CANNABIS, ALCOHOL AND DRIVING: EFFECTS ON SELECTED CLOSED-COURSE TASKS.

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INTRODUCTION

Since 1967 the use of marihuana and hashish, drugs derived from the cannabis sativa plant, has grown markedly among driving-aged Canadian adults. Le Dain (1972) published the results of a national survey which examined the non-medical use of drugs in Canada. The data indicated that the percentage of respondents who had used marihuana or hashish increased 5 times over a 3-year period between 1967 and 1970. The magnitude of the increase varied with the age of the respondents, but overall, in 1970, about 3.4 percent of the national household sample reported that they had used marihuana.

By 1978, even the 1970 figures had changed drastically. The results of a Gallup poll (Rootman, 1978) suggested that about 17.2 percent of the 1,057 adult householders questioned nationwide had used marihuana or hashish. In the 18-29 age range over 39 percent had used the drug. Of the total sample, 9.7 percent reported using marihuana or hashish in the past twelve months and 3.6 percent reported using it at least once per week in the past 30 days. Although the Gallup and Le Dain samples were not exactly the same, the difference between the 1970 and 1978 results suggests that marihuana use increased substantially among the Canadian public during the eight year period.

In addition to evidence indicating significant marihuana use among the general Canadian population, recent data suggests that marihuana is over-represented in traffic accidents. Cimburra et al. (1980) reported the drugs present in a sample of drivers and pedestrians who were killed in Ontario between April 1, 1978 and March 31, 1979. The sample consisted of all fatalities over 14 years of age, on who both bloods and urines were available and who died within one hour of the crash. Body fluids were screened for a number of licit and illicit drugs including alcohol and marihuana. Results indicated that cannabinoids were present in 12 percent of the sample and in 46 percent of those in whom drugs other than alcohol were detected. Ninety-nine percent of the sample who tested positive for cannabinoids had also consumed alcohol. The mean blood alcohol concentration (BAC) of this subset was approximately 150 milligrams (mg) alcohol/millilitres (ml) blood (150 mg%). In 27 percent of the cannabis cases, THC was detected in blood, providing evidence of recent use.

A number of studies have examined the effects of marihuana intoxication on driving performance. Hansteen et al. (1976) conducted a
closed-course driving experiment for the Le Dain Commission inquiry into the non-medical use of drugs. Subjects drove over a 1.1 mile course six times after smoking marihuana in doses of 21 and 88 micrograms (ug), delta-9-tetrahydrocannabinol (THC)/kg, or after taking alcohol to a BAC of 70 mg%. Increases were reported in the number of cones overturned in the slalom portion of the course for the high marihuana dose, but observers were unable to notice any increase in 'rough handling' behaviour due to marihuana. Alcohol, on the other hand, adversely affected both of the above performance measures.

In another road study, Klonoff (1974) had subjects perform closed-course manoeuvres and drive in live traffic under doses of 4.9 and 8.4 mg delta-9-THC. Results from a complex set of closed-course tasks showed some detrimental performance effects at the higher marihuana dose. In live traffic, the subjective data provided by license examiners suggested that marihuana could cause deterioration of performance in judgement, care and concentration aspects of the task. But, the results were not conclusive since the performance of some subjects was judged to be improved after taking marihuana.

Smiley et al (1974) compared the effects of five drug doses on several closed-course driving tasks. The doses included a placebo condition, alcohol at a BAC of 60 mg%, alcohol at a BAC of 60 mg% combined with three, 0.5 mg 'joints' of marihuana and alcohol at 60 mg% combined with either diazepam or diphenhydramine. Subjects performed the driving tasks once per day for five consecutive days. Each day they received one of the drug doses. Results indicated that, with one exception, alcohol and marihuana together had less adverse effect on driving performance than alcohol alone. The exception was a significant reduction in response times to a light that flashed at random times throughout the trial.

