The rider's stiffly-held arms will then pull on the right handlebar and push on the left, causing a clockwise (reverse steer) torque to be applied to the steering assembly. The consequent clockwise steering rotation causes the front wheel to track to the right and the main frame to roll to the left, as required. As the equilibrium roll angle

for the turn is approached, the rider simply leans right or left relative to the plane of symmetry of the motorcycle to generate appropriate steering inputs to maintain the desired roll angle and rate of turn. To come out of the turn, the rider leans to the right of the equilibrium lean position, his arms thereby applying the necessary anticlockwise steering torque to make the cycle roll right, towards the upright position.

The process just described seems consistent with the perceptions of many riders: Of fourteen riders asked by questionnaire (see Questionnaire Appendix B, Part B, Question 2.a.) to describe the sequence of body movements and/or steering actions they made in order to perform a left-hand lane change manoeuvre, twelve said that they "leaned their body left". Of the other two, one rider was obviously aware of the reverse steer mechanism; the other simply responded: "turn handlebars left".

In the 'real-world', however, the rider's arms would not be rigid at all times and the rider would be capable of independent lean and steering actions.

The latter form of control, consisting of uncoupled rider leaning and steering torque inputs is the only form of rider control suggested by other researchers in simulation and experimental studies (Van Lunteren and Stassen 1970; Weir, 1972; Rice and Kunkel 1976; Rice 1978; Weir et al., 1978) and is indicative of the state of the art. For example, in the Weir et al. (1978) simulation, the rider model has steer torque and upper torso lean as inputs to the cycle equations. In addition, reactive steer torque moments on the cycle, transmitted through the rider's arms, are represented. Roll stabilization is maintained by steer torque, whereas path following is controlled by leaning inputs. The rider model employed by Rice and Kunkel (1976) has passive lean control (i.e. the rider moves with the motorcycle) and hence control is by input steer torque alone.

The experimental results of Rice (1978) show signs of the lean-torque coupling mechanism. His data are shown in Figure 6.29(a), (b) and (c) with the various rider control inputs superposed for clarity. Take firstly the superposed rider lean, steer torque and rider lean, steer angle traces for rider C, a novice. It can be seen that indicated rider lean leads both steer torque and steer angle at the maximum positive lean angle, and leaning right (positive) causes an anti-clockwise steer torque (negative). As in the present experiments, the rider lean recorded may be slightly in error (see Appendix J). However, the rider's first control movement is related to the upper torso and the sense is consistent with the postulated steering mechanism.

Rider A (Figure 6.29(b)) exhibits a much smoother, well defined lean-torque coupling. The lean trace again seems to lead the steer torque trace. The amplitude of the measured lean is much less than for rider C.

The skilled rider, Rider B, applies an initial steering input completely independent of lean activity, which is consistent with the results of the previous section and is, according to the hypothesis to be presented, characteristic of a skilled performance.

(b) Hypothesized stages of learning to control the lateral motion of a motorcycle

The mechanism just described was based on a physical coupling (via the arms) between rider lean activity and steering torque and displacement inputs. A hypothesis is next presented for the stages of learning to control the lateral motion of a motorcycle, emphasizing the lean-torque coupling mechanism. The stages are as follows:

- Novice - A large part of rider control is present in lean-torque form, but still very crude and characterized by large and frequent leaning-steering corrections.

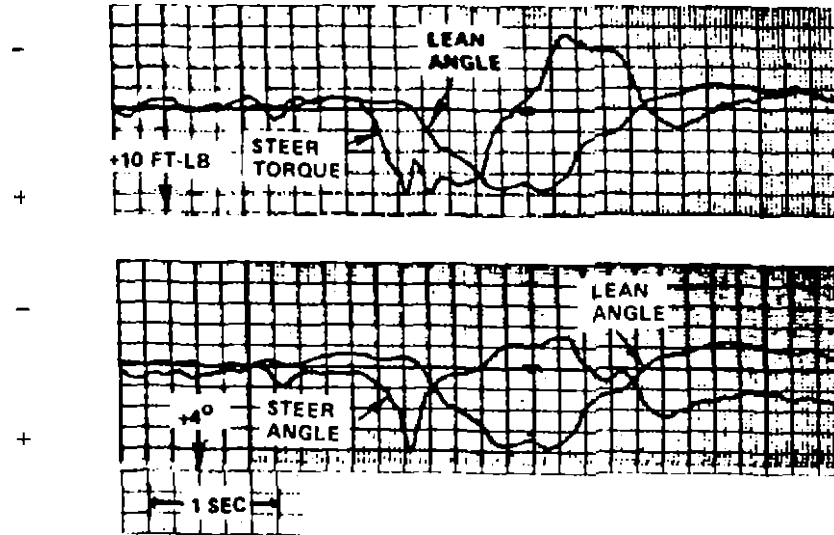


Figure 6.29 (a) Rider B, expert.

Lane change at 54 km/h (Rice, 1978).

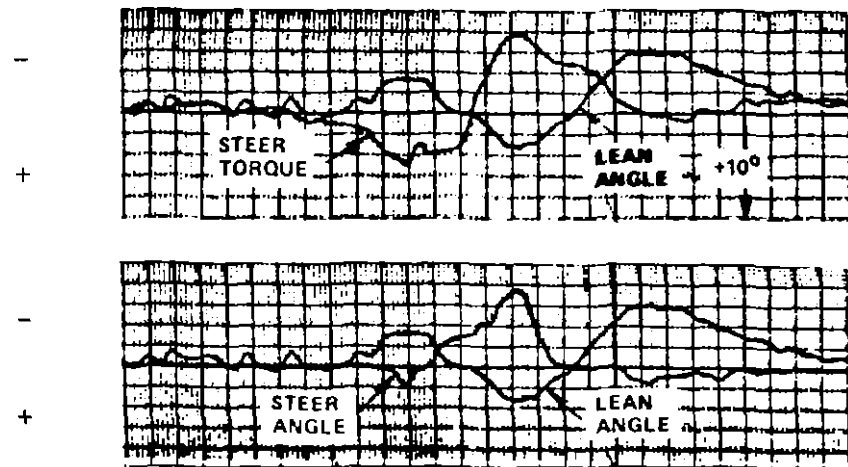


Figure 6.29 (b) Rider A, moderate experience.

Lane change at 54 km/h (Rice, 1978).

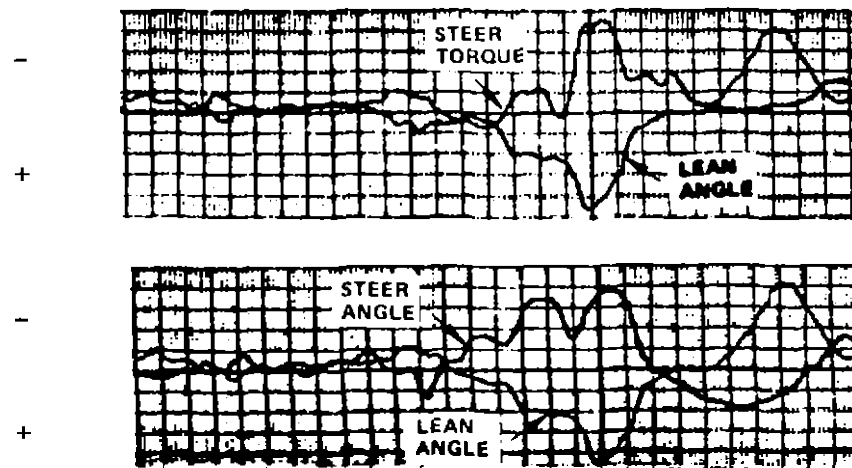


Figure 6.29 (c) Rider C, novice.

Lane change at 48 km/h (Rice, 1978).

- Intermediate - Lean-torque coupling is very well defined and performance is characterized by smooth moderate leaning with little, if any, lean corrections.
- Skilled - Steering inputs are executed in a learned manner and there is very little relationship between leaning and steer torque during the early phases of transient manoeuvres.

These characterizations of three levels of skill are illustrated and can be recognized in the data traces shown in Figures 6.29(a), (b) and (c) and in the data traces shown in Section 6.3.5 for the present study.

#### 6.3.7 Summary and Conclusion from the Analysis of the Obstacle Avoidance Data

Following is a summary of the findings from the analysis of the data collected on the instrumented motorcycle for the obstacle avoidance exercise:

- (i) A multiple linear regression was performed with overall MOST score (taken as a measure of rider skill) as the dependent variable, and various measures extracted from the obstacle avoidance data as independent variables. Of the measures used, the most important were found to be: Reaction Time, Maximum Turn Steer Angle and Reverse Steer Period. These alone accounted for 62.2% of the variance in MOST score. The overall regression was significant at the 1% level. The regression coefficients obtained from this regression indicate that the skilled riders have a shorter reaction time (this result is consistent with the emergency braking task result), achieve a larger maximum turn steer angle, and apply a reverse steer angle for a shorter period of time than the less-skilled riders.
- (ii) A second regression was performed to determine which of the measures are associated with turn success. Reaction Time was the only significant variable and its regression coefficient

indicated that riders with a short reaction time were more likely to succeed in this task. The observation that there were no discernible differences between the control inputs of riders for successful and unsuccessful runs is consistent with that of Rice and Kunkel (1976).

- (iii) Ensemble averaging of the data for some of the less critical (easier) MOST exercises revealed that the more skilled riders generated larger motion quantities, and more rapidly. In part, they achieved this through the application of definite 'reverse steer' inputs at the appropriate times. There was more inter-rider variability for the less skilled riders in this task.
- (iv) Ensemble averaging of the obstacle avoidance data for the MOST and AST showed that there is as much variation in the control and response parameters between riders who were classified as skilled as there is between riders classified as less-skilled, but less variation between successive runs of a skilled rider than a less-skilled one.
- (vi) Examination of individual rider data traces indicates that there is coupling between a rider's leaning motion and steering inputs. This coupling was shown to be stronger for the less-skilled riders than for the skilled ones.
- (vii) A mechanism which describes how riders utilize upper torso leaning to control the lateral motion of a motorcycle has been suggested. The mechanism has been used to develop a hypothesis on the stages of learning to ride: Novice riders appear to utilize upper body lean as their primary control input. Coupling of lean with steer torque by the proposed mechanism leads to appropriate, but slow steering inputs. As skill develops these inputs are made more smoothly, but at the highest levels of skill the rider is able to apply lean and steer control inputs independently of each other. This mechanism is consistent with the questionnaire results and the instrumented motorcycle data. Data traces taken from the work of Rice (1978) also support the hypothesis.



## CHAPTER 7

ANALYSIS OF THE RIDER-LEAN  
STEERING MECHANISM FOR CONTROLLING  
THE LATERAL MOTION OF A MOTORCYCLE

## 7.1 INTRODUCTION

The experimental evidence of the previous chapter suggested a strong coupling between the steering and upper-body lean inputs applied by riders, especially for the less skilled ones. In this chapter the consequences of the postulated steering mechanism have been investigated by introducing lean-torque coupling, firstly into Weir's (1972) single-loop roll angle to rider lean angle model, and finally into his multiple-loop model with rider lean as the primary control input.

The analysis is preceded by a section on operator models and single-loop systems to facilitate understanding of the subsequent analysis.

## 7.2 OPERATOR MODEL AND SINGLE-LOOP FEEDBACK SYSTEMS

To investigate the rider/cycle system as a coupled dynamic unit, with active rider control, it becomes necessary to examine and model the rider's behaviour as an operator. The operator's performance will depend, to a large extent, on his physiological and psychological states as well as other variables.

According to McRuer and Weir (1969), the human operator's characteristics depend on task variables (variables which are related to

system input and vehicle dynamics), environmental variables, operator variables (such as training, motivation, fatigue etc.), and procedural variables, which include instructions and their order of presentation.

They hypothesize that when these variables are approximately time stationary, then the system can be considered as a quasi-linear system. This is a system in which there is some linear correlation between input and output quantities, despite non-linearities and short term variations.

The assumed general form of the human-operator/vehicle feedback system is depicted in Figure 7.1 in block diagram form. The system operates in the following manner: The vehicle output motion, perceived by the operator, is compared with the desired, or command vehicle motion to provide an error signal. The error signal is acted upon by the operator to produce a vehicle control input which modifies the vehicle's subsequent motion. The aim is to null the error. The operator 'noise' or remnant, which is added to the vehicle input command, accounts for the human operator's control output which is not linearly correlated with his input. To study any control system for a vehicle analytically, the operator describing function,  $Y_p$ , needs to be determined.  $Y_c$ , the vehicle transfer function, has dynamics which can be described by derived equations of motion.

Operator equalization, or adjustment of  $Y_p$ , can be described by the approximate 'crossover model' (McRuer et al., 1965). This model is derived from experimental observations and on a general theory of manual control.

The conclusion is that the operator adjusts his describing function,  $Y_p$ , so that the magnitude of the open-loop transfer function, comprising the operator and effective vehicle dynamics,  $Y_p Y_c$ , has approximately a -20 db/decade slope in the region of the gain crossover frequency\*. The open-loop transfer function has the approximate

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\* The gain crossover frequency is the frequency for which the amplitude ratio of output/input is unity. On a frequency response (Bode) plot this is the 0 dB point.

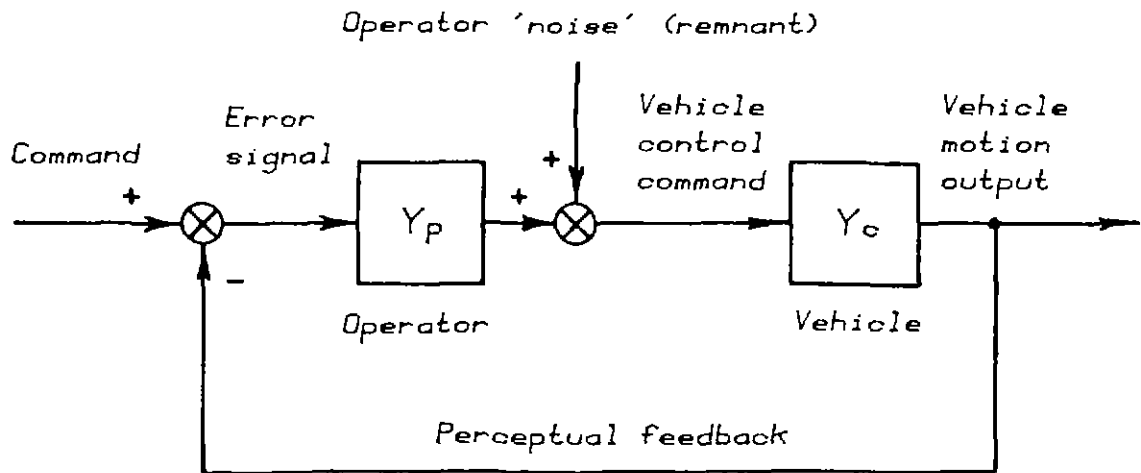


Figure 7.1 Single-loop feedback system.

form (McRuer et al., 1965):

$$Y_{\text{open-loop}} = Y_p Y_c = \frac{w_c}{jw} e^{-jwT_e}, \quad w \text{ near } w_c \quad (7.1)$$

where:

$w_c$  = crossover frequency

$T_e$  = an effective time delay which includes neuromuscular effects as well as any nett high frequency controlled element lags.

$jw$  = complex variable

The above emphasizes that the operator characteristics are modified to suit the situation and vehicle. The simplest operator describing function form, corresponding to the open-loop crossover model, contains a time delay  $T$ , and gain, lead and lag terms which may be adjusted by the operator:

$$Y_p = K_p e^{-jwT} \frac{(T_L jw + 1)}{(T_I jw + 1)} \quad (7.2)$$

### 7.3 ANALYSIS OF THE POSTULATED STEERING MECHANISM

The comparisons made by Weir between the various single-loop systems were based on control system performance criteria, namely, system crossover frequency, gain margin and phase margin. The gain and phase margin quantities indicate the degree to which the system is stable. Positive values of phase margin tends to indicate stability and a negative value of phase margin generally indicates instability. Useful design values are 30-60 degrees for phase margin and 4-12 decibels (dB) for the gain margin (Shinners, 1975). The crossover frequency is chosen within a (preferably broad) range of frequency where a -20 dB/decade slope exists for the amplitude ratio of the open-loop operator/vehicle transfer function. A fair stretch of -20 dB/decade slope is desirable so that a nominal change in gain is accompanied by only a small change in phase and hence system stability.

Table 7.1 shows a summary of the single-loop rider/cycle systems related to rider-lean control inputs evaluated by Weir (1972). Of these only  $r \rightarrow \phi R$ , and  $\phi \rightarrow \phi R$  are designated as 'good' systems. According to Weir, both of these systems may require, what seem to be, physically large rider lean angles. For a 1.0 and 1.2 rad/s crossover frequency, respectively, the gain for the  $r \rightarrow \phi R$  loop is 10 degrees rider lean per degree/sec yaw rate error, and for the  $\phi \rightarrow \phi R$  system 5.6 degrees rider lean per degree roll angle error. Only the second of these two systems was re-evaluated with the postulated steering mechanism included. This was done because all of Weir's multiple-loop systems have roll angle,  $\phi$ , fed back as the basic inner loop which serves to stabilize the roll instability (capsize mode).

The analysis proceeded by using Weir's linearized equations of motion to obtain the various open-loop system characteristics. To examine the stability of the closed-loop systems, the factored numerator and denominator polynomials of Weir's Appendix B were utilized. The motorcycle physical parameters used by Weir, for a B.S.A. motorcycle, were used here for comparison and verification purposes. The analysis was conducted for one forward speed of the motorcycle (70 ft/s) and hence the effect of speed variations was not explored.

### 7.3.1 Single-Loop Control of Roll Angle by Body lean

In Weir's analytical representation the rider's upper body is considered to be a rigid, symmetrical extension of the cycle rear assembly. The upper body is assumed to produce a gravitational torque about an upper body roll axis which is horizontal and parallel to the motorcycle longitudinal plane of symmetry. Associated with upper body control movement is a neuromuscular time delay of about 0.3 seconds.

The postulated lean-torque coupling is incorporated directly into Weir's single loop model for control of roll angle by body lean, as shown in the block diagram of Figure 7.2.

TABLE 7.1

SUMMARY OF WEIR'S (1972) SINGLE-LOOP RIDER/CYCLE SYSTEM  
POSSIBILITIES WITH RIDER LEAN CONTROL

System*	Feedback que	Comparative loop closure			Comparative system quality	Remarks
		Crossover frequency (rad/s)	Gain Margin (dB)	Phase Margin (deg)		
$r \rightarrow \phi R$	Heading rate	1.0	4	75	Good	May require large lean angles. Lag helps.
$\psi \rightarrow \phi R$	Heading angle				Poor	Requires large lead.
$\phi \rightarrow \phi R$	Roll angle	1.2	10	50	Good	May require large lean angles.
$\delta \rightarrow \phi R$	Steer angle	0.6	8	60	Poor	Cue may not exceed sensory threshold.
$v \rightarrow \phi R$	Lateral velocity				Poor	Difficult to sense.
$a_y \rightarrow \phi R$	Lateral acceleration				Poor	Degraded by otolith lag.
$y \rightarrow \phi R$	Lateral position				Very poor	Requires equalizing inner loops

\*  $a \rightarrow b$  Denotes that the feedback signal to 'b' is 'a'.

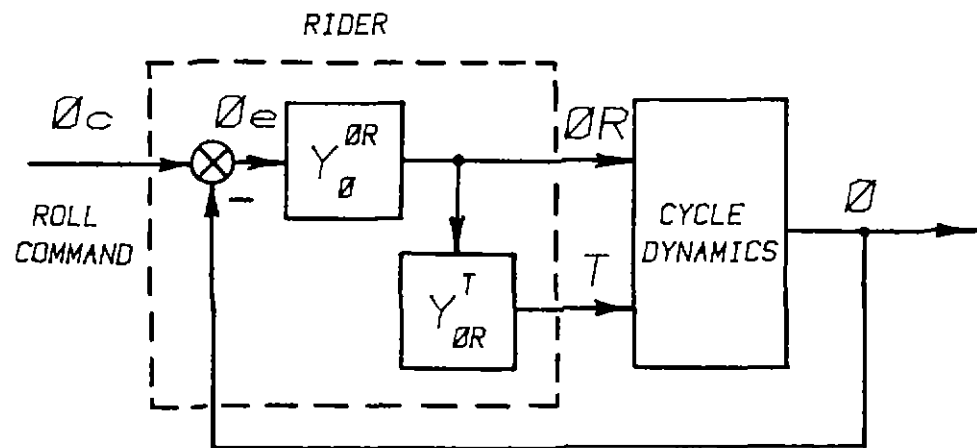


Figure 7.2 Roll angle control by rider-lean with lean-torque coupling.

The model rider responds to the perceived roll angle error,  $\phi_e$ , by leaning relative to the motorcycle by an amount  $\phi_R$ , passively applying a steer torque  $T$  by the coupling mechanism described in the previous Chapter. The rider describing function  $Y_{\phi}^{\phi_R}$ , relating response  $\phi_R$  to input  $\phi$ , and  $Y_{\phi_R}^T$ , relating steer torque response to the  $\phi_R$  input need to be determined.

The rider describing function adopted by Weir (1972) was based on equation 7.2 and consisted of gain only equalization, i.e. no lead or lag adjustment. For the crossover model the effective time delay,  $T$ , is found to be a function of the controlled vehicle dynamics and the forcing function frequency bandwidth (McRuer et al., 1965). For rider lean control a representative time delay is 0.5 seconds (Weir, 1972). Note that this value accounts for all of the operator lags, i.e. receptor excitation (the retina in the case of visual cues), nerve conduction, computational lags, neuromuscular lags etc. To facilitate calculations the time delay was represented by a first-order Padé function thus:

$$e^{-0.5j\omega} \approx - \frac{(j\omega - 4.0)}{(j\omega + 4.0)} \quad (7.3)$$

The rider describing function for lean control can be therefore represented as:

$$Y_{\phi}^{\phi_R} = K_{\phi}^{\phi_R} e^{-0.5j\omega} \approx - K_{\phi}^{\phi_R} \frac{(j\omega - 4.0)}{(j\omega + 4.0)} \quad (7.4)$$

In equation 7.4 the rider gain  $K_{\phi}^{\phi_R}$  is positive (lean right to roll right). The lean-torque coupling describing function,  $Y_{\phi_R}^T$ , is represented as a pure gain ( $K_{\phi_R}^T$ ). The magnitude of the (negative) coupling gain or stiffness, is determined by the muscular tension maintained in the rider's arms.

Combining the rider and cycle dynamics gives the following open-loop system transfer function for roll angle control:



$$\frac{\phi}{\phi_e} = Y_{\phi}^{\phi R} \frac{(N_{\phi R}^{\phi} + Y_{\phi R}^T N_T^{\phi})}{\Delta} \quad (7.5)$$

where:

$N_{\phi R}^{\phi}/\Delta$  ,  $N_T^{\phi}/\Delta^*$  = Motorcycle transfer function relating output  $\phi$  to input  $\phi_R$  and  $T$  respectively.

Bode plots of this transfer function are shown in Figure 7.3, for a number of values of the coupling gain  $K_{\phi R}^T$ . It can be seen that the overall open-loop gain is increased by the presence of lean-torque coupling, allowing a reduction in the gain  $K_{\phi}^{\phi R}$  while maintaining a constant crossover frequency of, say, 1.2 rad/s (as used by Weir (1972)). As Table 7.2 shows, this improved sensitivity to rider lean (from the extremely insensitive value of 5.5 degrees of rider lean required to correct one degree of roll error with no coupling) is achieved with minimal effects on the gain and phase margins.

Having chosen values for the rider gains, the closed loop properties for roll angle,  $\phi$ , to a roll command,  $\phi_c$ , can now be examined by analytically 'closing' the loop, i.e.

$$\frac{\phi}{\phi_c} = \frac{\phi/\phi_e}{1 + \phi/\phi_e} = \frac{Y_{\phi}^{\phi R} (N_{\phi R}^{\phi} + Y_{\phi R}^T N_T^{\phi})}{\Delta + Y_{\phi}^{\phi R} (N_{\phi R}^{\phi} + Y_{\phi R}^T N_T^{\phi})} \quad (7.6)$$

---

\* For the notation adopted by Weir and used here,  $N_b^a$  is a transfer function numerator relating output 'a' to input 'b', and  $\Delta$  is the transfer function denominator (vehicle alone). The denominator,  $\Delta$ , when set equal to zero becomes the characteristic equation of the system. Solution of the characteristic equation yields the characteristic modes of motion, the much talked about Capsize, Weave and Wobble modes (see Sharp, 1971; Weir, 1972). Roots for the above, and subsequently derived characteristic polynomials, are given in Appendix I.

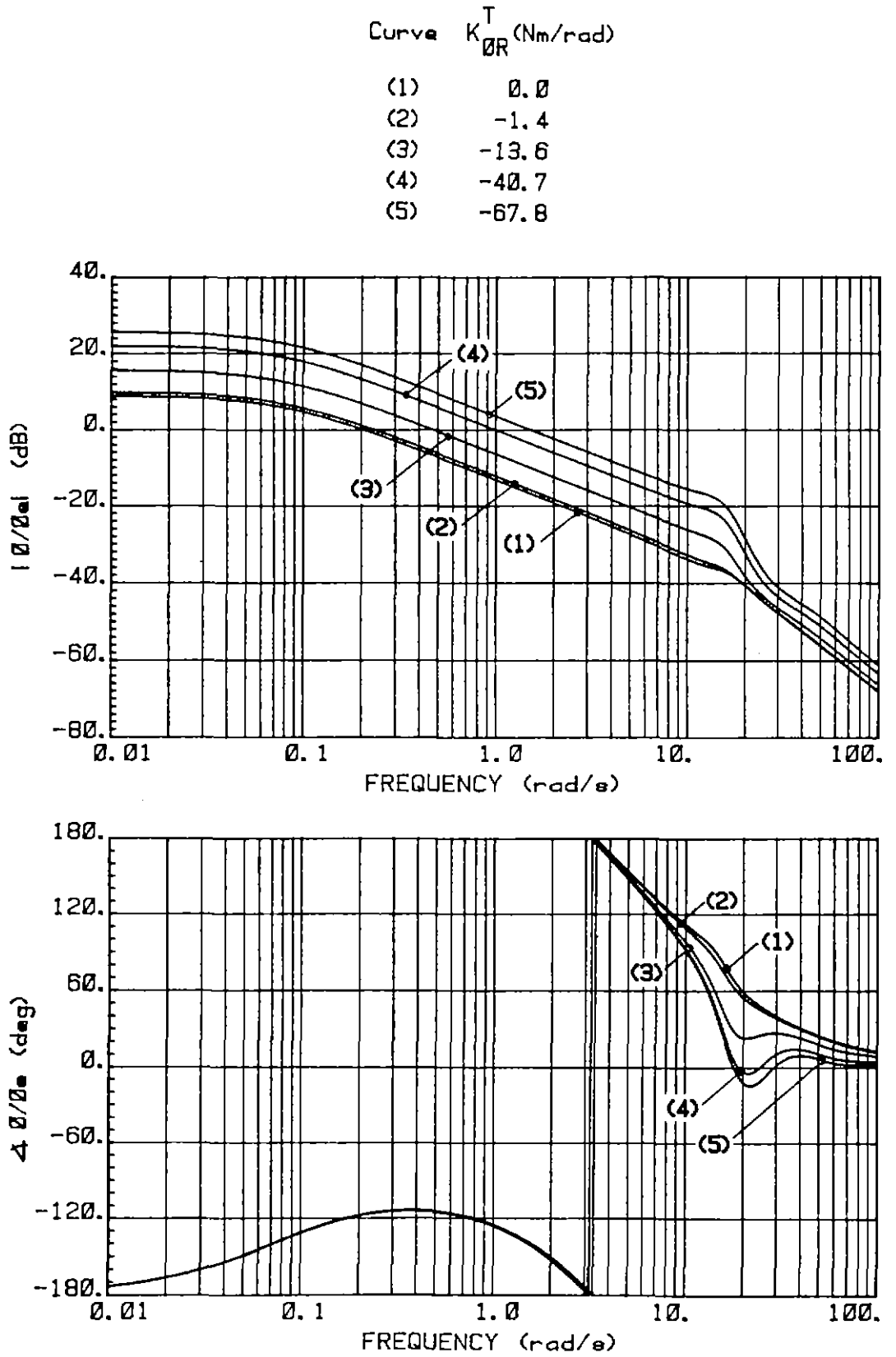


Figure 7.3 Open-loop bode plot for roll angle control with rider-lean and passive lean-torque coupling.

TABLE 7.2

PARAMETERS AND STABILITY MARGINS FOR CROSSOVER  
FREQUENCY OF 1.2 RAD/S WITH FIGURE 7.2 MODEL

$K_{\phi R}^T$	$K_{\phi}^{\phi R}$	Gain margin	Phase margin
Nm/rad	rad/rad	dB	deg
0.0	5.48	9.04	49.7
-1.4	4.91	8.94	49.5
-13.6	2.52	8.60	48.9
-40.7	1.21	8.43	48.5
-67.8	0.80	8.38	48.4

The denominator of this function is the new system characteristic polynomial of the rider/cycle system. The behaviour of the system to changes in rider gains can 'best' be shown on a Root-Locus plot. This is a locus of the roots (solutions) to the characteristic equation, plotted as a function of a physical parameter (in this case rider gain). It gives an instantaneous view of that parameter's effect on the behaviour of the system in general, and in particular information on stability. It is plotted on a complex plane.

The variation of the roots of the denominator of Equation 7.6 with the gain  $K_{\phi R}^T$  is shown in the root locus plots of Figure 7.4, for no lean-torque coupling and for a coupling stiffness of  $K_{\phi}^{\phi R} = -40.7$  Nm/rad. Note that the root-locus is symmetrical about the Real axis and therefore only one half is shown. The closed-loop roots corresponding to an open-loop crossover frequency of 1.2 rad/s are indicated by the hatched marks on the roots-loci (Appendix I gives the exact values for these and the other roots). The plots show that, apart from increasing the sensitivity to rider lean control, introduction of lean-torque coupling causes the 'weave mode' (complex pole at about 16 rad/s) frequency and damping to increase moderately as  $K_{\phi}^{\phi R}$  increases: both of these are desirable effects.

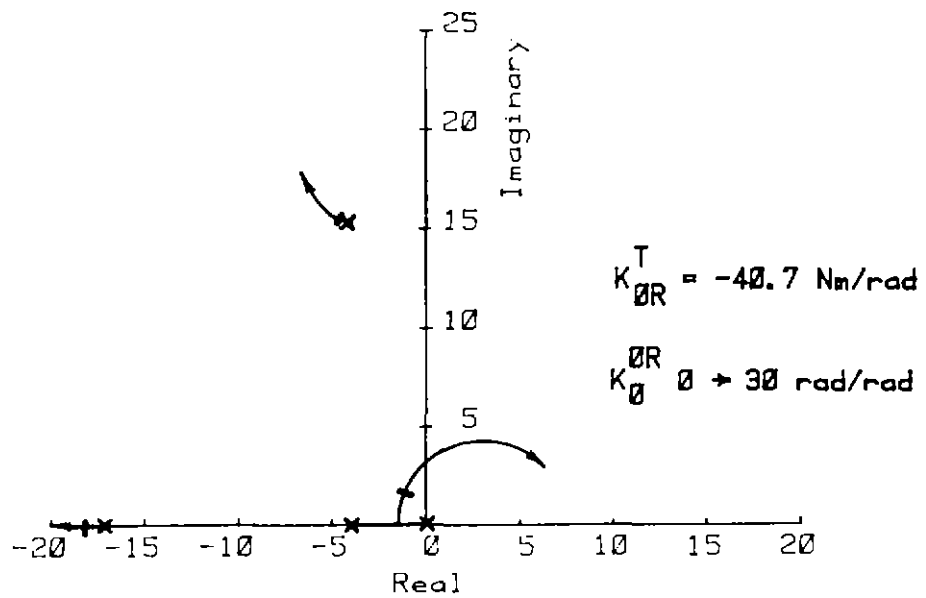
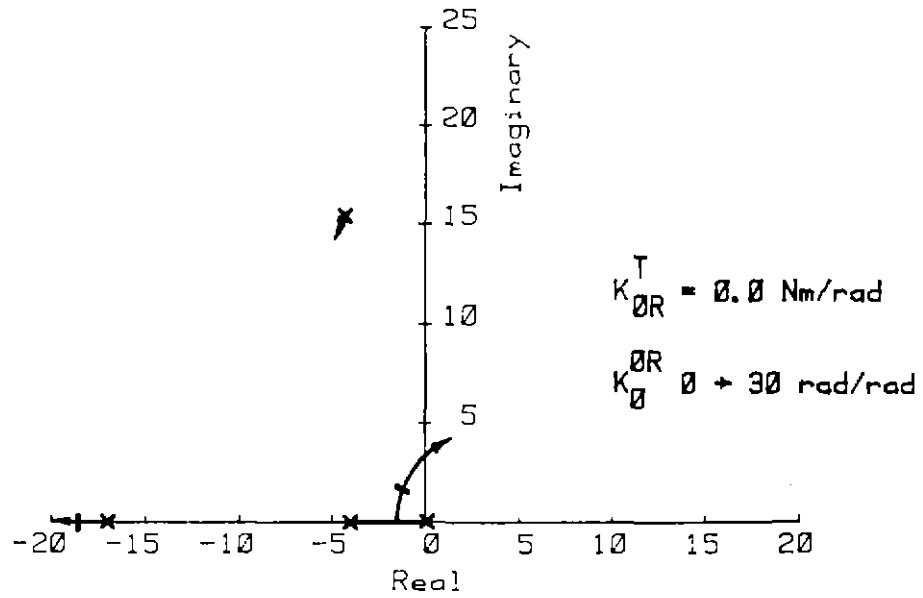


Figure 7.4 Roots-loci for the proposed closed-loop roll angle control system.

### 7.3.2 Multiple-Loop Path Control by Body Lean

The single loop system just discussed comprises the inner loop of the system shown in Figure 7.5, obtained by incorporating lean-torque coupling into Weir's multiple-loop system with active control of body lean only. This inner loop stabilizes the motorcycle, allowing the path-following outer loops, involving the heading angle  $\psi$  and lateral deviation  $y$ , to function.

For the intermediate, heading angle control loop, the effective vehicle dynamics are modified by closure of the inner, roll angle control loop. The open-loop transfer function for the heading loop is

$$\frac{\psi}{\psi_e} = \frac{Y_{\psi}^{\phi c} Y_{\phi}^{\phi R} (N_{\phi R}^{\psi} + Y_{\phi R}^T N_T^{\psi})}{\Delta + Y_{\phi}^{\phi R} (N_{\phi R}^{\phi} + Y_{\phi R}^T N_T^{\phi})} . \quad (7.7)$$

Given an inner-loop crossover frequency of 1.2 rad/s, the adjustments of the gain  $K_{\psi}^{\phi c}$  required to maintain a crossover frequency of 1.0 rad/s for the heading loop are shown in Table 7.3. The table also shows that maintaining this system bandwidth with increasing lean-torque coupling can only be achieved at the expense of the stability margins. Larger gain and phase margin could be obtained by choosing a lower crossover frequency by reducing the gain for  $K_{\psi}^{\phi c}$ . This would reduce the system bandwidth. The values shown in Table 7.3 are feasible and result in stable heading control systems.

The outer, lateral position control loop is required to prevent gradual drifting of the motorcycle from its intended path. With the effective vehicle dynamics now modified by closure of the roll and heading loops, the open-loop transfer function for lateral position control is

$$\frac{y}{y_e} = \frac{Y_y^{\psi c} Y_{\psi}^{\phi c} Y_{\phi}^{\phi R} (N_{\phi R}^y + Y_{\phi R}^T N_T^y)}{\Delta + Y_{\phi}^{\phi R} (N_{\phi R}^{\phi} + Y_{\phi R}^T N_T^{\phi}) + Y_{\psi}^{\phi c} Y_{\phi}^{\phi R} (N_{\phi R}^{\psi} + Y_{\phi R}^T N_T^{\psi})} . \quad (7.8)$$

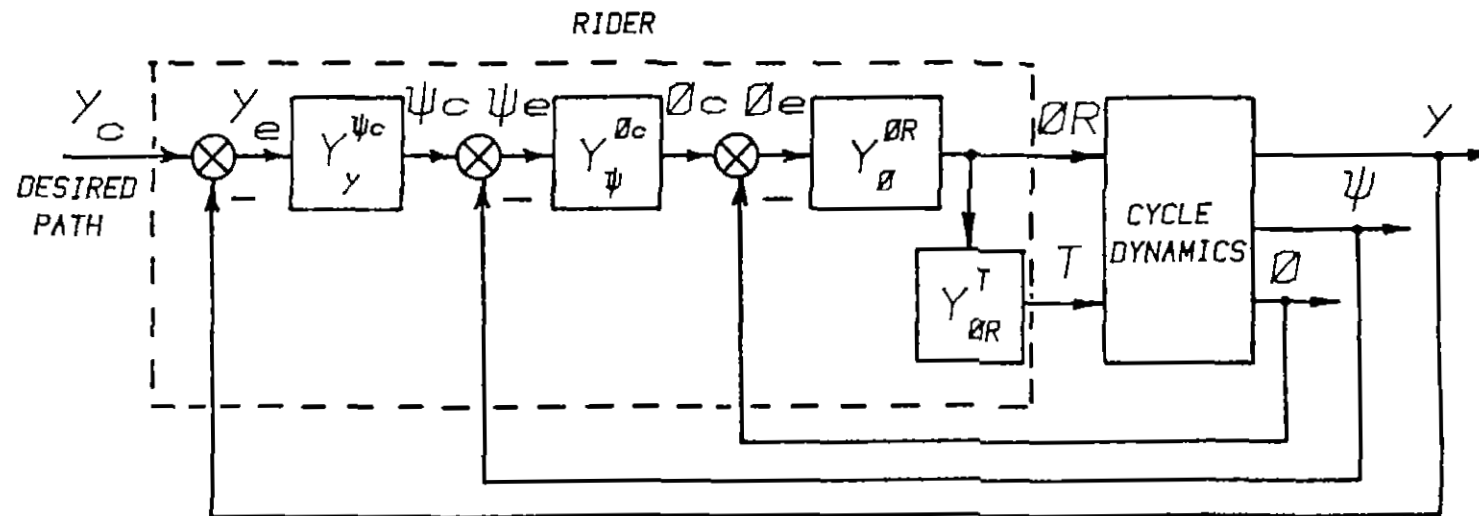


Figure 7.5 Proposed multiple-loop model for path control by body lean and passive lean-torque coupling.

TABLE 7.3

PARAMETERS AND STABILITY MARGINS FOR CROSSOVER FREQUENCY  
OF 1.0 RAD/S FOR HEADING ANGLE LOOP OF FIGURE 7.5

$K_{\phi R}^T$	$K_{\phi}^{\phi R}$	$K_{\psi}^{\phi C}$	Gain margin	Phase margin
Nm/rad	rad/rad	rad/rad	dB	deg
0.0	5.48	1.88	6.99	59.3
-1.4	4.91	1.88	6.44	56.9
-13.6	2.52	1.86	4.24	46.5
-40.7	1.21	1.81	3.29	40.9
-67.8	0.80	1.80	3.02	39.4

The effect on this function of the various values of the coupling stiffness  $K_{\phi R}^T$ , with the inner loop gains  $K_{\phi}^{\phi R}$  and  $K_{\psi}^{\phi C}$  adjusted as per Table 7.4, is shown in the Bode plots of Figure 7.6. It can be seen that increased coupling causes 'peaking' of the magnitude plot around 1.5 rad/s, thereby reducing the gain margin available if a constant crossover frequency is to be maintained.

Table 7.4 shows that for a crossover frequency of 0.6 rad/s, increased coupling causes only a marginal reduction in closed-loop stability (as reflected by the phase margin) but does adversely affect the 'robustness' of the system (reduced gain margin). The variation of the closed-loop characteristic roots with the outer-loop gain  $K_y^{\psi C}$  is shown in Figure 7.7, for coupling stiffnesses of zero and -40.7 Nm/rad. The roots corresponding to a crossover frequency of 0.6 rad/s are indicated by hatched marks on the roots-loci of Figure 7.7. Exact values for these roots and those for the other coupling gains are given in Appendix I.

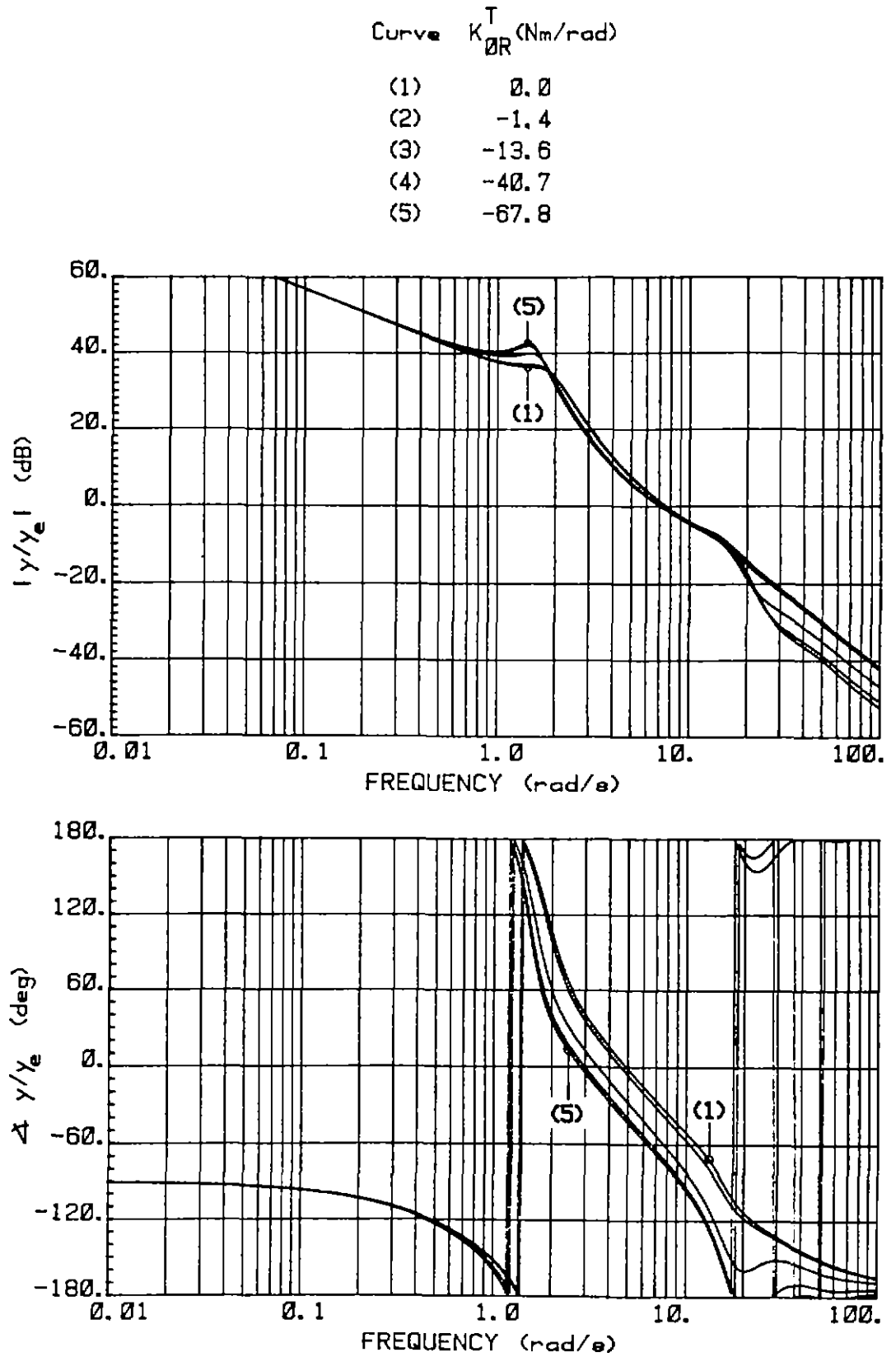


Figure 7.6 Open-loop lateral position system investigation for rider-lean and passive lean-torque coupling.