Casswell (1977) was one of the first researchers to report a driving study that examined the effects of moderate levels of marihuana and alcohol, given alone and in combination on several closed-course manoeuvres. However, drug doses were given at staggered intervals throughout the test period, so it is difficult to estimate precisely what the drug concentrations were at the time of test. Results indicated, nevertheless, that the effects of alcohol, both alone and in combination with marihuana, were similar to those reported by other researchers. Under alcohol, fine steering reversals decreased from the placebo level indicating a shift to more coarse steering corrections. Vehicle velocity tended to increase under alcohol and under the alcohol plus marihuana conditions and the lateral position of the vehicle in the roadway tended to become more variable. In contrast, under the effects of only marihuana the number of coarse steering corrections decreased along with the average vehicle speed. The author suggested that drivers under marihuana appeared to compensate for what they saw as the adverse effects of the drug by maintaining control effort and decreasing speeds thus reducing the rate of information processing required. In contrast, alcohol appeared to result in more risky behaviour.

Except for performance on some tasks that are reported to be representative of driving, there is no consistent evidence that normal social levels of marihuana seriously affect driving performance. There is some indication, however, that the effects of marihuana and alcohol are additive when taken together though the evidence is by no means clear. Considering the high proportion of people who drive after taking marihuana and alcohol together, the problem deserves additional attention.
The experiment reported herein will compare the effects of alcohol and marihuana, alone and in combination, on driving performance in a number of closed-course tasks. The tasks that were employed are representative of routine driving and do not include slalom-type courses or other abnormal manoeuvres. The techniques used to detect differences between drug conditions assume that driving is a complex, highly overlearned task that can best be described in terms of multivariate descriptors (Attwood, 1975).

In a previous experiment (Attwood et al., 1980), subjects performed similar tasks to those employed in this experiment when sober and when intoxicated to nominal BACs of 33, 63, and 79 mg%. Information on control position and on vehicle parameters such as velocity and lane position were collected with an on-board, computer-based system. Both univariate and multivariate analyses were performed on the data. Results indicated that univariate analyses were unable to consistently discriminate between sober and intoxicated (63 mg% BAC) performance. Multivariate analyses, however, produced linear weighted functions of up to four different performance variables that were able to discriminate between sober and drunk driving performance. Moreover, on two of the tasks, the functions were able to correctly classify all drivers as intoxicated from the performance data obtained at the 79 mg% BAC condition.

**METHOD**

**Subjects:**
The subject drivers for this experiment were eight male volunteers between the ages of 20 and 28 with between 60,000 and one million kilometres of driving experience. Each claimed to be a moderate social drinker and to be familiar with marihuana.

Each subject was screened medically before the experiment.

**Equipment and Facilities:**
The experiment was performed on the 1700 metre taxiway of Canadian Forces Base Toronto. The experimental vehicles consisted of three, 1978 Chev­rolets. Each vehicle was equipped with power steering and brakes and automatic transmission.

The Chevrolet that was used as the subject vehicle was equipped with a computer-based, data-acquisition system (Eatock et al., 1978) that permitted the simultaneous recording of nine variables at a sampling interval of 100 msec.

The second Chevrolet which was used as a lead-car, contained a closed-circuit TV system that was aimed rearward to record the subject vehicle. Off-line reduction of the video tapes provided headways (in metres) and relative velocities at two second intervals. The third Chevrolet was used as an on-coming target vehicle during a simulated two-lane passing task.

**Driving tasks:**
The data examined herein were obtained from the following three closed-course driving tasks.

Velocity maintenance, open-road driving (60 kph): Subjects were instructed to accelerate to 60 kph and to maintain that velocity for the length of the taxiway. They were also instructed to maintain the same distance from
the centreline as they normally would on the highway.

The thirty-one summary variables calculated for each subject from the data collected during each trial are listed in Table 1.

Velocity maintenance, open-road driving (80 kph): Subjects were instructed to accelerate to 80 kph and to maintain that velocity for the length of the taxiway. They were also instructed to maintain the same distance from the centerline as they normally would on the highway.

Table 1 lists the thirty-one summary variables that were also calculated for each subject from the data collected during each trial.

Car-following, variable lead-car velocity: Subjects were instructed to follow a lead-car as though they wanted to pass it, but the traffic was too heavy to let them. During the run the velocity of the lead-car averaged 70 kph, but varied between 60 and 80 kph according to several different profiles. The lead-car was driven in second gear during the run in order to achieve the desired deceleration rates without having to brake.