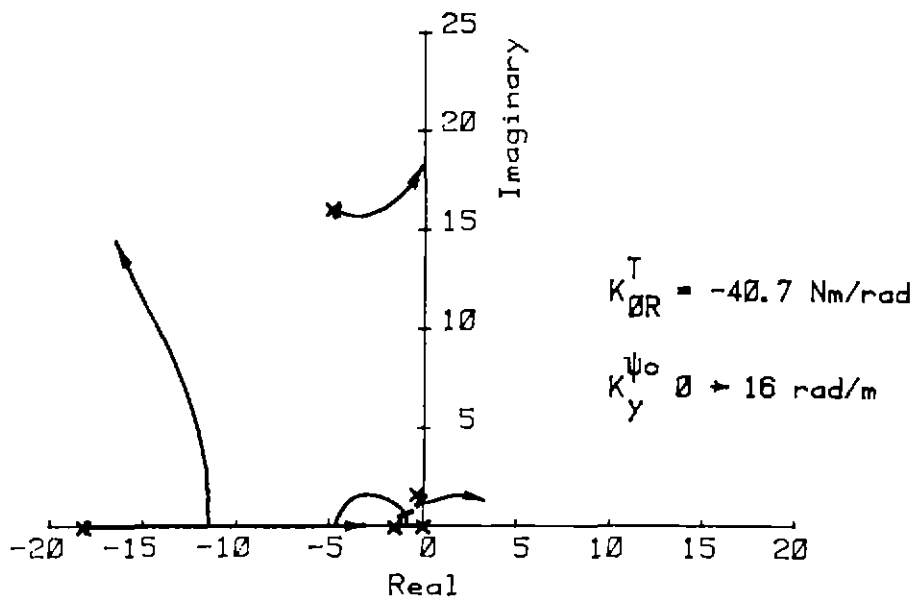
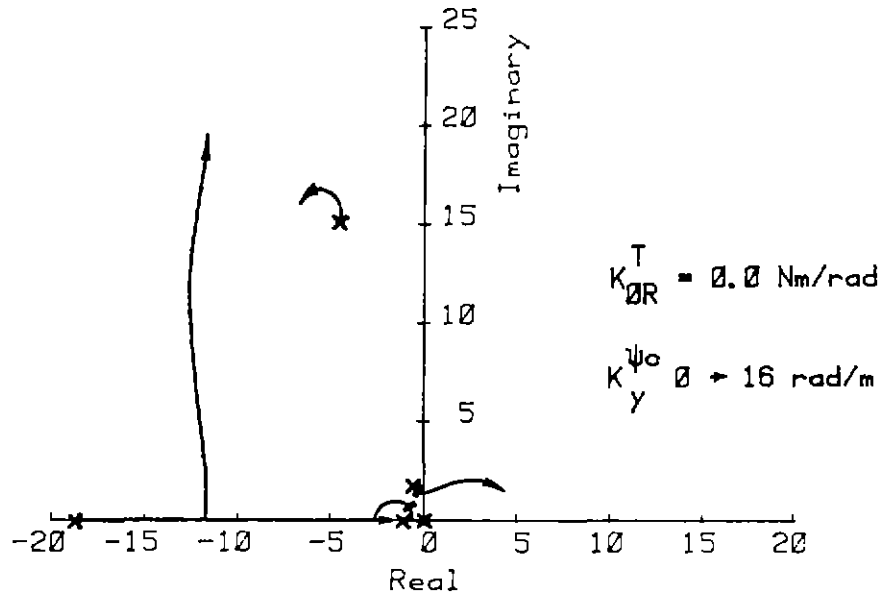


Figure 7.7 Roots-loci for the proposed closed loop lateral control system.

TABLE 7.4

PARAMETERS AND STABILITY MARGINS FOR CROSSOVER FREQUENCY  
OF 0.6 RAD/S WITH FIGURE 7.5 MODEL

$K_{\phi R}^T$	$K_{\phi}^{\phi R}$	$K_{\psi}^{\phi C}$	$K_y^{\psi C}$	Gain margin	Phase margin
Nm/rad	rad/rad	rad/rad	rad/m	dB	deg
0.0	5.48	1.88	0.028	4.89	52.6
-1.4	4.91	1.88	0.028	4.49	52.4
-13.6	2.52	1.86	0.026	2.55	51.4
-40.7	1.21	1.81	0.025	1.49	50.3
-67.8	0.80	1.80	0.025	1.09	50.2

### 7.3.3 Comparison of Models

For comparison with the results in Table 7.4 for the proposed model of Figure 7.5 (in which active control by rider lean only is exercised), Table 7.5 shows the system performance parameters presented by Weir for the model of Figure 7.8 (in which independent control of body lean and steer torque is maintained). For the same crossover frequency, Weir's model appears somewhat more stable than the proposed model with lean-torque coupling. However, it should be noted that Weir's model again requires the rather large gain of 8.2 deg of rider lean per degree of heading error (increased to 20 deg/deg in his 'refined estimate' of parameters for this model Weir (1972)).

Figure 7.7 shows that, for the proposed model, the system response is dominated by two low frequency oscillatory modes, the damping of one of which decreases with increased lean-torque coupling. By comparison, the response of Weir's Figure 7.8 model is dominated by an aperiodic mode and an oscillatory mode, the damping ratio of which is 0.049. The damping of the 1.3 rad/s mode in the present model is reduced to a similarly low value when the coupling stiffness is about -24 Nm/rad.

TABLE 7.5

PARAMETERS AND STABILITY MARGINS FOR CROSSOVER FREQUENCY  
OF 0.6 RAD/S WITH FIGURE 7.8 MODEL

$K_{\phi}^T$	$K_{\phi}^{\phi R}$	$K_y^{\psi c}$	Gain Margin	Phase Margin
Nm/rad	rad/rad	rad/m	dB	deg
-54.0	8.22	0.022	2	60

The models discussed here are intended to represent the tracking and disturbance regulation response of the rider/cycle system to continuous, low frequency, random-appearing inputs, rather than its discrete manoeuvre performance. However it is of interest to compare the model responses to classical control system inputs, such as a unit step or a unit ramp of lateral displacement command. (In observing these responses the qualification should be borne in mind that the time delay in the rider's response has been represented by a Padé approximation.)

In Figure 7.9 the step response of Weir's Figure 7.8 model, with control by lean and torque, is compared with that of the lean-torque coupling model of Figure 7.5, for three values of the coupling stiffness  $K_{\phi R}^T$ . The 'best' transient response is actually obtained with lean-only control ( $K_{\phi R}^T = 0$ ), but this requires the undesirably large rider gain of  $K_{\phi}^{\phi R} = 5.5$  degrees of lean per degree of roll error. Increasing the coupling stiffness reduces this gain, but makes the response more oscillatory, consistent with the discussion of the roots-loci in Figure 7.7. Recalling that discussion, it is clear from the plots in Figure 7.9 that the performance of the proposed model would be very similar to that of Weir's when the coupling stiffness was about -24 Nm/rad. The gain margin for this stiffness is 2 dB, the same as for Weir's model. However the rider gain  $K_{\phi}^{\phi R}$  is only 1.8

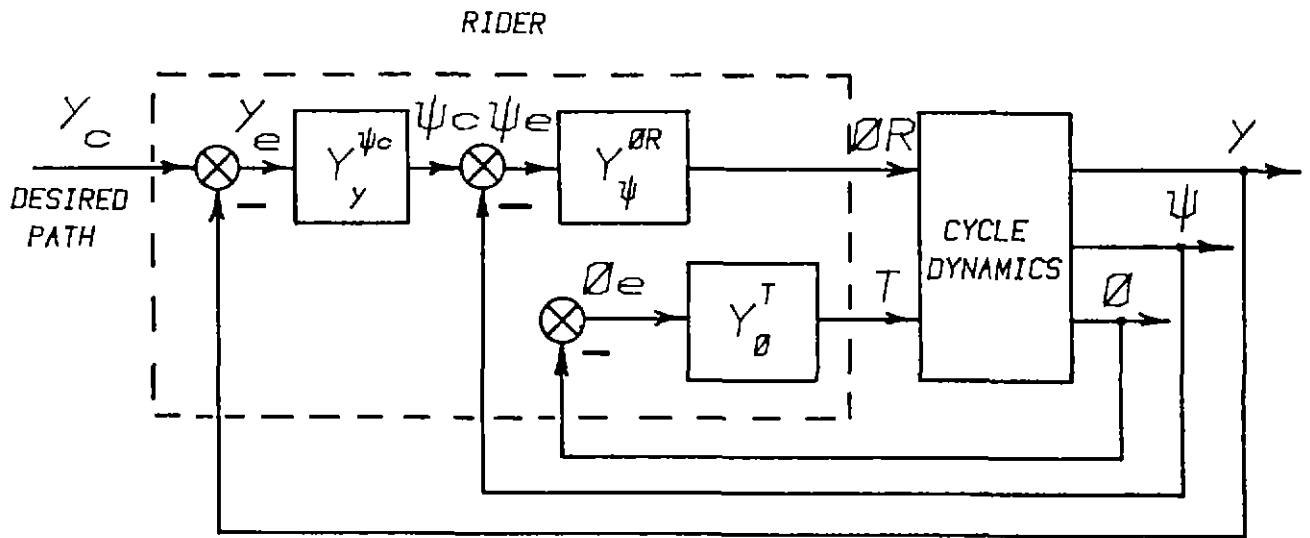


Figure 7.8 Weir's multiple-loop rider/cycle system.

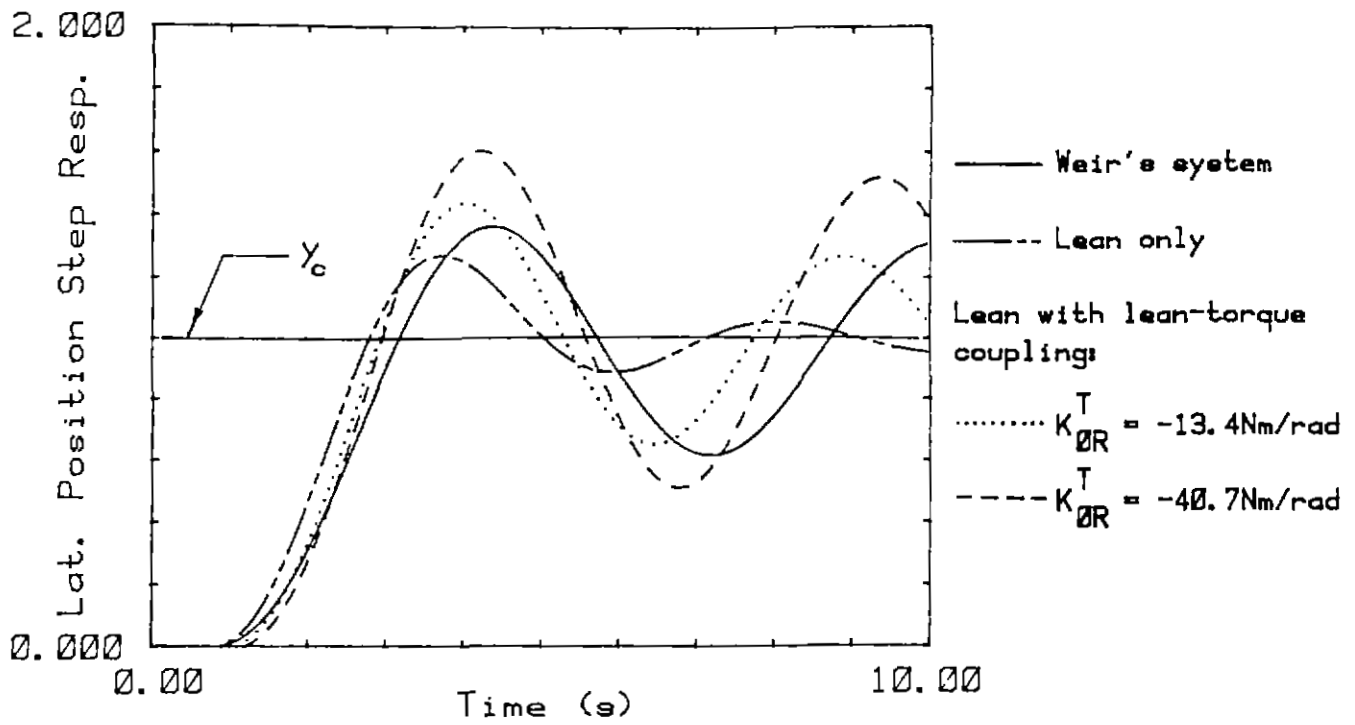


Figure 7.9 Lateral position step responses.

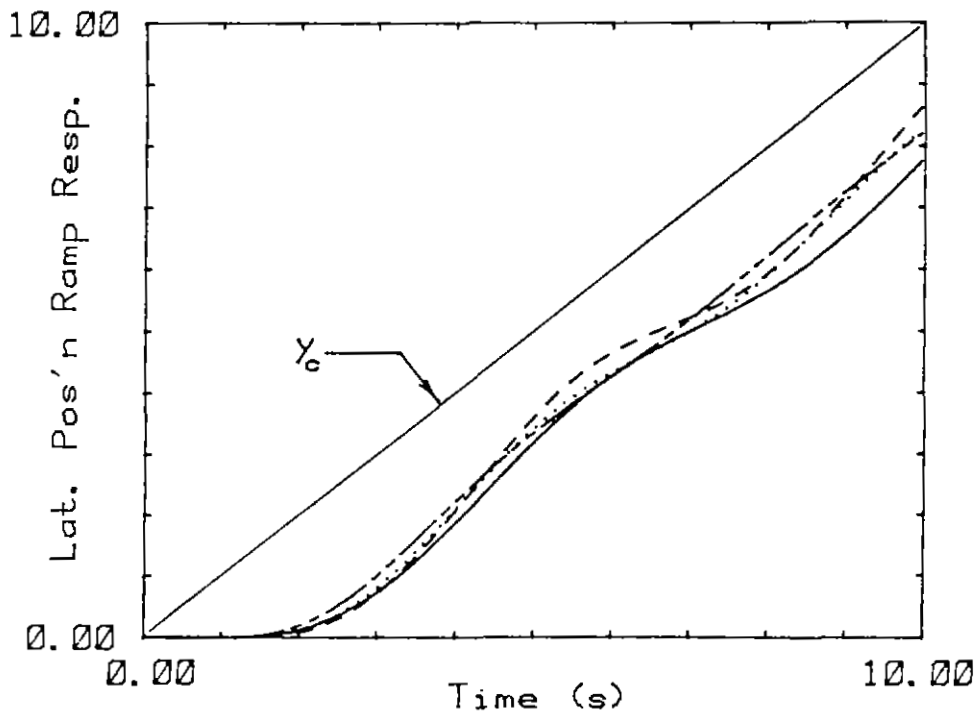


Figure 7.10 Lateral position ramp responses.

deg/deg, whereas Weir's model requires 8.2 deg of rider lean per degree of heading error.

A step input excites the high frequency dynamics of the system in a rather dramatic way. An input with less high frequency content, and which might be used to generate more realistic 'commands' for the discrete manoeuvres, is a unit ramp of lateral displacement. It can be seen from the plots in Figure 7.10 that there is little to choose between the responses of the various models. Apart from the effects of the time delay, which riders could be expected to compensate for by preview of the path ahead, all the models could be expected to track a practical lane-change path with reasonable precision.

#### 7.4 CONCLUSIONS FROM THE ANALYTICAL ANALYSIS

The following conclusions can be drawn from the analysis of the preceding sections:

- (i) With the introduction of lean-torque coupling into Weir's (1972) single loop model for control of roll angle by body lean, the cycle's sensitivity to body lean inputs is improved from the extremely insensitive value of 5.5 degrees of rider lean required to correct one degree of roll error with no coupling, to a physically more realistic value of about 1.0 deg/deg. This is achieved with minimal effects on the system performance measures, namely, open-loop gain and phase margins.
- (ii) A comparison between Weir's (1972) model, and the proposed model, for control of the lateral position of the motorcycle indicates that comparable system performance can be achieved. The proposed 'unskilled rider' model may have lower stability margins, but requires physically less extreme upper body motions.
- (iii) The lean-torque coupling mechanism appears to represent a feasible control strategy, with the advantage for the unskilled rider that active control of only one input to the motorcycle is required.

## CHAPTER 8

### SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

#### 8.1 INTRODUCTION

A prerequisite to effective training and licensing of motorcycle riders is an understanding of the characteristics of skilled motorcycle riding performances, the types of manoeuvres which challenge these skills, and control strategies employed by skilled riders which might be communicated to inexperienced riders. Furthermore, if rider performance characteristics representative of the riding population are identified, specific goals can be set for motorcycle design to fit existing rider performance capabilities. A summary of the findings of this study, which has attempted to answer these questions, is presented in this chapter together with recommendations for further work and suggestions for rider training.

#### 8.2 SUMMARY OF CONCLUSIONS

The Motorcycle Operator Skill Test (MOST) was used in the first experiment to obtain a skill grading of the 59 riders tested. Their behaviour in controlling the instrumented motorcycle was recorded while they performed the variety of steering and braking tasks in the MOST. Analysis of the scores assigned to riders revealed a number of deficiencies in the test. The performance check used for the emergency braking exercises in the MOST was found to be biased. There was evidence suggesting that riders are more likely to perform the obstacle avoidance task successfully when manoeuvring to the left. As riders only receive one attempt at this task in the MOST, those receiving a right-turn could be disadvantaged. Furthermore, use of an

unfamiliar motorcycle with a sensitive rear brake appeared to have a detrimental effect on emergency braking in a curve: riders, on average, could not attain the required stopping distance in this task. Stopping distances achieved during straight-path emergency braking were considerably better.

As a result of the experience with the MOST, an Alternative Skill Test (AST) was developed with the objective of providing a simpler test which would require a smaller test area, yet which would retain the best features of the MOST, while correcting some of its deficiencies. Further, the test was designed to incorporate elements of surprise and decision-making, in an attempt to make it more representative of in-traffic situations, and because it has been suggested in the accident literature that the accident-involved riders often make inappropriate choices between steering and braking avoidance manoeuvres. A smaller sample of riders (18) were administered the AST. The AST and MOST led to a similar skill grading of the test subjects. Riders generally performed better in the AST than the MOST - they were able to achieve higher mean decelerations in the emergency braking tasks and succeeded more often on the obstacle turns in the AST than the MOST. However it is not possible to determine whether this was due to differences between the methodology of the tests, or whether there was a general improvement in subjects' riding ability during the less-than-two-month interval between tests.

How does a skilled performance on a motorcycle differ from a less-skilled one? The answer to this question is of some importance as it will allow specific goals for rider training and licensing to be defined. This question was tackled by making detailed observations of riding performances over a wide range of skill levels with the instrumented motorcycle. Two tasks were identified from the MOST experiment as 'good' skill discriminators - the emergency straight-path braking and obstacle turn exercises. The data for these two tasks were extensively examined and the following patterns of behaviour were identified: During braking it was found that skilled riders (as indicated by their score in the MOST) applied larger front and rear brake forces, had shorter reaction times, and were able to independently



modulate their front and rear brake force inputs so that, as the motorcycle deceleration increased, the ratio of front to rear force increased in the manner required for optimum utilization of the available tyre/road friction. The obstacle avoidance data revealed that the skilled riders had a shorter reaction time (consistent with the emergency braking result), achieved a larger steer angle during the turning phase of the manoeuvre, and applied a reverse steer angle for a shorter period of time than the less-skilled riders. It was also found that riders with a short reaction time were more likely to succeed in this task. A coupling between a riders leaning motion and steering inputs was identified and was shown to be stronger for the less-skilled riders. A mechanism was proposed to describe how riders utilize upper body leaning to control the lateral motion of a motorcycle. The mechanism has been used to develop a hypothesis on the stages of learning to control the lateral motion of the motorcycle: Novice riders appear to utilize upper body lean as their primary control input. Coupling of lean with steer torque by the proposed mechanism leads to appropriate, but slow, steering inputs. As skill develops these inputs are made more smoothly, but at the highest levels of skill the rider is able to apply lean and steer control inputs independently of each other.

### 8.3 RECOMMENDATIONS FOR FURTHER WORK

If the MOST is to be used as a licence test then it is strongly recommended that the scoring criterion for the emergency braking task be modified so that riders travelling within the allowable test speed range are all required to achieve the same level of braking performance (see Section 4.9). Furthermore, the use of an unfamiliar motorcycle and the influence of brake feel characteristics on a rider's emergency braking-in-a-curve performance should receive attention.

It is important to establish - with a larger sample of riders - how significant is the asymmetry in riders' obstacle-turn manoeuvring ability and whether or not this asymmetry extends to other turning manoeuvres. If the asymmetry is found to be significant, then the

MOST should be modified so that riders receiving a right-turn in the obstacle-turn exercise are not disadvantaged. It is also of some importance to determine the relationship between rider characteristics, such as left or right handedness, and a rider's left- and right-turning ability, to determine if the other MOST exercises in which a turn is required need to be redesigned to avoid disadvantaging some riders during testing.

Comparisons between the MOST and AST showed that the two tests led to a similar grading of the test subjects. The sample of riders tested had a wide range of riding skills and was not, it is believed, representative of a sample of typical licence applicants. It is recommended that the AST be evaluated with a sample of riders representative of licence applicants to determine, firstly, whether or not the AST will effectively grade such a group, and secondly, whether the test exercises are appropriate - in their modified form (see Section 5.7.9) - or whether further modifications are required for effective grading of licence applicants.

The instrumented motorcycle has been shown to be an extremely useful tool for examining the dynamic characteristics of the motorcycle and for observing and comparing rider control behaviour related to task demands and motorcycle handling properties. It is recommended that the instrumented motorcycle be used in further similar studies.

## 8.4 SUGGESTIONS FOR RIDER TRAINING

### 8.4.1 Braking

The importance of proper utilization of the braking capabilities of a motorcycle in an emergency braking situation cannot be overemphasized. The data collected on the instrumented motorcycle have indicated that the skilled riders were able to proportion their braking effort in an optimal manner. As discussed in Section 6.2.4 this is a very difficult perceptual-motor task as it requires correct proportioning of braking effort to the front and rear wheels in response

to cycle deceleration. It is recommended that serious attention be given to examining the braking behaviour and performance of novice riders on motorcycles equipped with a linked front and rear brake system.

#### 8.4.2 Controlling the Lateral Motion of the Motorcycle

Very few of the riders to whom the handling questionnaire was administered (see Appendix B, Part B, Question 2.a.) were aware of the reverse steer mechanism by which the lateral motion of a motorcycle can be controlled. Although this may not be important for moderate manoeuvres, for emergency lateral excursions, for which a rapid response is generally desired, knowledge, or some awareness, of the reverse steer mechanism and its utilization are of paramount importance. On the basis of the proposed lean-steer mechanism, it can be demonstrated to the trainee that leaning in the required direction and maintaining fairly rigid arms will produce the required steering actions. However, it should be stressed that in order to make the cycle respond most quickly, a deliberate application of reverse steer is the most effective method of initiating, or recovering from, a turn.

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## APPENDIX A

## MOTORCYCLE DATA ACQUISITION SYSTEM (MDAS)

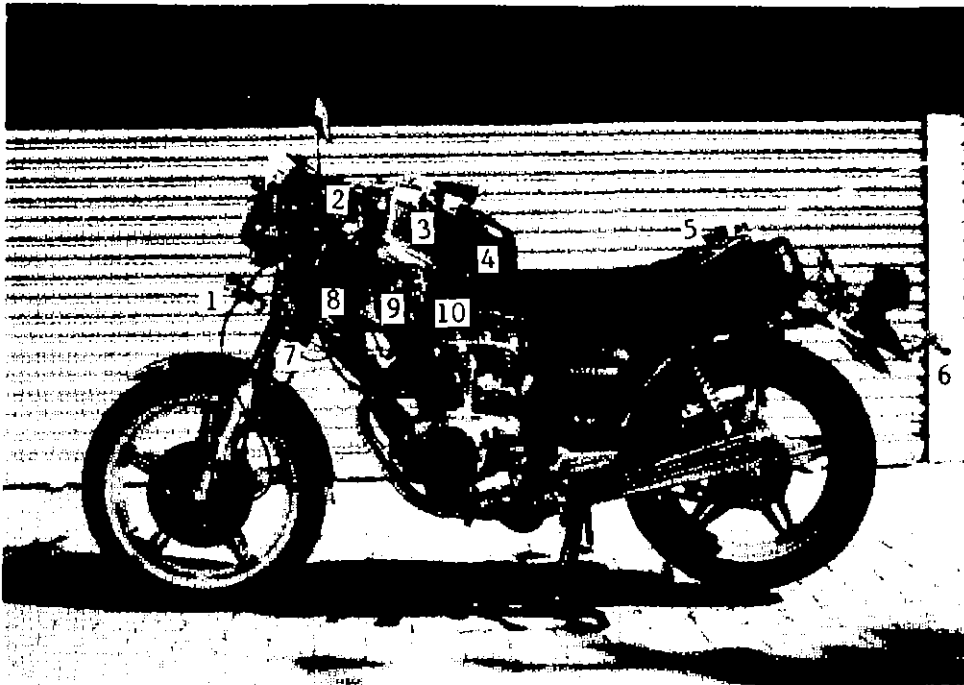
## A.1 INTRODUCTION

In order to examine, in detail, the magnitude and sequencing of control inputs applied to the cycle by the rider and the response of the cycle, a motorcycle instrumentation package was developed which can readily be adapted to different motorcycles. The package is capable of monitoring 8 channels of analogue information. Lightweight transducers attached at various positions on the motorcycle/rider (shown in Figure A.1) produce signals which, after suitable conditioning, are encoded and recorded. The general flow diagram is shown in Figure A.2. The various parts of the system used in the present study are described in this appendix.

## A.2 ENCODING, MULTIPLEXING AND RECORDING OF SIGNALS

The onboard data acquisition system, less the transducers and their associated signal conditioners (amplifiers and filters), includes the following:

- 8 channels of data encoding and multiplexing (analogue signal input level 0 to -10V, frequency response: DC to 20Hz).
- Audio high fidelity Nakamichi 350 cassette recorder.
- 6 x 6V Yuasa sealed lead-acid batteries.
- Voltage regulation box with multiple outlets and manual switches.
- Meter with switchable channel selection for displaying conditioned transducer outputs.
- Input plug for event marker on channel 8.



- 1 - Speed Transducer.
- 2 - Steer Torque Sensor.
- 3 - MDAS.
- 4 - Roll and Yaw Rate Gyros.
- 5 - Rider Lean and Pitch Transducer.
- 6 - Event Marker.
- 7 - Steer Angle Transducer.
- 8 - Petrol Canister (1 Litre).
- 9 - Batteries.
- 10 - Lateral Acceleration Transducer.

Figure A.1 General layout of the instrumented motorcycle.

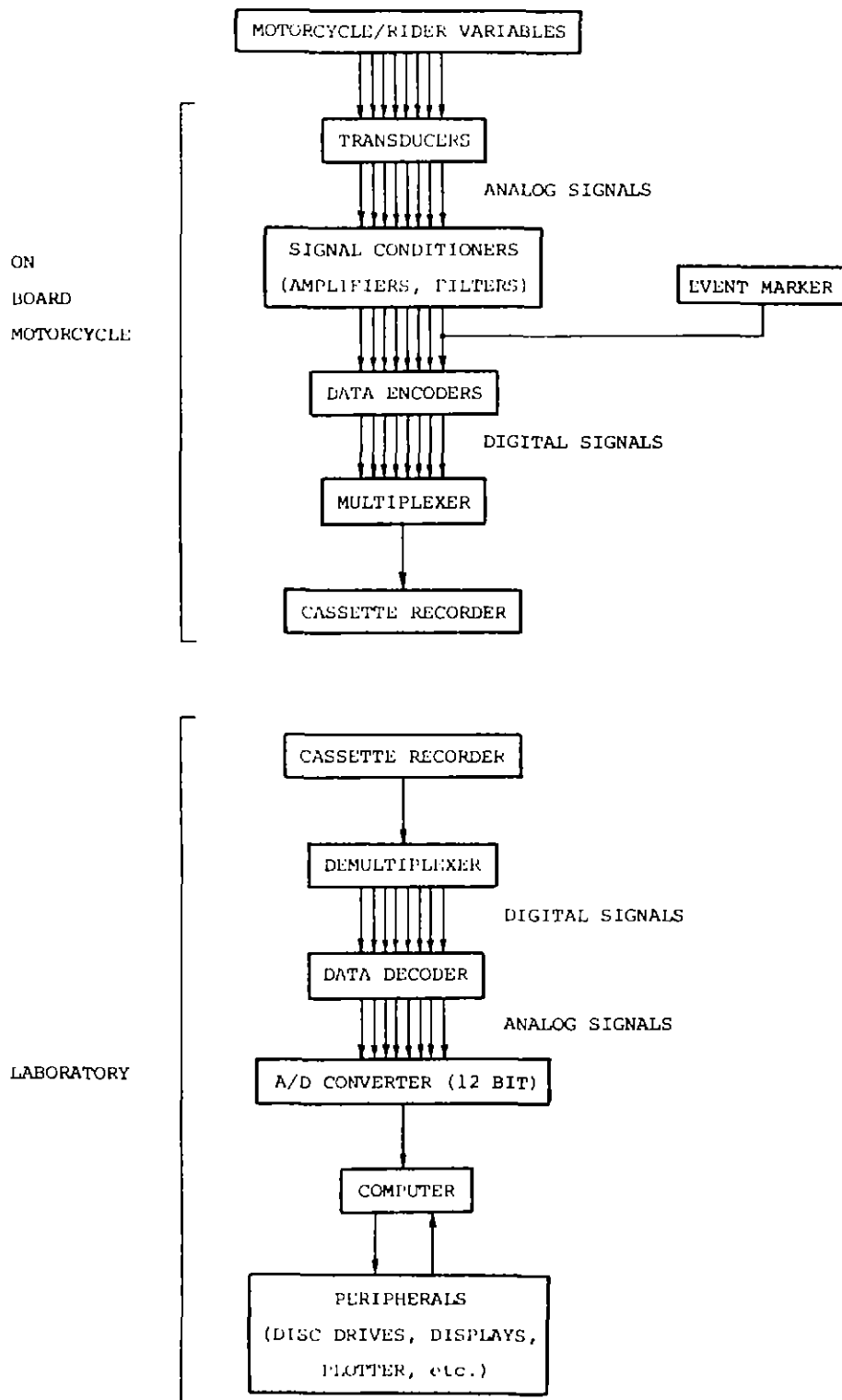


Figure A.2 Flow chart depicting data acquisition, recovery and manipulation.



All of these components were mounted in a shaped box designed to be mounted in place of the fuel tanks, so as to have a minimal effect on the inertial properties of the motorcycle. The general arrangement of the components is depicted in Figure A.3.

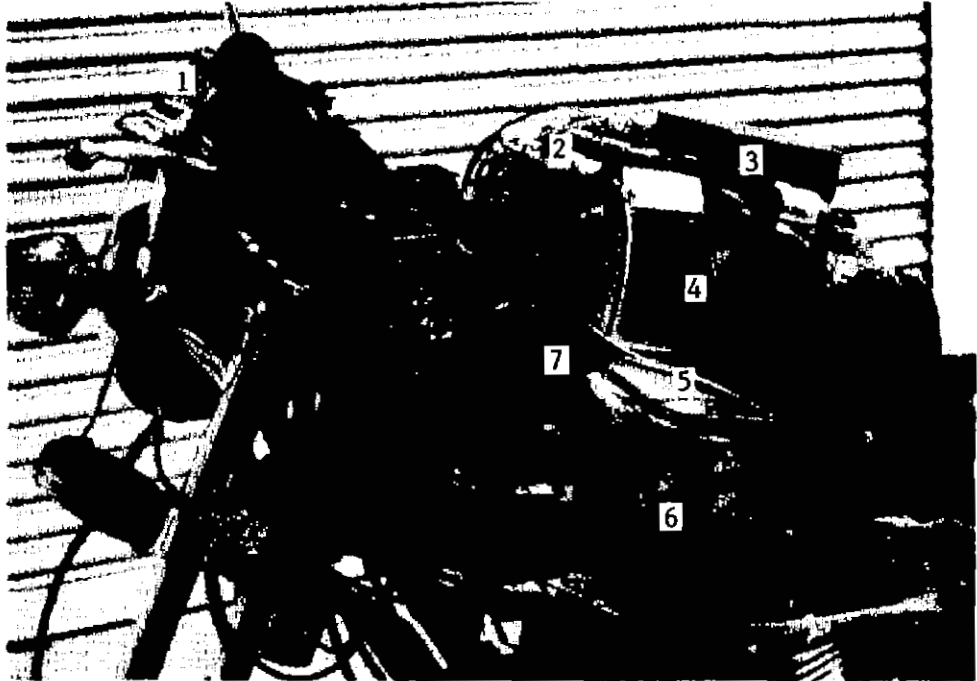
A major portion of the time spent developing the instrumentation package was devoted to getting the 8 channels encoding, addressing and decoding system to work. The system (known as 'Deltaverta Time Division Multiplexing') was purchased in modular form from Hybrid Systems Corporation, U.S.A., because it had been used for similar work overseas (Weir et al., 1978).

However, the system as delivered proved unsuitable (with a frequency response limited to 3 Hz) and required extensive modification. It was subsequently learned that Weir et al. had similar problems - unfortunately these had not been referred to in their report! Many of the original modules were dispensed with and a new system built, using the same working principle, but with much improved performance.

### A.3 POWER SUPPLIES

Two power sources were used for running the MDAS. The 12V lead-acid motorcycle battery, after suitable filtering, was used to power the cassette recorder. Six 6V, 4.0 amp-hr Yuasa rechargeable lead-acid batteries gave the following regulated and unregulated supplies.

- $\pm 18\text{V}$  DC unregulated.
- $+28\text{V}$  DC (for the Humphreys rate gyroscopes).
- $\pm 15\text{V}$  DC (for the amplifiers, filters, various transducers and potentiometer type sensors).



- 1 - Meter with switchable channel selection for displaying conditioned transducer outputs.
- 2 - Voltage regulation box.
- 3 - General purpose amplifier box.
- 4 - Nakamichi 350 cassette recorder.
- 5 - 8 channels of data encoding and multiplexing.
- 6 - 3 x 6V Yuasa lead-acid batteries.
- 7 - Input plug for event marker.

Figure A.3 General arrangement of MDAS.

#### A.4 DEMULTIPLEXING, DECODING

The off-board system consisted of the following:

- Audio high fidelity Nakamichi 350 cassette recorder.
- Demultiplexing and decoding of data - 8 channels.
- Access to raw 'digital' data.

Recovery of the original signal was performed in the laboratory where the decoded analogue signals (low-pass filtered at 20 Hz) were each digitized (sampling rate 102.4 Hz) and stored on floppy and/or hard disk. Once in this form they could be processed using a digital computer.

#### A.5 TRANSDUCERS

##### A.5.1 Steer Torque

Figure A.4 shows the general design of the steer torque transducer. This was mounted so that the sensing element was parallel with the steering axis. Non-standard handlebars had to be fitted since the transducer raised the original handlebars approximately 4.0 cm. The transducer without strain gauges is shown mounted on the motorcycle with original handlebars in Figure A.5.

The strain gauges were mounted in a full bridge configuration and an Analog Devices 2B31J strain gauge amplifier was used to raise the steer torque signals to the required level.

The sensor was designed to take stress levels produced during normal on- and off-motorcycle manoeuvring and hence no protection against overstrain was incorporated. During the course of the experiments, however, the transducer failed suddenly three times: the first two times for no apparent reason, and the third time when a subject dropped the motorcycle during a test exercise. The calibrations shown below are for the originally gauged transducer and regauged transducer

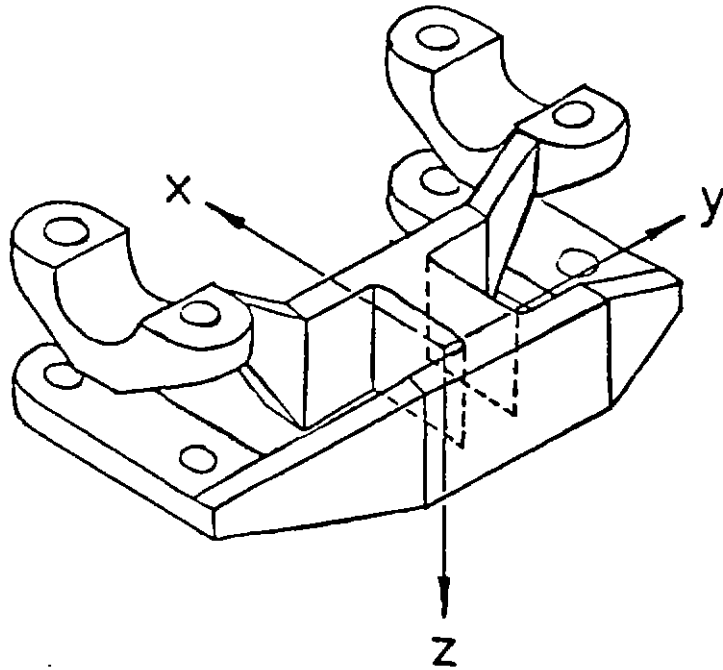


Figure A.4 Steer torque transducer.



1 - Sensing element onto which strain gauges are mounted.

Figure A.5 Steer torque transducer shown mounted with original handlebars and no strain gauges.

after the fall (shown in parenthesis). Calibrations for the other two times were not significantly different than for the first.

Specifications:

- Range:  $\pm 27.9$  Nm ( $\pm 27.3$ )
- Frequency response: DC to 100 Hz
- Cross axis sensitivity:  $-1.0\text{mV/Nm}$  ( $-0.5$ ) , -ve moment about y-axis  
 $3.5\text{mV/Nm}$  ( $4.8$ ) , -ve moment about x-axis

#### A.5.2 Steer Angle

The measurement of steer angle requires high resolution since small changes in this control variable have a significant influence on motorcycle motion. The transducer used in this application was a TRANSTEK Angular Displacement Transducer (ADT) Model No. 600-00. The ADT is a precision differential capacitor coupled to a solid state oscillator, demodulator, and amplifier to yield DC output. It is stated to have infinite resolution, limited only by the detecting equipment.

As depicted in Figure A.6 the shaft of the ADT was aligned with the steering axis of the motorcycle, whilst the body of the ADT was fixed firmly to the main frame.

Specifications:

- Range:  $\pm 20$  deg.
- Accuracy: 0.10% (linearity).
- Maximum angular velocity: 1440 deg/s (equivalent to  $>11\text{Hz}$  frequency for  $\pm 20$  deg. amplitude sine wave).
- Nominal mass: 350 gm.

#### A.5.3 Roll and Yaw Rate

The roll and yaw rate gyros used were Humphrey Rate Gyros Model RG51-0124-1 ( $\pm 60$  deg/s) and No. RG51-0165-1 ( $\pm 200$  deg/s). These were mounted in the position shown in Figure A.7 in vibration isola-

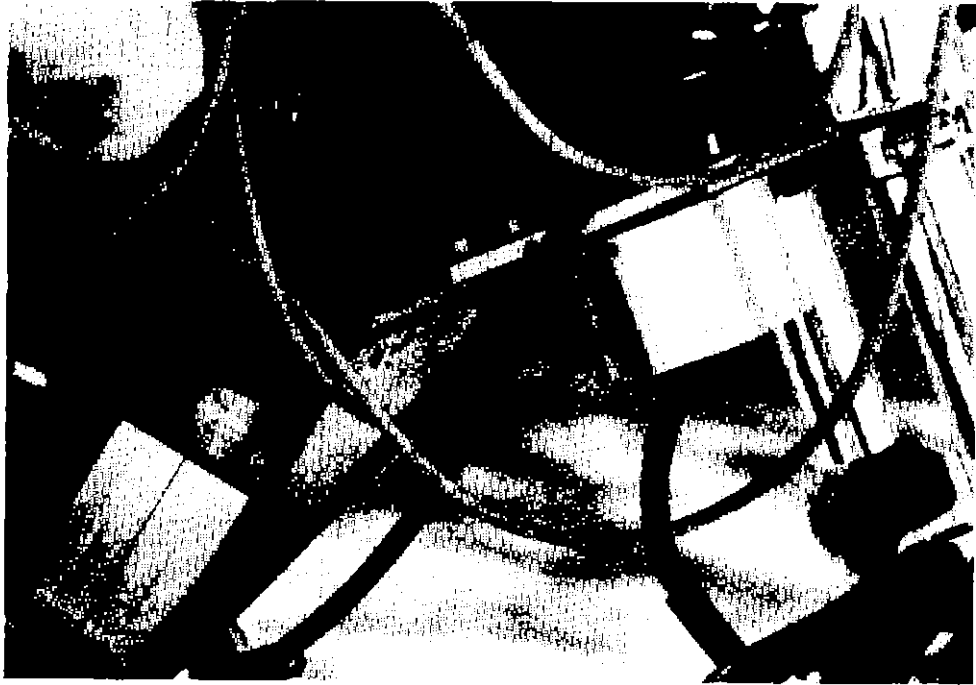


Figure A.6 Steer angle transducer.



- 1 and 2 - Gyro mounting rings.
- 3 - Yaw rate gyro.
- 4 - Roll rate gyro.