Sixty-two summary variables were calculated for each subject from the data collected during each trial. These are listed in Table 1.

Procedure
A maximum of four subjects performed the experiment each day. The experiment consisted of five sessions, one session per week, spaced one-week apart. The week between each drug treatment permitted clearance from the body of significant levels of the drugs used. The first session was used to acquaint the subjects with the automobile and each of the driving tasks. On the remaining sessions, each subject drove three times over the 135-minute experimental schedule. The first driving period consisted of a 30-minute warm-up. The next two were experimental periods performed after the subjects had been given a drug treatment. Each was 25 minutes long and they were separated by a 15-minute break.

During each session the velocity maintenance and car-following tasks were performed twice, once travelling in the north-bound direction, once travelling south. The data from the two runs were combined for the majority of computations.

The tasks were performed according to four different random orders that were randomly assigned to subjects across the four experimental sessions. The only restriction on randomization was that each task be performed equally often in each of the 25-minute driving periods.

Drug Administration
The following four the drug treatments were administered at one week intervals:

1. Placebo drink + placebo marihuana cigarettes
2. Alcoholic drink + placebo marihuana cigarettes
3. Alcoholic drink + marihuana cigarettes
4. Placebo drink + marihuana cigarettes

When both drugs were administered concomitantly the dose of each was reduced to one-half to avoid adverse drug interactions which are seen at the
higher dose levels (nausea, vomiting, vertigo, dysphoria etc...). Double blind technique was used, in which neither the subject nor the experimenter knew the treatment condition. The dosing schedule was determined by modified Latin square design, balance being maintained to eliminate order effects.

The marihuana cigarettes were prepared individually for each subject to assure a presented dose of delta-9 -tetrahydrocannabinol (delta-9-THC) of either 150 ug/kg body weight (when no alcohol was given) or of 75 ug/kg when alcohol was administered concomitantly.

The marihuana containing the required dose was divided into three equal portions and rolled by machine into three cigarettes of equal weight. Placebo cigarettes of equal dimensions and weight were prepared using marihuana from which the delta-9-THC had been extracted. The cigarettes were smoked using a standard technique in which the duration of inhalation, a specified breath following smoke inhalation, breath holding, and inter-puff interval were utilized. Subject compliance was verified by a trained observer in all cases.

Alcohol was administered orally as vodka (40% alcohol by volume) at the rate of 1.25 gm ethanol per litre of body water for the high dose (target of 100 mg% BAC) and 0.63 gm per litre body water for the low dose (target of 50 mg% BAC). The vodka was diluted with orange or tomato juice to an ethanol concentration of 15% for the high dose or 7.5% for the low dose. The placebo beverage consisted of a volume of orange juice equal to the above on top of which was floated 0.5 ml of vodka. In addition, just prior to the administration of the placebo drink, the glass was rimmed with vodka. The initial dose of alcohol was administered a three drinks of equal volume. Subjets were instructed to consume each drink at a uniform pace over a 10-minute period. Maintenance doses of alcohol were given to each driver five minutes into each driving session and during the break. The maintenance doses, while the same concentration as the initial doses, were only 20% of the volume.

Summary Statistics Employed:

Common summary statistics such as means, variances, quartiles and ranges that were calculated for the data obtained during each trial need no explanation. However, several statistics which were custom designed for some tasks require clarification.

Reversal rate: For a given variable over time, the size of a reversal is the number of units (eg. degrees rotation) between a local maximum and the next minimum or a local minimum and the next maximum. The statistic is the number of reversals of a given size occurring per minute. Ten reversal rates were calculated for each variable chosen.

Autocorrelation: The autocorrelation measure, \( Q \), derived for use in these analyses is an index of the rate of change of the autocorrelation function \( A(\tau) \) between time \( \tau=0 \) and time \( \tau=10 \) (ie, 1000 msec ahead).

\[
Q = \frac{A(\tau=10) - A(\tau=0)}{A(\tau=0)} \times 100
\]

\( Q \) has a maximum value of 100, and a minimum value of -100. A value close to 100 (-100) indicates a high positive (negative) correlation. A value close to zero indicates a low correlation.
Brake Pressure Limits: Two statistics were derived to monitor gross brake pedal activity during the car-following task. The first statistic calculated the total number of seconds that the brake pedal force was greater than 2.27 Kg. The second statistic calculated the total number of times that the brake pedal force exceeded 2.27 Kg.