Figure A.7 Position of roll and yaw rate gyros.

tion mounts which attenuated vibrations above about 20 Hz. Both roll and yaw gyros used initially had a range of  $\pm 60$  deg/s, which was found to be adequate during moderate manoeuvres. However, during the more severe manoeuvres these gyros were too sensitive. In order to capture the maximum roll and yaw rates achieved by the more skilled riders it was necessary to use  $\pm 200$  deg/s gyros!

Specifications:

- Range:  $\pm 60$  deg/s.
- Accuracy: (including linearity and hysteresis) 1.0% of full scale at 0 deg/s rate input, increasing to 2.0% of fullscale at maximum rate.
- Frequency Response: DC to 22 Hz.
- Nominal mass: 340 gm.
- Range:  $\pm 200$  deg/s.
- Accuracy: (including linearity and hysteresis) 4.0%.
- Frequency response: DC to 10 Hz plus.
- Nominal mass: 400 gm.

Note: Since the yaw rate gyro is fixed to the motorcycle frame, the measured yaw rate ( $r$ ) will differ from the yaw rate ( $R$ ) about a vertical axis by the cosine of the roll angle ( $\phi$ ):

$$r = R \cos \phi$$

Unless otherwise specified the values shown for yaw rate are the body-fixed component  $r$ .

#### A.5.4 Front and Rear Brake Force

Strain gauges positioned as shown in Figures A.8 and A.9 were used (full bridge configuration).

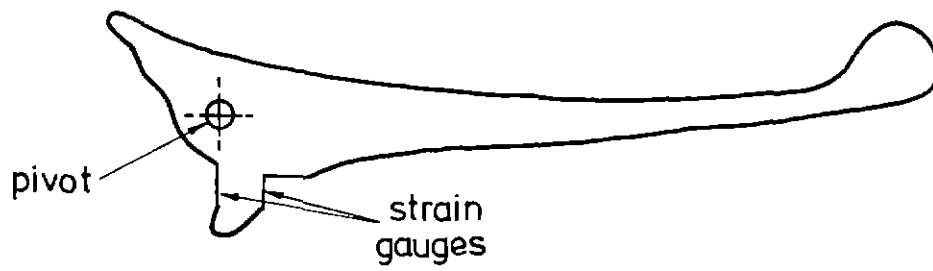
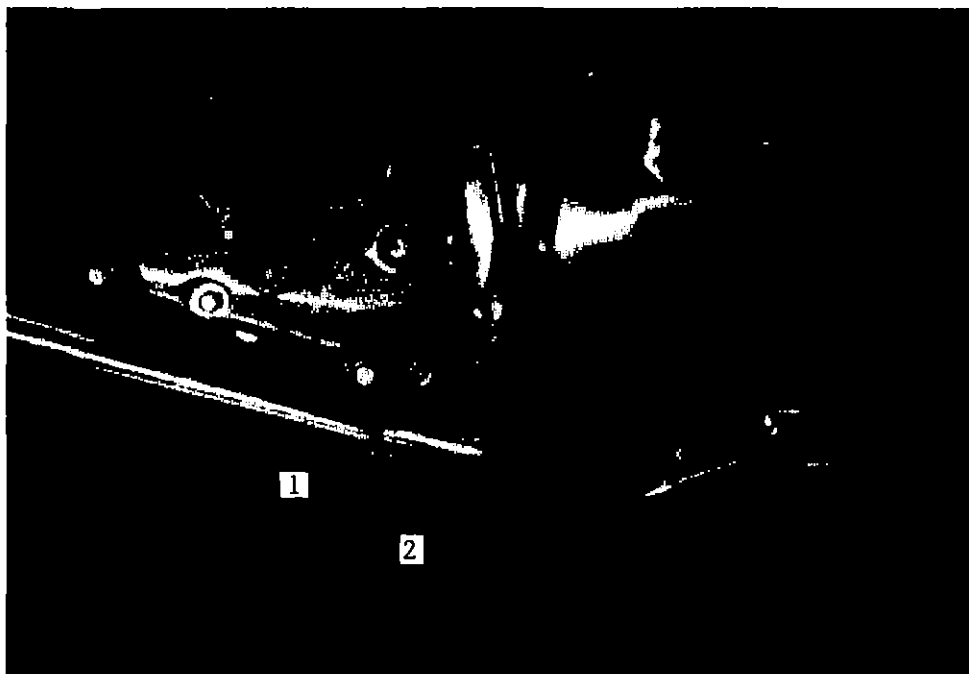


Figure A.8 Position of strain gauges for front brake force.



1 - Fulcrum.

2 - Strain gauges.

Figure A.9 Position of strain gauges for rear brake force transducer.



The sensitivities are as follows:

Front brake<sup>\*</sup>: 62.6 N/Volt

Rear Brake<sup>+</sup> : 30.2 N/Volt

\* The point of application of the load for calibration was 12 cm from the lever fulcrum. This point represents the 'usual' position of the middle finger when a force is applied to the front lever by a rider.

+ For the rear brake the point at which the rider applies force to the lever is approximately 300 mm from the lever fulcrum. The signal from the strain gauge arrangement, which was mounted close to the fulcrum, was found to be relatively insensitive to normal variations in foot position on the brake pedal during force application.

#### A.5.5 Rider Lean and Pitch Angle

The set-up, depicted in Figure A.10 and A.11, consists of two precision potentiometers mounted orthogonally to measure any combination of rider pitch and lean angles. The pots are connected to a balsa-wood rod which passes through a small ring attached to the rider's back, thereby causing no restriction to the rider's movements. The pivot point of the arrangement is positioned to coincide, approximately, with the rider's effective upper body hinge point just aft of the rider's hips. It should be noted that this arrangement monitors the rider's lean and pitch angle relative to the motorcycle. The performance of this transducer, and a modified transducer for measuring the three rotational degrees of freedom of the upper torso, was examined in detail in Appendix J.

#### Specifications:

- Range: Lean  $\pm 20$  deg.  
Pitch  $\pm 20$  deg.
- Accuracy: 0.3 deg.

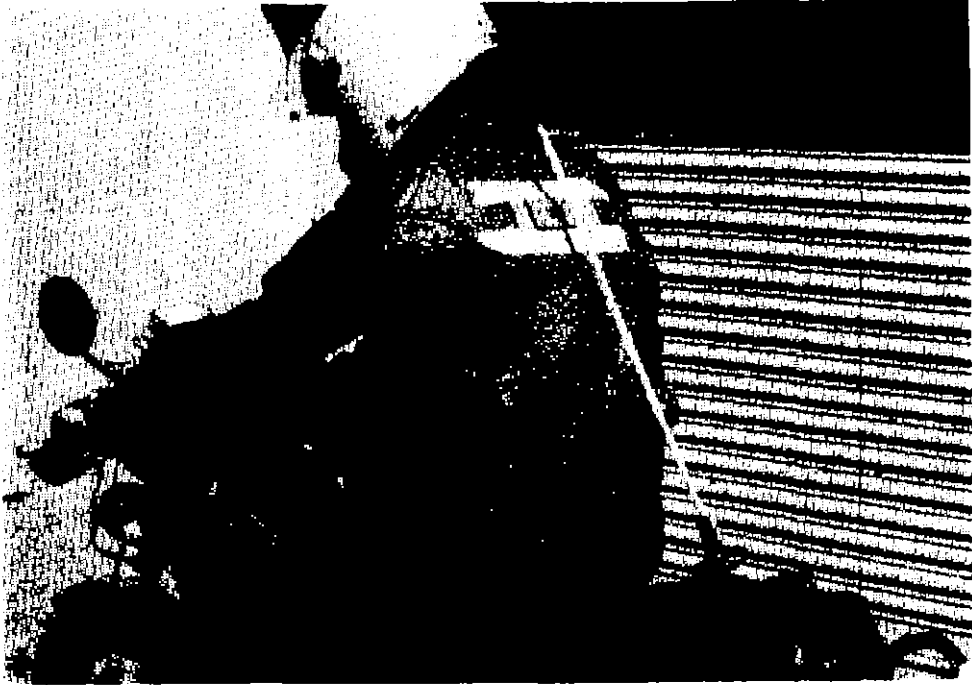
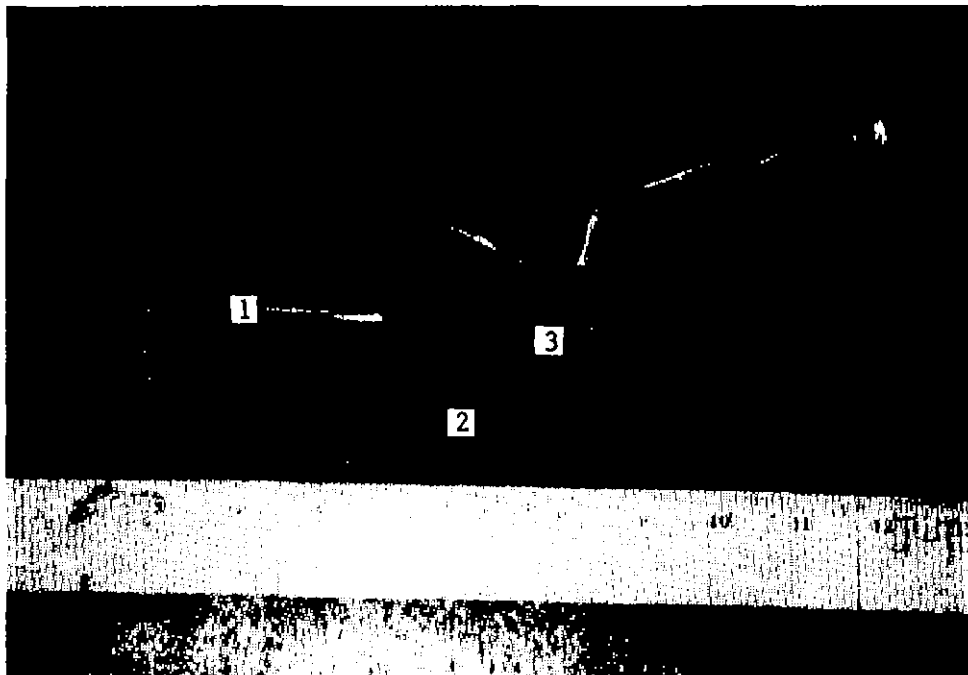


Figure A.10 Rider lean and pitch angle transducer.



- 1 - Rod.
- 2 - Pitch potentiometer.
- 3 - Lean potentiometer.

Figure A.11 Rider lean and pitch transducer.

#### A.5.6 Lateral Acceleration

The transducer used for this application was a Schaevitz linear servo accelerometer model no. LSMP-1. It was mounted rigidly to the main frame of the motorcycle, in the position shown in Figure A.12, such that its sensitive axis was perpendicular to the plane of symmetry of the motorcycle. Since the environment in which the transducer operates is rather noisy, the output of the accelerometer was filtered at 20 Hz.

##### Specifications:

- Range:  $\pm 1g$ .
- Linearity: 0.01%
- Frequency response (unfiltered): DC to 98 Hz.
- Nominal mass: 60gm.

#### A.5.7 Speed

Speed was monitored by driving a slotted disc from the speedometer cable which is driven by the front wheel (see Figure A.3 and A.13). Rotation of the disc produced a signal, via an optical pickup, the frequency of which was proportional to the angular velocity of the disc. A frequency to voltage converter acted on this signal to produce an output which was proportional to the speed of the motorcycle.

This arrangement proved to be most suitable since it was necessary that the speedometer still function so as to give the rider feedback on speed.

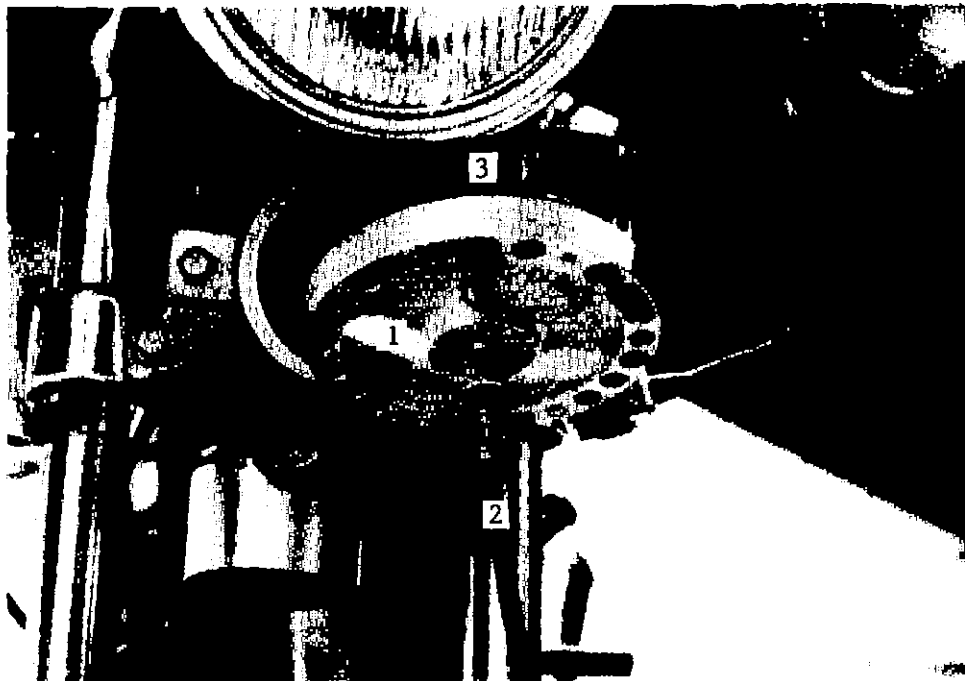
- Range: 0 to 160 km/h.
- Frequency response: DC to 2 Hz.
- Nominal mass: 470 gm.

Note: Since the system is only capable of monitoring 8 channels, a switch is incorporated so that it is possible to switch between channels and hence monitor any 8 of the 10 variables described. This was necessary for some of the experiments.



1 - Accelerometer

Figure A.12 Location of lateral acceleration transducer.



1 - Slotted disc housing.

2 - Drive cable.

3 - Cable to speedometer.

Figure A.13 Speed transducer driven by speed cable.

SUBJECT NO. \_ \_ \_ \_

QUESTIONNAIRE FOR MOTORCYCLE/RIDER TESTS

PART A

1. NAME \_ \_ \_ \_ \_
2. SEX                      MALE ☐                      FEMALE ☐
3. AGE                      YEARS \_ \_ \_ \_ MONTHS \_ \_ \_ \_
4. WHICH OF THE FOLLOWING DO YOU HAVE
  - a. DRIVERS LICENCE ☐
  - b. MOTORCYCLE LICENCE ☐
  - c. LEARNERS PERMIT FOR MOTORCYCLE ☐
  - d. ANY OTHER LICENCE \_ \_ \_ \_ \_  
\_ \_ \_ \_ \_
5. HOW MUCH ON STREET RIDING EXPERIENCE DO YOU HAVE?

NONE <input type="checkbox"/>	1-6 MONTHS <input type="checkbox"/>	6-12 MONTHS <input type="checkbox"/>
	1-3 YEARS <input type="checkbox"/>	3-5 YEARS <input type="checkbox"/>

IF GREATER HOW MANY YEARS? \_ \_ \_ \_ \_
6. HOW MUCH OFF-ROAD RIDING EXPERIENCE DO YOU HAVE?

NONE <input type="checkbox"/>	1-6 MONTHS <input type="checkbox"/>	6-12 MONTHS <input type="checkbox"/>
	1-3 YEARS <input type="checkbox"/>	3-5 YEARS <input type="checkbox"/>

IF GREATER HOW MANY YEARS? \_ \_ \_ \_ \_
7. HAVE YOU HAD ANY COMPETITION EXPERIENCE?

YES <input type="checkbox"/>	NO <input type="checkbox"/>
------------------------------	-----------------------------

IF YES, DESCRIBE:-

8. HOW MANY KILOMETRES/MILES DO YOU RIDE IN THE AVERAGE WEEK?

ON ROAD \_ \_ \_ \_ \_ (KILOMETRES/MILES)

OFF ROAD \_ \_ \_ \_ \_ (KILOMETRES/MILES)

IN THE AVERAGE YEAR? (MAY NOT APPLY TO SOME RIDERS)

ON ROAD \_ \_ \_ \_ \_ (KILOMETRES/MILES)

OFF ROAD \_ \_ \_ \_ \_ (KILOMETRES/MILES)

9. WHAT KIND OF MOTORCYCLE DO YOU OWN?

NONE ☐

ROAD BIKE ☐

HOW MANY? \_ \_ \_ \_ \_

WHAT ENGINE CAPACITY? \_ \_ \_ \_ \_ CC

\_ \_ \_ \_ \_ CC

\_ \_ \_ \_ \_ CC

TRAIL BIKE ☐

HOW MANY? \_ \_ \_ \_ \_

WHAT ENGINE CAPACITY? \_ \_ \_ \_ \_ CC

\_ \_ \_ \_ \_ CC

\_ \_ \_ \_ \_ CC

10. WHICH ONE DO YOU RIDE MOST OFTEN? \_ \_ \_ \_ \_

11. IF YOUR ANSWER TO 9 IS "NONE" WHICH KIND OF  
MOTORCYCLE IS AVAILABLE TO YOU TO RIDE? \_ \_ \_ \_ \_

12. WHO TAUGHT YOU TO RIDE A MOTORCYCLE?

FRIEND ☐

DEALER ☐, GIVE DETAILS \_ \_ \_ \_ \_

RELATIVE ☐

SELF ☐

MOTORCYCLE COURSE ☐, IF SO GIVE DETAILS:

DRIVING SCHOOL ☐, GIVE DETAILS:

PART B

1. IF YOU WERE REQUIRED TO BRAKE SUDDENLY ON A DRY ROAD, WOULD YOU USE

- a. BACK BRAKE ONLY ☐
- b. FRONT BRAKE ONLY ☐
- c. BOTH BRAKES ☐

ON A WET ROAD WOULD YOU USE

- a. BACK BRAKE ONLY ☐
- b. FRONT BRAKE ONLY ☐
- c. BOTH BRAKES ☐

2. DESCRIBE BRIEFLY THE SEQUENCE OF BODY MOVEMENTS AND/OR STEERING ACTIONS YOU WOULD PERFORM IN ORDER TO:

- a. MAKE A LEFT HAND LANE CHANGE -
- b. KEEP YOUR BIKE UPRIGHT GOING IN A STRAIGHT LINE -
- c. KEEP YOUR BIKE AT A CONSTANT ANGLE OF LEAN IN A STEADY TURN -

3. YOU HAVE JUST ENTERED A STEADY CURVE AND REALIZE THAT YOU ARE GOING TOO FAST AND ARE LIKELY TO RUN WIDE. WHAT WOULD YOU DO TO PREVENT THIS HAPPENING?

IF YOU COULD NOT BRAKE IN THE ABOVE SITUATION WHAT WOULD YOU DO?



## APPENDIX C

## APPLICANT TEST INSTRUCTIONS

## GENERAL TEST INSTRUCTIONS

The Skill Test you will take is not hard. People fail to pass it on their first attempt simply because they do not use the correct procedures. Follow these steps:

1. Read the description of the test exercises and scoring criteria given.
2. Practice performing the manoeuvres called for in the exercises. In particular, practice the following:
  - Making quick stops using both brakes.  
You cannot pass the Test using the rear brake alone.
  - Stopping in a turn without straightening up the motorcycle or locking the rear wheel.
  - Reaching a set speed (24 and 32 kph) and holding it without looking at the speedometer.
3. Warm up before you take the Test. You can warm up in any part of the paved area except in the test area itself.
4. When you take the Test, follow these rules:
  - Make sure you stay within the painted lines on all exercises. Going outside the lines means failing the exercise. On Exercise VI you will be asked to ride a curved path as fast as you safely can. You shouldn't go so fast that you can't stay within the path.
  - On the last three exercises, you will be asked to approach a signal light at a set speed. You should set your speed as you approach the exercise and then concentrate on watching the signal light.

## TEST EXERCISES AND SCORING CRITERIA DESCRIPTION

### Exercises 2 - 5

#### Sharp Turn, Turning Control Right/Left, and Stopping Judgment

For these test exercises, the applicant accelerates from a stop and immediately makes a sharp right turn followed by a gradual turn to the right. The path is 1.5 m wide at first and then narrows to 1 m for the gradual left-right turning exercises. The applicant is required to accelerate to 32 kph before completion of the gradual right turn. The left turn employs the same path but from the opposite direction. The applicant must re-enter for the left turn at 32 kph, slow while on the gradual left-hand curve, and then gradually bring the motorcycle to a complete stop.

The applicant is scored on:

##### Sharp Turn

- Staying within the path
- Unnecessary use of the feet while moving

##### Turning Control Right/Left

- Staying within the path
- Travel time

##### Stopping Judgment

- Skidding the wheels
- Stopping at a predetermined area

### 6. Turning Speed Judgment

For this manoeuvre, the applicant rides on a 2.4 m curved path. The applicant rides as fast as he safely can.

The applicant is scored on:

- Staying within the path
- Travel time for the curve

### 7. Quick Stop - Straight

The applicant rides a straight path shifting up to second gear and stabilizes cycle speed at 32 kph. The path is 1 m wide. At the predetermined point, a red light automatically flashes signalling the applicant to stop. When the light is activated, the applicant is to bring the motorcycle to a stop as quickly and as safely as possible. The motorcycle speed is recorded by a timing device which provides an accurate measure of speed to one-thousandth of a second.

The applicant is scored on:

- Distance travelled from signal light point.