RESULTS

Pharmacology

For the lower (75 ug/kg) marihuana dose, the delta-9-THC levels just prior to the first experimental drive ranged from 4.9 to 21.2 nanograms (ng)/ml with a mean level of 11.2 ng/ml. Following the first driving period, the third marihuana cigarette, containing the last one-third of the total dose, was smoked. Just prior to the second experimental drive the mean delta-9-THC level had reached 13.0 ng/ml (range = 8.5 to 17.7 ng/ml), while at the conclusion of this drive the mean level had fallen to 5.4 ng/ml (range = 1.6 to 7.8 ng/ml).

Following the smoking of the first two cigarettes at the higher marihuana dose (150 ug/kg), the mean level achieved was 18.1 ng/ml (9.1 to 26.0 ng/ml). After all three cigarettes had been smoked (dose = 150 ug/kg) the mean level was 22.4 ng/ml just before the second driving period (range = 12.9 to 31.2 ng/ml), and 10.1 ng/ml just after (range = 6.0 to 16.3 ng/ml).

Figure 1 plots the blood alcohol concentrations as determined both by head space analysis of venous blood (using a gas liquid chromatograph) and by breath analysis (using a Borkenstein Model 901 Breathalyzer) as a function of time after drinking commenced. For the full dose schedule (target BAC = 80 to 100 mg%) the mean blood concentrations achieved were those desired during the critical period of the second experimental drive. In the case of readings determined by breath analysis, the mean concentration window is exactly between 80 and 100 mg%; while that measured by head space analysis of venous blood is slightly greater than anticipated (102.8 to 107.5 mg%). A disparity is noted between the blood alcohol levels determined by the two methods — the head space analysis being lower for the reading taken 40 minutes after the beginning of the drinking schedule, and higher for subsequent readings (80 and 110 minutes after the beginning of drinking).

Driving tasks: Univariate analyses.

Owing to the large number of summary variables analyzed for the three tasks reported herein, not all analyses will be tabled nor will all data be discussed. Only those variables showing significant effects will be reported in this section. The reader interested in examining the summary variables derived for each subject under each drug condition is invited to contact the principal author.

Velocity-Maintenance: 60 kph. Separate analyses of variance were conducted across subjects and drug treatments for each of the 31 summary variables obtained from this task. Results indicated that seven variables, each associated with the subject's ability to maintain lateral control of the vehicle, were significantly different across drug conditions (p<.05). Figures 2 and 3 illustrate two of the variables whose trends are representative of all seven.

Figure 2 plots mean fine steering reversal (<5.5 degrees) rate against drug treatment. The data suggest that under the alcohol condition the
rate of fine manipulative steering movements is significantly less than that observed in the placebo or marihuana conditions. In fact, under marihuana the number of fine steering movements actually increases and under the combined alcohol-plus-marihuana treatment mean reversal rates are little different from the placebo condition.

Figure 3 plots the ratio, mean lateral position divided by the standard deviation, against drug condition. The decrease in this variable signifies large variability in lane position combined with a small mean position (i.e., closer to the centreline). Results illustrate a significant difference between lane tracking performance under the combined alcohol-plus-marihuana dose and performance under the placebo treatment. Under the combined drug condition lateral position was significantly more variable than under the placebo condition.

Velocity-maintenance: 80 kph. Only four of the 31 summary variables analyzed were significantly different across drug conditions. Each was a measure of steering reversal rate. The results from this task are similar to those plotted in Figure 2 for the 60 kph task; significantly fewer fine reversals under alcohol than under placebo (p<.05) or than under marihuana (p<.01). Again, the fine steering activity seems to increase from the placebo to the marihuana conditions though there is no reason to believe the change is significant.

Car-Following. Only four of the 62 variables analyzed showed significant differences (at p<.05) across drug conditions. Two of these are associated with longitudinal acceleration (standard deviation (SD), and the mean/SD). The other two are associated with headway (interquartile range and 75th percentile).