## 8. Signal Turn

For this exercise, the applicant rides a 1 m path at 32 kph. Speed is measured with a timing device. A light is automatically activated which signals the applicant to turn quickly to the left or right in the direction of the activated signal. This manoeuvre simulates avoidance of a frontal barrier (i.e, car) and recovery to the original heading without leaving the travel lane. The frontal barrier is 2.4 m wide. The recovery is delineated by restricting lines 1.8 m on each side of the frontal barrier. The direction of the turn is not known by the applicant. The examiner presets the signal light in the desired direction of the turn.

The applicant is scored on:

- Following the course signalled.

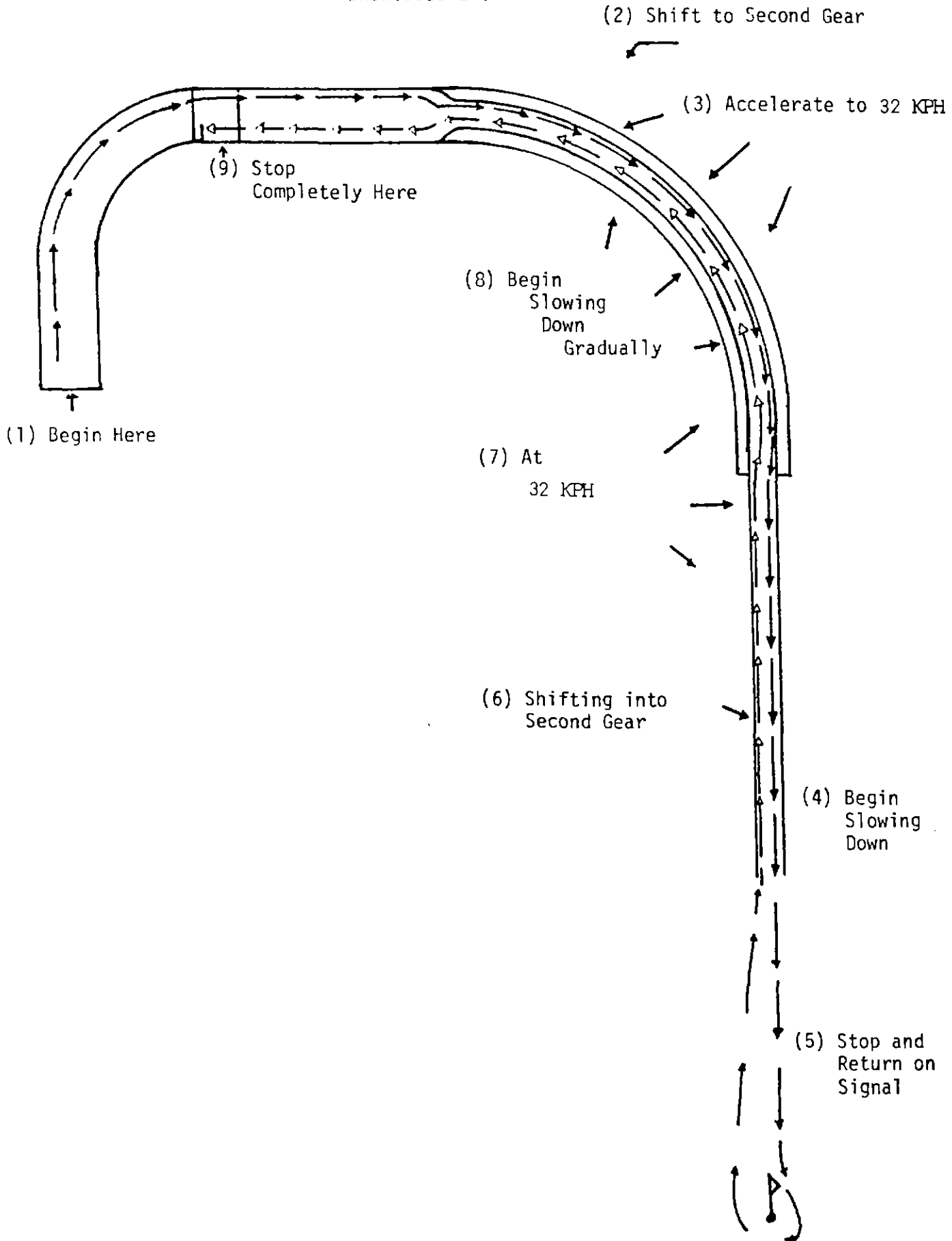
## 9. Quick Stop - Curve

The applicant rides at 24 kph and enters a left-hand curve. At a predetermined point, a signal light activates automatically and the applicant must stop the motorcycle quickly and safely while following the path. The path is 1 m wide. Operator speed is recorded with a timing device.

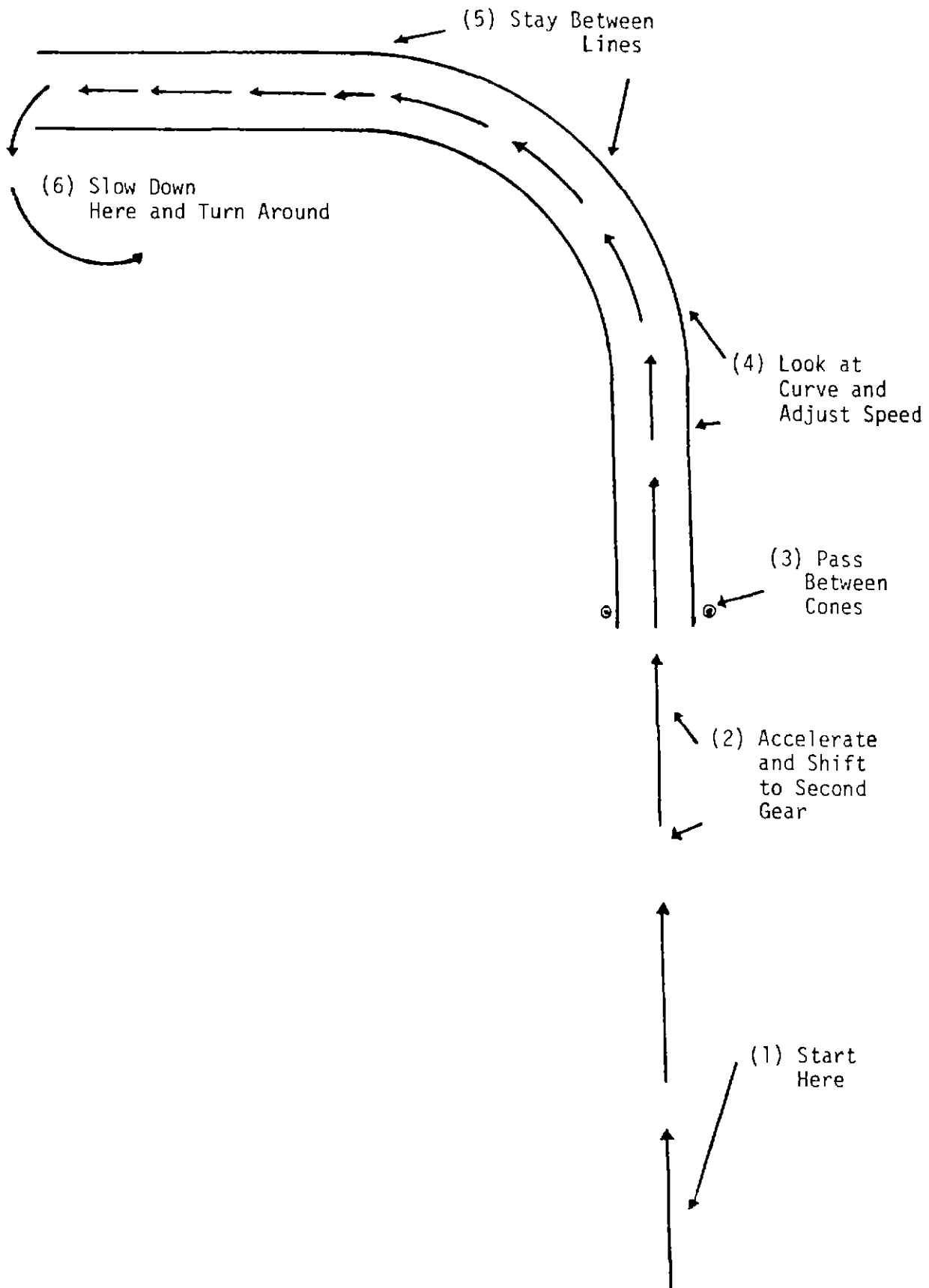
The applicant is scored on:

- Staying within the path
- Distance travelled in stopping.

APPLICANT INSTRUCTIONS  
EXERCISES 2-5



APPLICANT INSTRUCTIONS  
EXERCISE 6

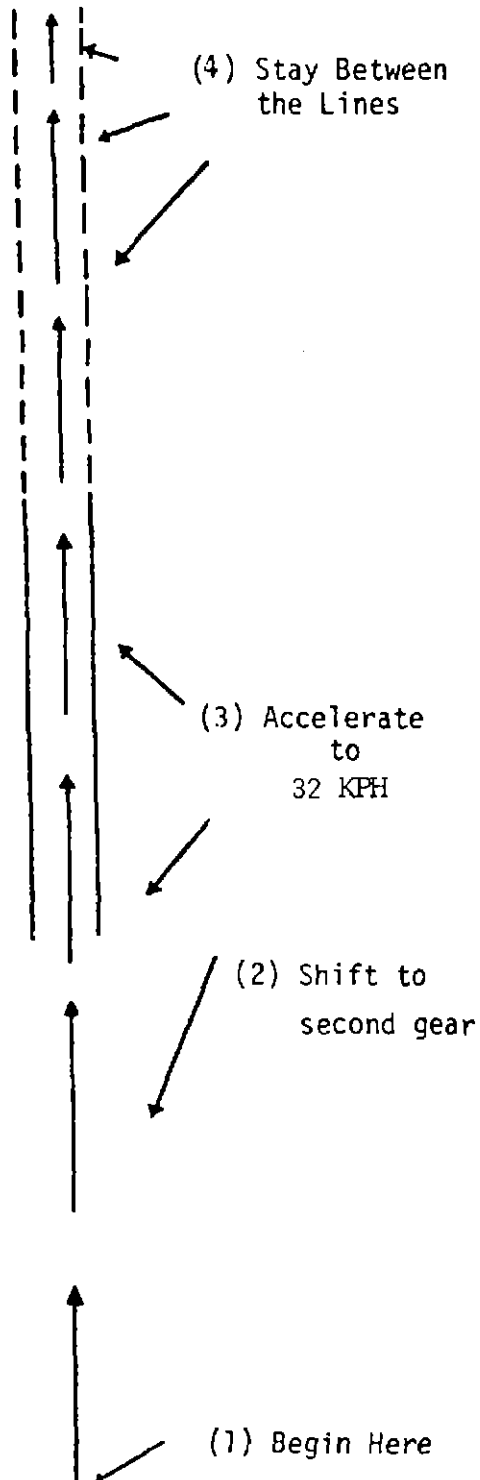


## APPLICANT INSTRUCTIONS

## EXERCISE 7

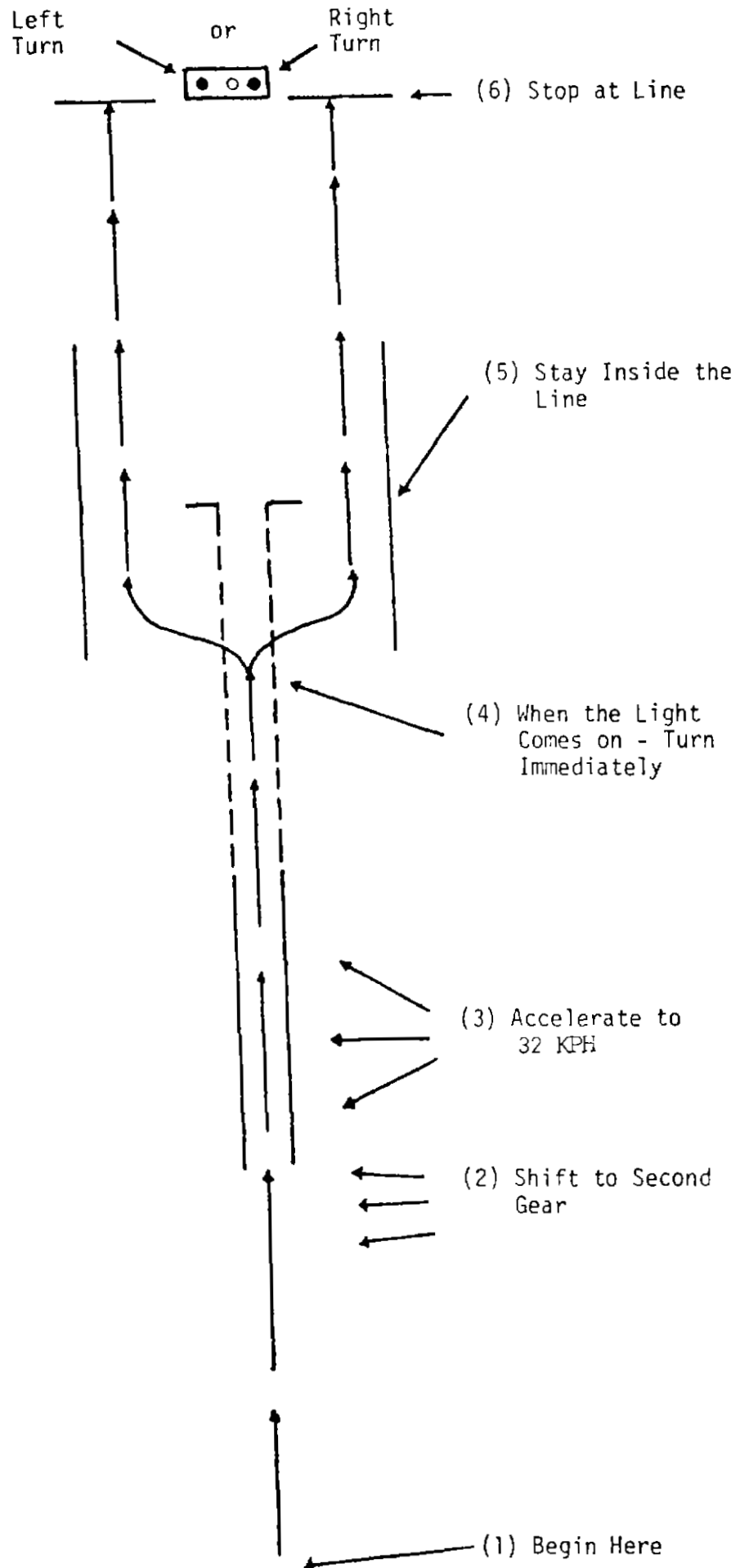


(5) When the Red Light Comes On - Stop the Motorcycle



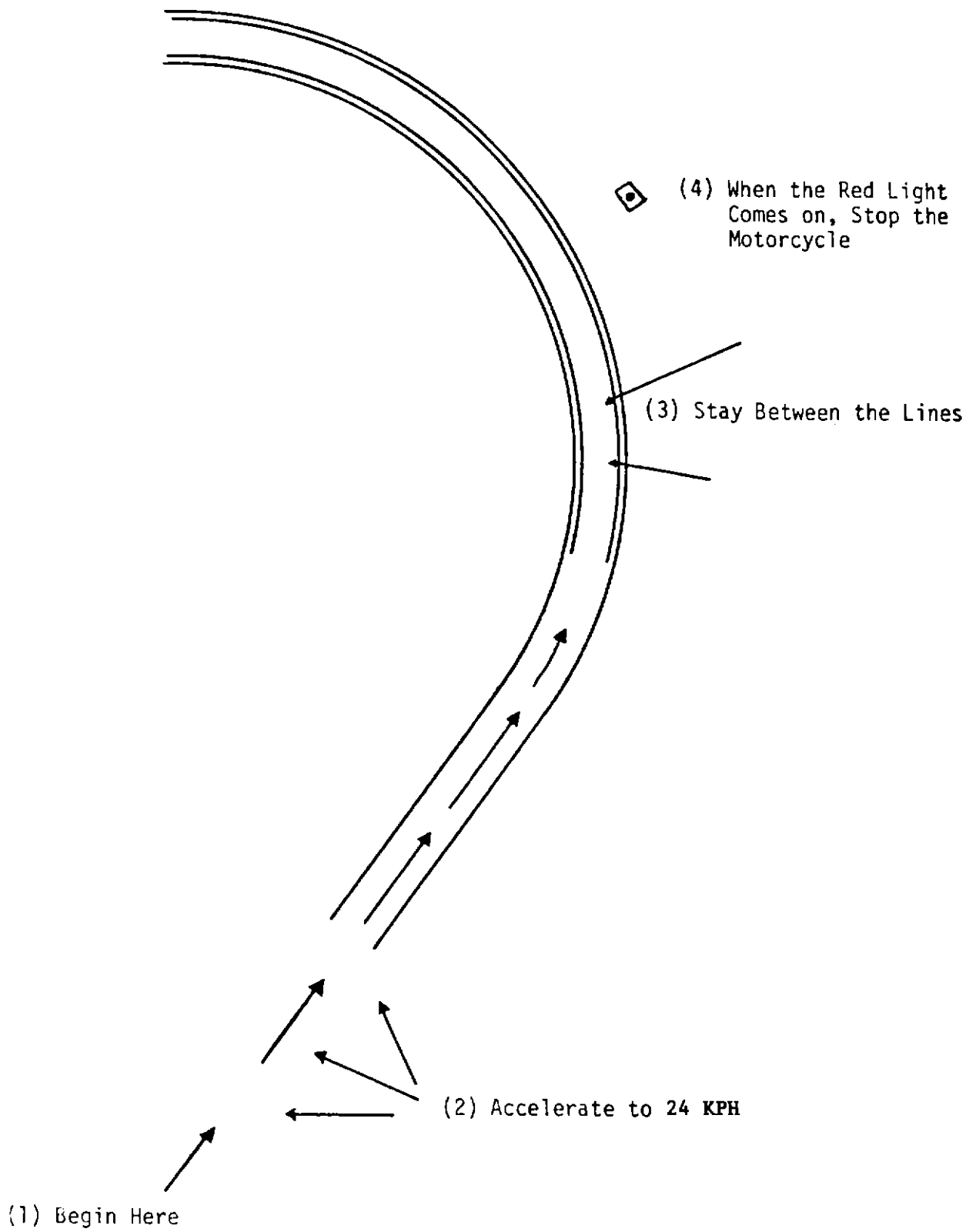
## APPLICANT INSTRUCTIONS

## EXERCISE 8



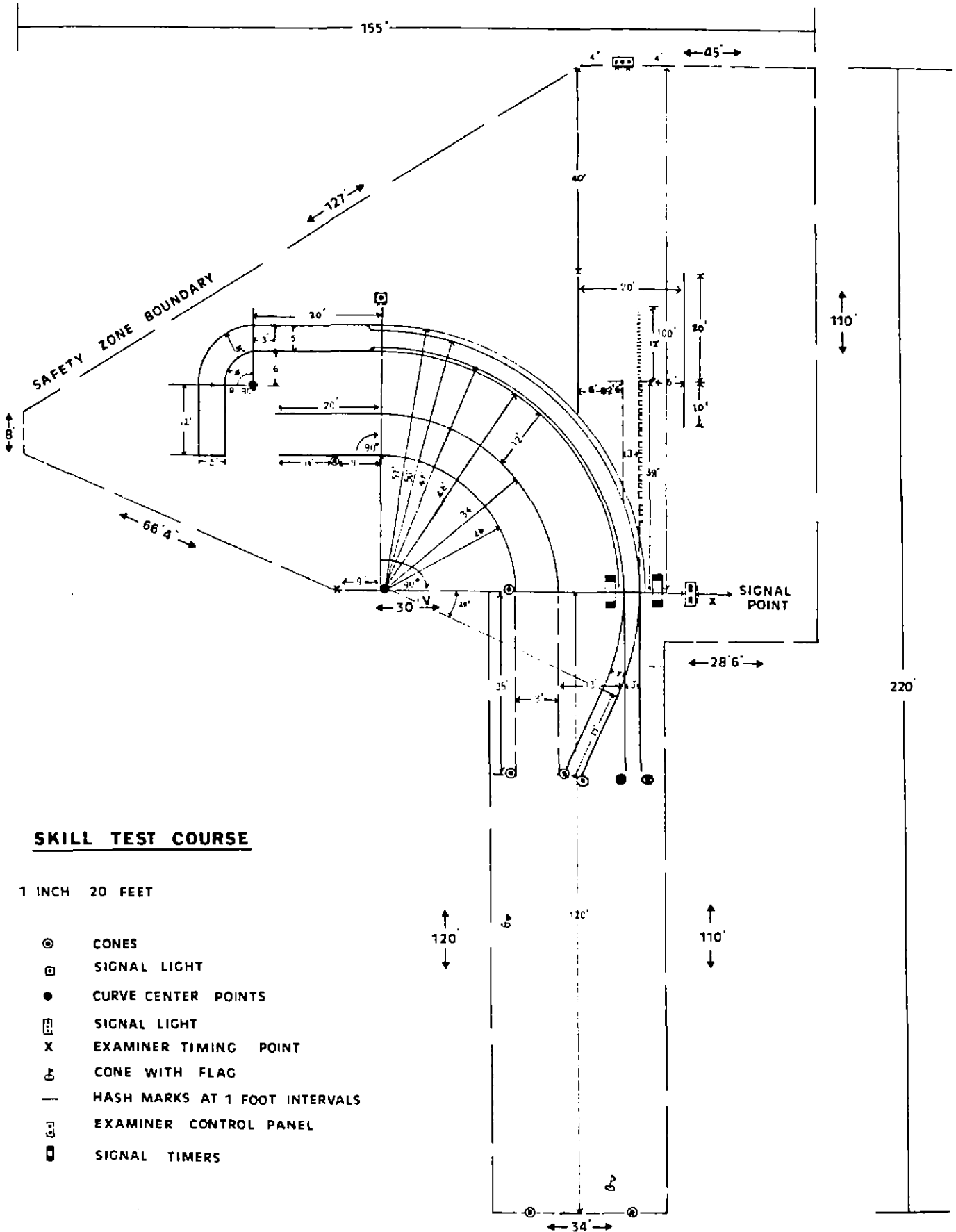
## APPLICANT INSTRUCTIONS

## EXERCISE 9





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APPENDIX D



## APPENDIX E

**EXERCISE II — Sharp Turn, EXERCISE III — Accelerating In A Turn, EXERCISE IV — Slowing In A Turn, EXERCISE V — Normal Stop**

- BEGIN HERE WITH A RIGHT TURN, AND
- RIDE THIS WHITE PATH (POINT) TO THE END.
- BE RIDING AT 32 KPH IN SECOND GEAR WHEN YOU REACH THE END — THE WHITE CONES.
- THEN SLOW DOWN AND TURN AROUND BY THE WHITE FLAG.
- THEN RE-ENTER THE PATH AT THE WHITE CONES AT 32 KPH IN SECOND GEAR.
- SLOW ON THE CURVE AS NECESSARY IN ORDER TO COME TO A SMOOTH STOP WITH YOUR FRONT TIRE IN THAT BOX (POINT).
- DO YOU HAVE ANY QUESTIONS?

**EXERCISE VI — Turning Speed Selection**

- GO TO THAT WHITE FLAG (POINT).
- THEN RIDE BETWEEN THE 2 YELLOW CONES (POINT), AND
- FOLLOW THE YELLOW CURVED PATH UNTIL YOU RIDE BEYOND THE LINES.
- WHEN YOU FINISH, SLOW DOWN AND RIDE OVER TO ME.
- THIS IS IMPORTANT — RIDE THE CURVE AS FAST AS YOU SAFELY CAN WITHOUT TOUCHING A LINE.
- DO YOU HAVE ANY QUESTIONS?

**EXERCISE VII — Quick Stop — Straight**

- START AT THE WHITE FLAG.
- AT A SPEED OF 32 KPH IN SECOND GEAR RIDE STRAIGHT DOWN THIS WHITE PATH AND ENTER THE GREEN PATH (POINT). YOU SHOULD BE IN SECOND GEAR AND STABILIZED AT 32 KPH WHEN YOU REACH THE WHITE PATH.
- WHEN THE RED LIGHT GOES ON (POINT)
- COME TO A COMPLETE STOP AS QUICKLY AND AS SAFELY AS YOU CAN, THEN
- REMAIN STOPPED.
- REMEMBER, 32 KPH
- DO YOU HAVE ANY QUESTIONS?

**EXERCISE VIII — Obstacle Turn [Left/Right]**

- RIDE THE SAME PATH (WHITE/GREEN) AGAIN AT 32 KPH
- YOU SHOULD BE IN SECOND GEAR.
- THIS TIME YOU WILL BE GIVEN A SIGNAL LIGHT TO TURN LEFT OR RIGHT (POINT).
- WHEN THE LIGHT GOES ON (POINT)
- TURN IN THE DIRECTION OF THE LIGHT IN ORDER TO GO AROUND THE RED LINE IN FRONT OF YOU.
- TURN BACK BEFORE YOU CROSS THE RED LINE ON THE SIDE (THAT ONE OR THAT ONE, POINT).
- STOP NEAR THE LINE DOWN THERE (POINT), THEN RIDE OVER TO ME.
- IF YOU ARE GOING TOO FAST, ALL LIGHTS WILL COME ON. DON'T ATTEMPT TO TURN, SLOW DOWN AND RIDE BACK TO ME.
- DO YOU HAVE ANY QUESTIONS?

**EXERCISE IX — Quick Stop — Curve**

- START AT THE RED FLAG.
- ENTER THE RED PATH AT 24 KPH, AND CONTINUE INTO THE WHITE CURVED PATH (POINT).
- WHEN THAT RED LIGHT GOES ON (POINT)
- COME TO A COMPLETE STOP AS QUICKLY AND SAFELY AS YOU CAN, WITHOUT TOUCHING ANY LINE, THEN
- REMAIN STOPPED.
- REMEMBER, STAY ON THE CURVE AND RIDE AT 24 KPH
- DO YOU HAVE ANY QUESTIONS?

EXERCISE II--Sharp Turn

Performance	Criteria	Penalty Points	Maximum Penalty Points	Exercise Points
A. Remaining on path.	Motorcycle operated out of manoeuvre path.			
	(1) Tyre touches lateral manoeuvre boundary line.	3		
	(2) Tyre crosses lateral manoeuvre boundary line.	5	5	
B. Feet for Balance.	Uses feet to support the motorcycle during movement.			
	(1) Touches the surface with either foot or both feet or drags either or both feet on the surface.	1	1	6

EXERCISE III--Accelerating In A Turn

A. Remaining on path.	Any deviation from the manoeuvre path marked by two sets of lateral boundary lines.			
	(1) Tyre touches the inside boundary line, goes between boundary lines, or touches the outside boundary line.	3		
	(2) Tyre crosses outside boundary line.	5	5	
B. Total time in seconds to complete exercise.	Elapsed time from the beginning of Exercise II to the end of Exercise III.			
	(1) More than ten through eleven seconds	1		
	(2) More than eleven through twelve seconds	3		
	(3) More than twelve seconds	5	5	10

## EXERCISE IV--Slowing In A Turn

Performance	Criteria	Penalty Points	Maximum Penalty Points	Exercise Points
A. Remaining on path.	Any deviation from the manoeuvre path marked by two sets of lateral boundary lines.			
	(1) Tyre touches inside boundary line, goes between boundary lines, or touches outside boundary lines	3		
	(2) Crosses outside boundary line	5	5	
B. Total time in seconds to complete exercise.	Elapsed time from the beginning of Exercise IV to the moment the front tire crosses the front line of the stopping box in Exercise V, or stopping of the motorcycle any time before the stopping box.			
	(1) More than seven through eight seconds	1		
	(2) More than eight through nine seconds	3		
	(3) More than nine seconds	5	5	10

## EXERCISE V--Normal Stop

A. Skid.	Locking either wheel at any time.			
	(1) Any detectable skid	3	3	
B. Stopped position.	In the final stopped position, any portion of the front wheel touching the stopping box line(s) (tyre in surface contact with the painted stop box lines or surface outside the box).			
	(1) Short or long of stopping box	5	5	8

## EXERCISE VI--Turning Speed Selection

Performance	Criteria	Penalty Points	Maximum Penalty Points	Exercise Points
A. Total time in seconds to complete exercise.	Elapsed time recorded from the first timing point to the second timing point.			
	(1) 2.4 seconds	1		
	(2) 2.5 seconds	3		
	(3) 2.6 seconds and over	5	5	
B. Remaining on path.	Any deviation from the manoeuvre path marked by solid boundary lines.			
	(1) Tyre touches or crosses boundary line	5	5	10

## EXERCISE VII--Quick Stop--Straight

A. Distance in feet for stopping.	Stopping distance measured from the extreme front of the fronttyre . The distance standard is associated with acceptable entry speeds. The Time/Distance Chart must be used to score the applicant.			
	(1) One foot beyond standard	1		
	(2) Two feet beyond standard	2		
	(3) Three feet beyond standard	3		
	(4) Four feet beyond standard	4		
	(5) Five feet beyond standard	5	5	5

## EXERCISE VIII--Obstacle Turn (Left/Right)

Performance	Criteria	Penalty Points	Maximum Penalty Points	Exercise Points
A. Follows course.	Any deviation from the prescribed path in the direction signalled.			
	(1) Tyres touch the frontal barrier or a lateral boundary, fail to turn, or a turn in the wrong direction .	5	5	5

## EXERCISE IX--Quick Stop--Curve

A. Remaining on path.	Any deviation from the manoeuvre path marked by the inside boundary lines.			
	(1) Either tyre touches or crosses boundary lines.	3	3	
B. Distance in feet for stopping.	Stopping distance measured from the extreme front of the front tyre. The distance standard is associated with acceptable entry speeds. The Time/Distance Chart must be used to score the applicant.			
	(1) One foot beyond standard	1		
	(2) Two feet beyond standard	2		
	(3) Three feet beyond standard	3		
	(4) Four feet beyond standard	4		
	(5) Five feet beyond standard	5	5	

TOTAL TEST SCORE

8

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# RIDERS WANTED

LEARNERS, JUST LICENSED AND EXPERIENCED RIDERS

ARE NEEDED FOR MOTORCYCLE/RIDER TESTS BEING CONDUCTED BY THE DYNAMIC SYSTEMS GROUP IN THE DEPARTMENT OF MECHANICAL ENGINEERING OF THE UNIVERSITY OF MELBOURNE.

YOU WILL BE REQUIRED TO RIDE AN INSTRUMENTED MOTORCYCLE WHICH ALLOWS US TO MONITOR HOW THE MOTORCYCLE IS BEING CONTROLLED AND HOW IT RESPONDS TO THE CONTROL.

THE TESTS ARE PURELY EXPERIMENTAL AND WILL NOT IN ANY WAY AFFECT YOUR CURRENT RIDING STATUS.

THIS IS AN IDEAL OPPORTUNITY TO SEE HOW YOU RIDE.

THE ONLY REWARD WE CAN OFFER IS THAT OF HAVING RIDDEN THIS TWO-WHEELED MARVEL.

IF YOU ARE AT ALL INTERESTED, AND/OR HAVE FRIENDS WHO WOULD BE INTERESTED, PLEASE CONTACT HANS PREM ON 341 6736. IF I'M NOT THERE, PLEASE LEAVE YOUR NAME AND DETAILS OF HOW YOU CAN BE CONTACTED.

## APPENDIX H

INSTRUCTIONS

At a speed of 32 KPH ride down this path. You should be in second gear and stabilized at 32 KPH when you reach the path.

When on the path you will be given one of the following combinations of lights.

All three red - if this occurs you will be required to come to a complete stop as quickly and as safely as you can. Try to stop before you reach the line representing the obstacle.

Green only, left or right - If this occurs turn in the direction of the light in order to go around the line representing the obstacle in front of you (point). Turn back before you cross the boundary line (point).

Green-Red-Green - if this occurs you have to make a choice. You can brake to stop before the line representing the obstacle and/or avoid the obstacle by going to the left or the right. Imagine the obstacle to be a vehicle and you have to decide how you can avoid hitting it. Remember you can brake and/or avoid the obstacle to the right or left.

No lights - If this occurs there is no hazard. Continue straight through.

If you are given a left hand manoeuvre continue around to the left and re-enter the path there (point).

If you are given a right hand manoeuvre continue around to the right and re-enter the path at the same point, continue until I instruct you that the test is over. If you are given a braking manoeuvre you can choose the direction to go to re-enter the path.



NOTE:

The difficulty of each task performed will vary randomly and tasks may be repeated. You may not perform some manoeuvres successfully, do not despair, the harder tasks have been designed this way. Try your best and attempt what you can. Any questions?

## APPENDIX I

CHARACTERISTIC EQUATION ROOTS FOR THE ANALYSIS OF THE  
RIDER-LEAN STEERING MECHANISM

This appendix gives the roots of the characteristic equation of the various closed-loop rider/cycle control systems presented in Chapter 7.

The notation used to write the poles of the factored characteristic polynomial is that adopted by Weir (1972), i.e.,

$$A(s + a) \text{ is written } A(a)$$

$$A[s^2 + 2\zeta\omega_n s + \omega_n^2] \text{ is written } A[\zeta, \omega_n]$$

where:

$$\zeta = \text{damping ratio for the second order mode,}$$

$$\omega_n = \text{natural frequency (rad/s)}$$

The roots of the characteristic equation for the vehicle alone is as follows:

$$\Delta = 0.241(-0.0957)(17.1)[0.27, 16.0][0.43, 54.0]$$

and for the rider/cycle system, with the amount of lean-torque coupling indicated, they are:

Coupling stiffness (Nm/rad)	Characteristic equation roots
-----------------------------------	-------------------------------

$\phi/\phi_c$  system

0.0	0.241(-18.6)[0.59, 2.01][0.27, 15.9][0.43, 54.0]
-1.4	0.241(-18.6)[0.58, 2.01][0.27, 15.9][0.43, 54.0]
-13.6	0.241(-18.3)[0.57, 2.00][0.28, 16.1][0.43, 54.0]
-40.7	0.241(-18.2)[0.56, 1.99][0.29, 16.2][0.43, 54.0]
-67.8	0.241(-18.2)[0.56, 2.00][0.29, 16.2][0.43, 54.1]

$\psi/\psi_c$  system

0.0	0.241(-1.05)(-18.6)[0.27,1.84][0.29,15.9][0.43,54.0]
-1.4	0.241(-1.11)(-18.5)[0.25,1.79][0.29,16.0][0.43,54.0]
-13.6	0.241(-1.35)(-18.3)[0.19,1.60][0.29,16.5][0.43,53.9]
-40.7	0.241(-1.46)(-18.1)[0.16,1.51][0.29,16.7][0.43,53.9]
-67.8	0.241(-1.49)(-18.1)[0.14,1.49][0.29,16.8][0.43,53.9]

 $y/y_c$  system

0.0	0.241(-18.6)[0.76,0.99][0.20,1.48][0.28,15.9][0.43,54.0]
-1.4	0.241(-18.5)[0.77,1.01][0.18,1.43][0.29,16.0][0.43,54.0]
-13.6	0.241(-18.2)[0.85,1.08][0.074,1.29][0.28,16.5][0.43,53.9]
-40.7	0.241(-18.1)[0.87,1.10][0.025,1.22][0.28,16.7][0.43,53.9]
-67.8	0.241(-18.1)[0.88,1.10][0.010,1.21][0.28,16.8][0.43,53.9]

## APPENDIX J

### ANALYSIS OF THE UPPER-BODY MOTION TRANSDUCER

#### J.1 INTRODUCTION

The transducer used to measure upper-body lean and pitch for the experiments outlined in Chapters 4 and 5 is shown in Appendix A. The arrangement described is simple in principle and has been used by other researchers (Rice et al., 1976; Rice, 1978; Weir et al., 1978). During the course of the experiments it was observed, from the position of the 'lean stick' part of the transducer, that the riders were twisting their upper-body in some sort of synchronism with their steering action. It was realized that their twisting action would induce apparent rider lean angles in the transducer output which were not related to a lateral shift in the centre of mass of the upper-body. The performance of this transducer is examined in detail in this appendix to determine what effect twisting of the upper-body has on the lean measurements made. Further, a modified transducer was developed and used to measure the three degrees of freedom of the upper-body of three riders performing lane-change manoeuvres.

#### J.2 ANALYSIS OF UPPER-BODY MOVEMENT

The rider's upper-body during 'normal' riding has effectively three degrees of freedom relative to the motorcycle. These are lean, which corresponds to sideways motion of the upper-body; pitch, a fore and aft motion; and twist, defined here as a rotation of the rider's upper-body about an axis which is parallel to the rider's spine and which passes through the lumbar vertebra.

Consider the angular displacement of the upper-body, shown in Figure J.1 as consisting of the rotations,  $\phi_R$  (lean),  $\theta_R$  (pitch), and  $\psi_R$  (twist) as shown. The three Euler angles,  $\phi_R$ ,  $\theta_R$  and  $\psi_R$ , specify the position of the x-y-z triad which is fixed in the rider. The z and twist axes are collinear and the y-axis is perpendicular to the rider's upper-body plane of symmetry. Fixed to the origin of this triad and aligned with the x, y and z axes are, respectively, the unit vectors  $\underline{i}$ ,  $\underline{j}$  and  $\underline{k}$ . Another set of axes is defined, X-Y-Z, which is fixed in the motorcycle and its origin coincides with the x-y-z axes origin. It has unit vectors  $\underline{I}$ ,  $\underline{J}$  and  $\underline{K}$ . The X-axis points forward and lies in the plane of symmetry of the motorcycle, the Y-axis points to the right of this plane, and the Z-axis points vertically downwards. These directions, and clockwise rotations about these axes, are defined as positive. Assume that the effective upper-body rotation axes all intersect at a unique point, and the origin of the X-Y-Z triad, and the point of rotation of the lean stick part of the transducer, are coincident with this point. Also shown in Figure J.1 is the vector  $\underline{r}$ , which defines the position of the transducer ring, through which the lean stick passes, and the vector  $\underline{R}$ , which defines the position of the upper-body centre of mass. In the x-y-z coordinate system these two vectors are given by:

$$\underline{r} = -b\underline{i} - a\underline{j} \quad (\text{J.1})$$

and

$$\underline{R} = -B\underline{i} + A\underline{j} \quad (\text{J.2})$$

The order in which the rotations are prescribed determines the final angular position of the upper-body (i.e. the rotations are not commutative). The rotation sequence was established by examining the angular displacement freedom of the original transducer, shown in Appendix A, and the modified one which is shown in Figures J.2 and J.3. The modified transducer differs from the original one in that it allows a component of upper-body twist to be measured. It operates as follows: The rod which drives the three potentiometers slides through

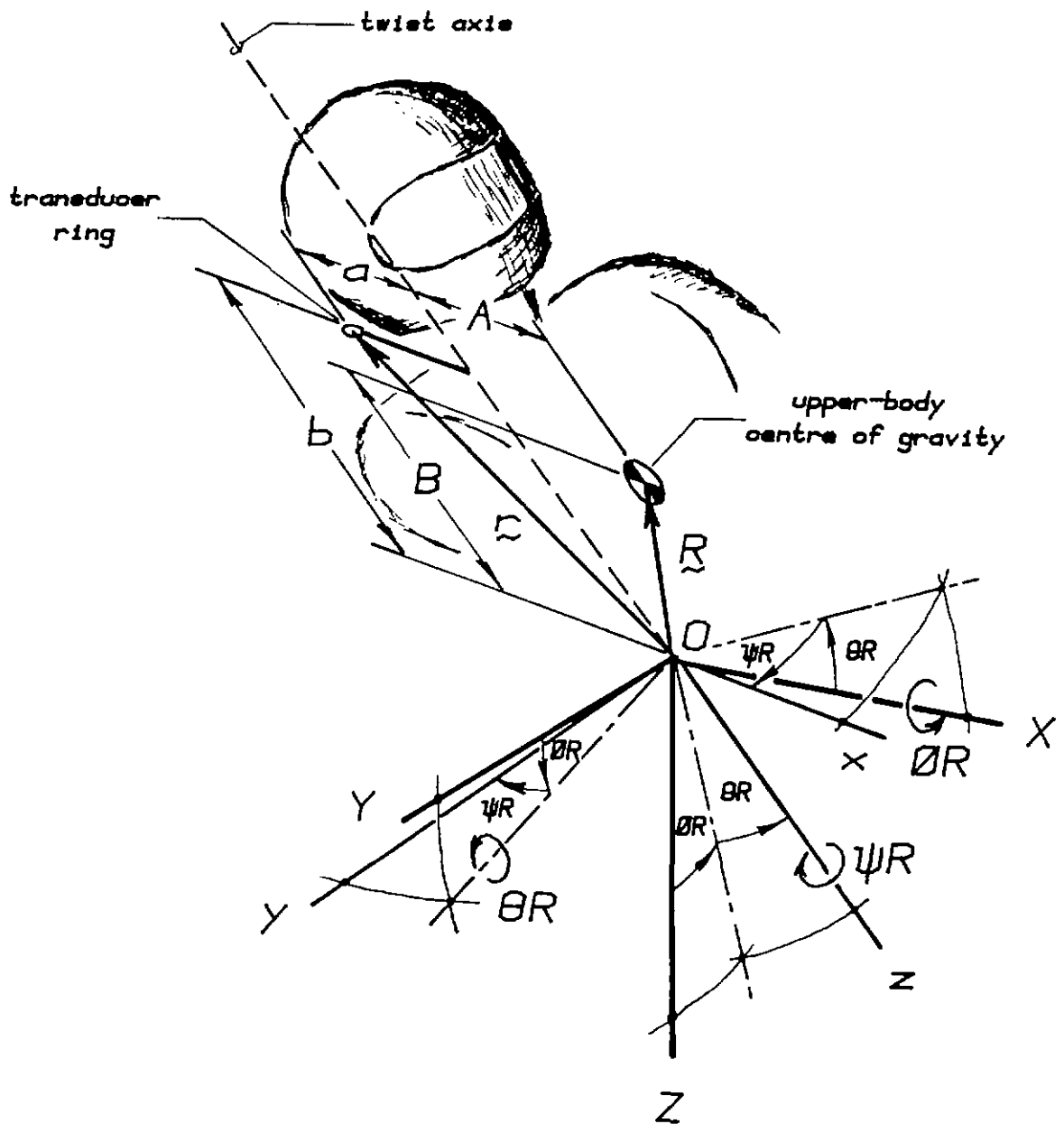
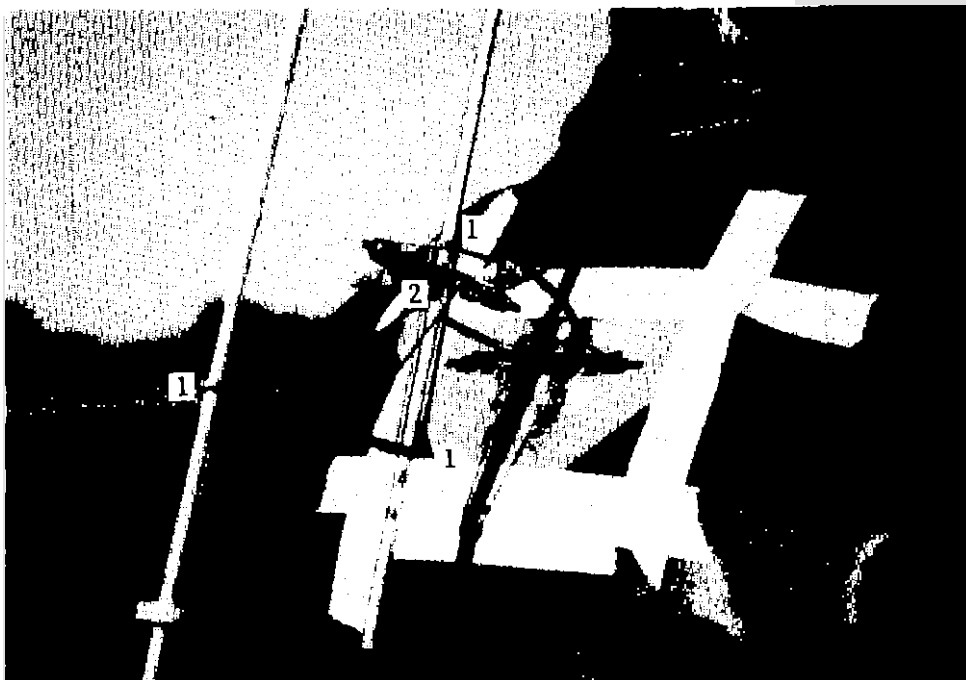


Figure J.1 Reference frames and position vectors for analysis of upper-body motion.

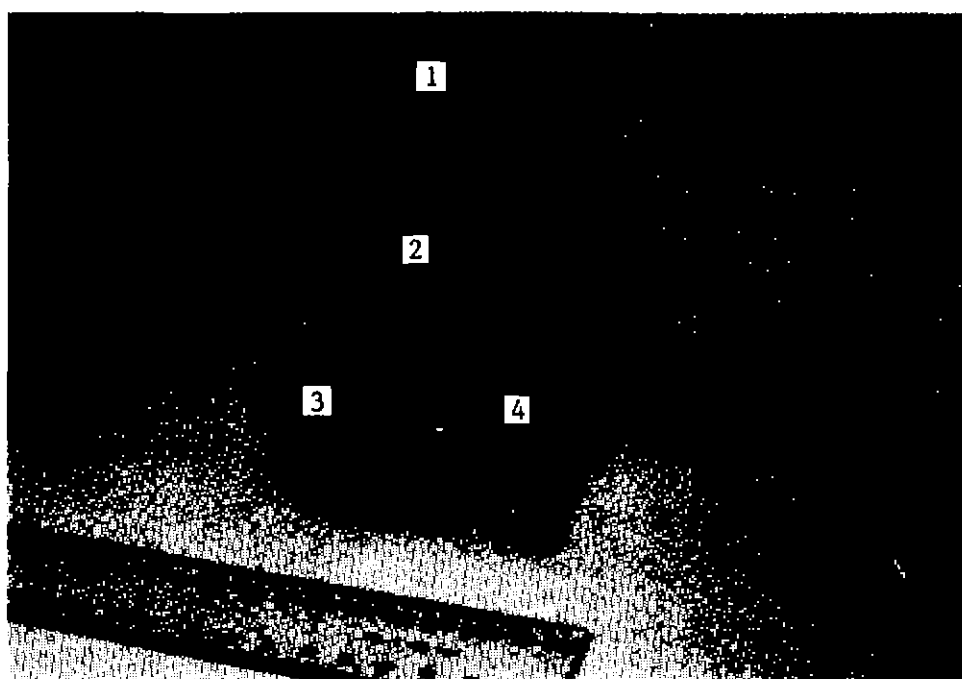


1 - Potentiometer drive rod  
2 - Gimbal



1 - Ceramic rings  
2 - Inner gimbal ring

Figure J.2 Upper-body angular displacement transducer.



- 1 - Drive rod
- 2 - Twist potentiometer
- 3 - Pitch potentiometer
- 4 - Lean potentiometer

Figure J.3 Potentiometer arrangement for modified transducer.



three ceramic rings mounted in the cage which is fixed to the inner ring of the gimbal. The gimbal bearing clearances are adjustable, and the slide clearances between the two rods (which transmit the 'twist' motion) and the ceramic rings are small, allowing backlash to be reduced to a minimum. The three variables could thus be measured without restricting the movement of the rider's upper-body. Despite its complicated appearance the transducer functioned extremely well during the experiments. For the axis system chosen, the order of rotation to obtain x-y-z from X-Y-Z is lean ( $\phi_R$ ), pitch ( $\theta_R$ ) and twist ( $\psi_R$ ).

The components of the vectors  $\underline{r}$  and  $\underline{R}$ , in the X-Y-Z axes system, following three finite rotations are obtained via the three dimensional space rotation matrix as follows:

$$\{u^*\} = [T_{\phi_R}][T_{\theta_R}][T_{\psi_R}]\{u\} = [T_{\phi_R \theta_R \psi_R}]\{u\} \quad (J.3)$$

where:

$\{u\}$  = vector components in the x-y-z axes system.

$\{u^*\}$  = vector components in the X-Y-Z axes system.

$[T_s]$  = two dimensional plane rotation matrix, s is the angular displacement of the vector  $\underline{u}$  in a plane.

and

$[T_{\phi_R \theta_R \psi_R}]$  = three dimensional space rotation matrix, where the rotations are ordered  $\phi_R$ ,  $\theta_R$  and  $\psi_R$ .

$$= \begin{bmatrix} \cos\theta_R \cos\psi_R & -\cos\theta_R \sin\psi_R & \sin\theta_R \\ \cos\phi_R \sin\psi_R & \cos\phi_R \cos\psi_R & -\sin\phi_R \cos\theta_R \\ +\sin\phi_R \sin\theta_R \cos\psi_R & -\sin\phi_R \sin\theta_R \sin\psi_R & \\ \sin\phi_R \sin\psi_R & \sin\phi_R \cos\psi_R & \cos\phi_R \cos\theta_R \\ -\cos\phi_R \sin\theta_R \cos\psi_R & +\cos\phi_R \sin\theta_R \sin\psi_R & \end{bmatrix}.$$

By substituting, in turn, equations (J.1) and (J.2) into (J.3), and using the  $\underline{J}$  and  $\underline{K}$  components of the resulting vector for the no lean case, it can be shown that the lean angle measured with the transducer will differ from the actual lean angle by an amount:

$$\phi_d = \arctan \left[ \frac{-\frac{a}{b} \sin \psi_R}{\frac{a}{b} \sin \theta_R \cos \psi_R - \cos \theta_R} \right] - \arctan \left[ \frac{\frac{A}{B} \sin \psi_R}{\frac{A}{B} \sin \theta_R \cos \psi_R + \cos \theta_R} \right]. \quad (J.4)$$

The first term in the right-hand side of the expression arises because the transducer ring is aft of the twist axis and the second term because the upper-body centre of gravity is forward of it.

The parameters required to make use of the right-hand side of equation (J.4) were determined by actual measurement and by referring to the literature. Estimates for components 'a' and 'b' were measured when each of the three riders was seated, in an upright position, on the motorcycle prior to the conduct of an experiment. The variable 'a' was taken to be the distance from the transducer ring to a point on the spine directly behind it. The distance from this point to the lean potentiometer axis was taken as 'b'. A value for 'B' was found in Weir et al. (1978) and the anthropometric data of Damon et al. (1966) provided centre of gravity information for the various body members from which it was possible to estimate 'A'. Because of the variability in the physical characteristics of human beings, and because the location of the three axes defined earlier are difficult to determine, the estimates for the parameters should be considered as approximate. The values are listed in Table J.1

Figure J.4 illustrates the behaviour of the two components of lean, as predicted by equation J.4, for a range of values of the a/b and A/B ratios and no inclination angle. For the values of a/b and

TABLE J.1

PARAMETER VALUES FOR EQUATION J.4

Subject	Pitch angle*	b	a	B	A
	(deg)	(cm)	(cm)	(cm)	(cm)
1	-11.2	41	6	39	12
2	-6.0	38	6	39	12
3	-8.0	40	6	39	12

\* In the 'normal' riding position the rider's back is inclined. These values are for the three riders tested and were measured relative to the vertical.

A/B shown in the Table, the component due to the centre of gravity being forward of the twist axis is about twice that due to the transducer ring being aft of the twist axis and, from Figure J.5 the effect of inclination angle on the difference between the measured and actual lean angle is seen to be small. For a positive twist angle the difference  $\phi_d$  is positive indicating that the position of the centre of mass is to the right of the lean stick.

The analysis shows that the measured lean angle can differ from the actual lean angle by about one-half of the value of the upper-body twist angle. If the twisting motion is large then its effect on measured lean can be significant. The next section presents the results of experiments which were carried-out to measure the twisting motion of the upper-body during turning manoeuvres.

### J.3 TWIST EXPERIMENT

The transducer used for this experiment has already been described. Three riders were recruited and classified by riding experience as novice, intermediate and expert. Each rider performed about ten left- and right-hand obstacle avoidance turns which were

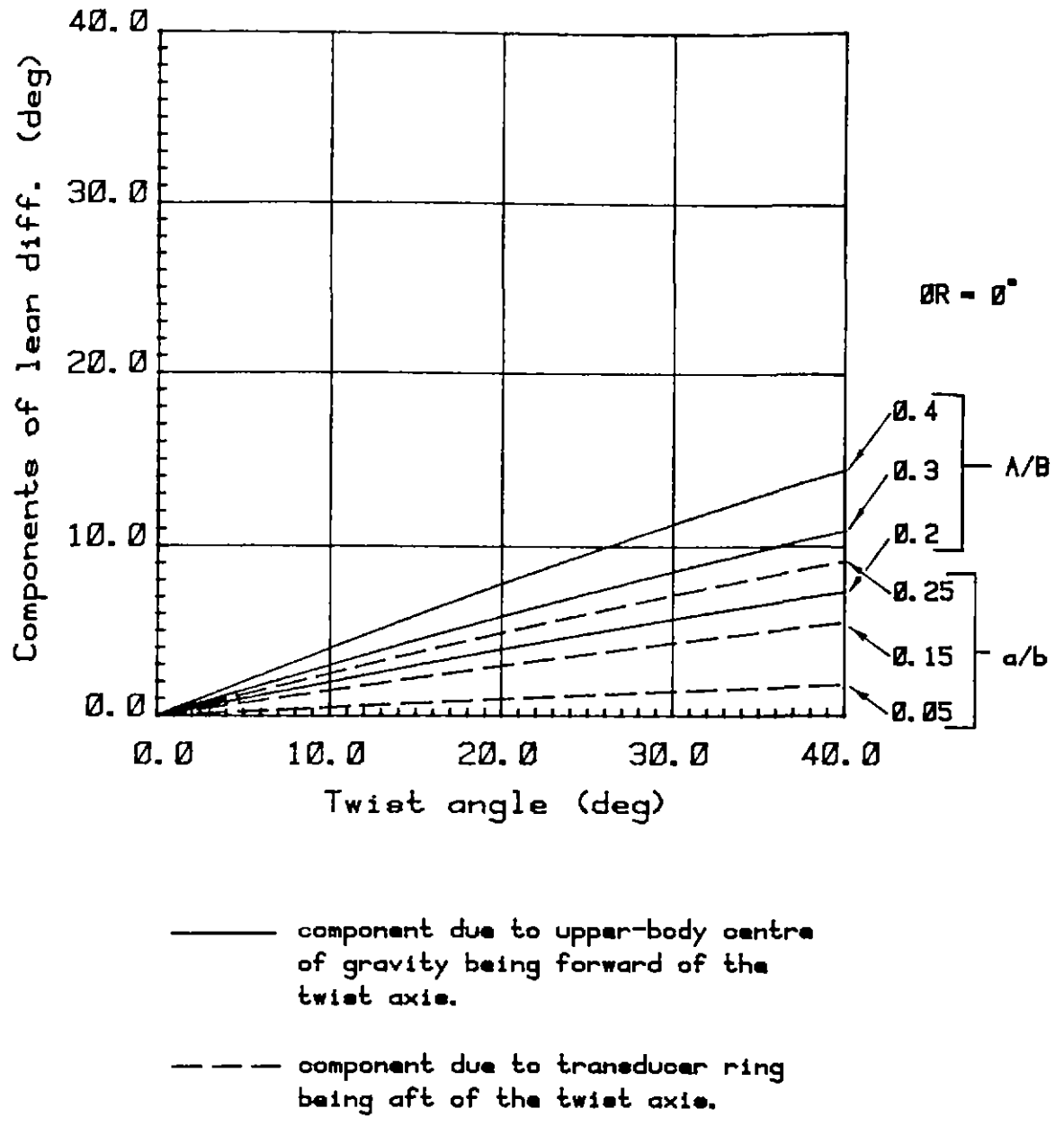


Figure J.4 Behaviour of the two components of the lean angle difference.

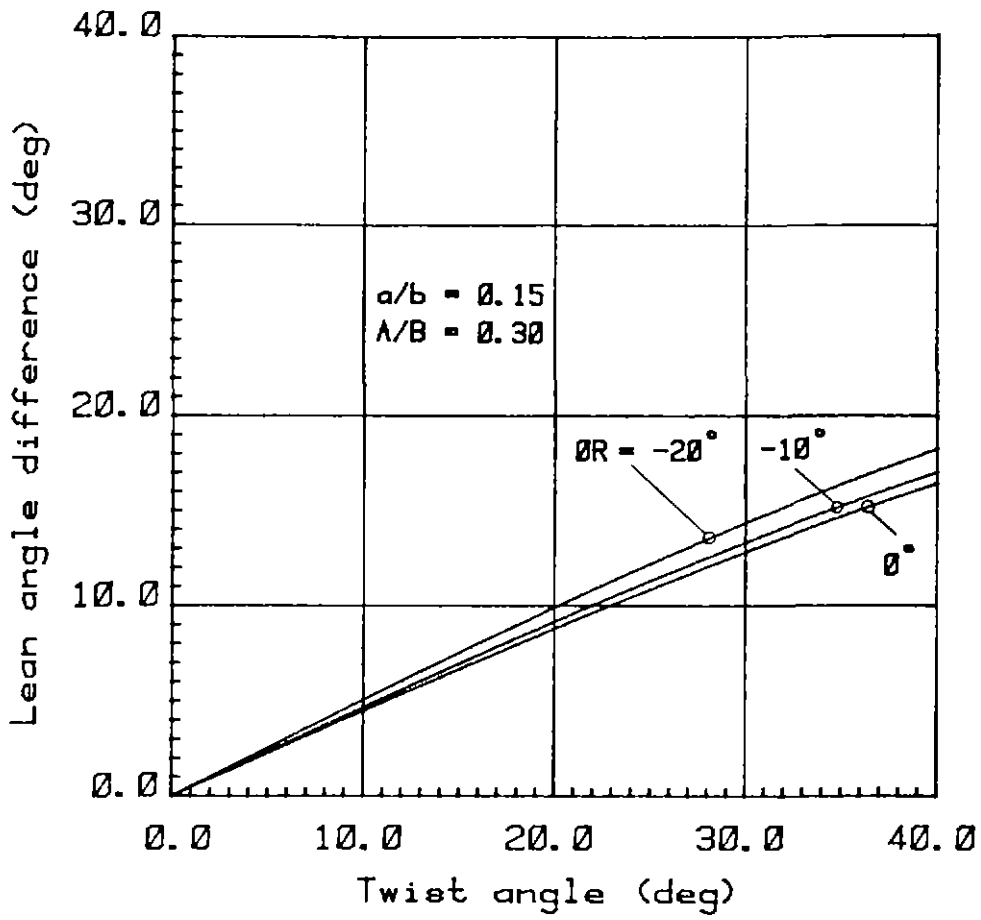


Figure J.5 Behaviour of overall lean angle difference.

assigned at random. This minimized the possibility of the rider preparing in advance for a particular manoeuvre. The course lay-out and test procedure was similar to the experiments outlined in Chapter 5. Test speed was about 30 km/h.

The data for the runs which were successful were averaged for each of the three riders. The averaged traces (10 averages) for the intermediate rider, for a left-hand turn, are shown in Figures J.6(a) through J.6(g). Shown also are the 90% confidence intervals for the mean of the traces. These represent a measure of inter-run variability. The averaged data for the other two riders are similar to those shown. The major difference between riders is the size of the confidence intervals which, for the expert rider, are about one-half the width of the ones shown. The sense of the transducer outputs was defined in the main text. The zero position on the data trace for the upper-body motion variables is for the 'normal' straight ahead riding position. Note that the twist angle measured represents a component of the 'actual' twist because the lean stick passes through transducer ring. However, this component will differ only slightly from the 'actual' twist angle because the lean stick is long compared to the distance from the transducer ring to the assumed position of the twist axis.

From Figure J.6(c) - the averaged twist angle data - the 90% confidence interval has a maximum absolute value of about 6 degrees. For the three riders tested, for the left and right turn directions, this value is representative. For the time period between 0.9 and 1.5 seconds, average lean and twist are positive. Average twist has a maximum value of about 4 degrees. For this case then the rider's upper-body centre of mass is actually more vertical than indicated by the lean trace of Figure J.6(b) during this period. Although the peak magnitude of twist is about the same for the three riders tested, the sequencing of twist and lean is different and seems to be rider dependent. If the values of twist measured for the three riders tested are representative of all the riders tested, then it appears that the lean trace can be in error at times by about 3 degrees.

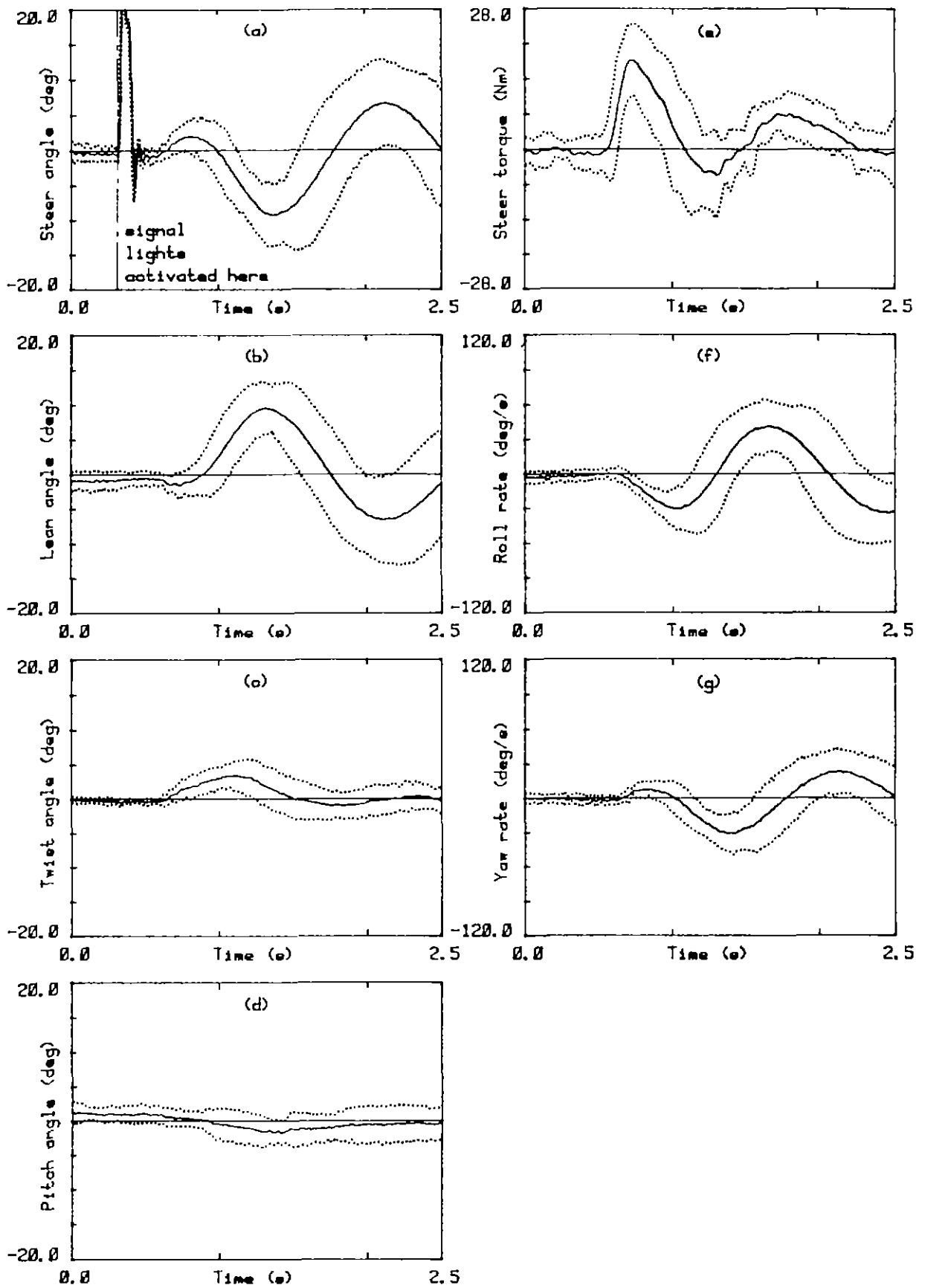


Figure J.6 (a) to (g) Various averaged data traces for a rider performing left obstacle turns in the twist experiment.