Figure 4 plots the interquartile range of headway against the standard deviation of longitudinal acceleration. The results illustrate the different behavioural effects that appear to be brought on by the two drugs. On one hand marihuana seems to elicit more variable headway behaviour and less variable longitudinal accelerations. On the other hand, the alcohol treatments seem to trade-off high longitudinal acceleration behaviour for a reduction in headway variability.

Driving tasks: Multivariate analyses.

The above results clearly illustrate that univariate analyses did not uncover many more significant summary variables that one would expect to discover by chance at the 5 percent level. Moreover, only four of the fifteen significant variables found in the three tasks were significant at the p<.01 level.

In recognition of the driving task as the integration of a number of individual responses, the data were analyzed using multivariate techniques to determine whether a set of variables could be found that would differentiate between drug conditions better than any single variable. Discriminant analyses were conducted separately for each task on the data from the four drug conditions to identify the smallest n-variable set that would best assign drivers to their correct drug group. The theory behind the discriminant procedures is given in Lachenbruch (1975).

Two separate discriminant analyses were performed for each driving task. The first analysis searched for the smallest n-variable set that would
discriminate alcohol-related performance from non-alcohol-related performance. To do this, the data from the alcohol-only and alcohol-plus-marihuana conditions were combined and the resultant data set was compared against the set composed of the placebo and marihuana-only data.

The second analysis searched for the smallest n-variable set that would discriminate marihuana-related performance from non-marihuana-related performance. So, the data from the marihuana-only and alcohol-plus-marihuana conditions were combined and this new data set was compared against the set composed the placebo and alcohol-only data.

The step-wise discriminant procedure that was used to eliminate all but the most useful variables in each of the above analyses is explained in Attwood et al. (1980).

The above analyses resulted in two linear weighted functions: One more sensitive to alcohol than marihuana, the other more sensitive to marihuana than alcohol.

Velocity-Maintenance: 60 kph. The alcohol-sensitive function for this task is given by:

\[ D_{60:ALC} = 0.14 V_{31} + 9.26 V_{14} - 10.96 V_4 + 28.85 V_{19} \]  

where,

- \( V_{31} \) = Steering-wheel: Reversals (total) per minute
- \( V_{14} \) = Steering-wheel: Interquartile range
- \( V_4 \) = Steering-wheel: Standard deviation
- \( V_{19} \) = Lane position: Interquartile range

The marihuana-sensitive function is given by:

\[ D_{60:MAR} = -9.21 V_2 + 7.25 V_{11} + 0.08 V_{28} \]  

where;

- \( V_2 \) = Velocity: Standard deviation
- \( V_{11} \) = Velocity: Interquartile range
- \( V_{28} \) = Steering-wheel: Reversals (<5.5 degrees) per minute

The functions given by equations 1 and 2 were each evaluated 32 times; once for each subject at each drug condition. For each evaluation the values of variables 31, 14, 4, and 19 from one subject at one drug condition were substituted into equation 1 and the values of variables 2, 11 and 28 were substituted into equation 2. 95 percent confidence limits on the mean were established for each function using the eight data points obtained in each drug condition. Figure 5 combines the confidence limit data for the alcohol-sensitive (equation 1) and the marihuana-sensitive (equation 2) functions into a series of four ellipses; one for each drug condition.

The most important characteristic of Figure 5 is the relative location of the four ellipses. The ellipse that was formed from the data in the alcohol treatment is composed of high scores on the alcohol-sensitive axis (equation 1) and low scores on the marihuana-sensitive axis (equation 2). The marihuana ellipse, on the other hand, scores high on the marihuana axis and low on the alcohol axis. Placebo, as expected, scores low on both functions, while the data from the combined alcohol-marihuana treatment results in high
scores on both functions.

The lack of virtually any overlap in the ellipses suggests that performance as given jointly by equations 1 and 2 differs substantially between the four drug doses. So, the information given by the equations could be used to classify drivers as being intoxicated by alcohol or by marihuana or by both drugs as follows. Suppose a driver, whose drug level was unknown was tested on this task and the values of summary variables 31, 14, 4 and 19, that were obtained during the test were substituted into equation 1 and values of variables 2, 11 and 28 were substituted into equation 2. The two values resulting from equations 1 and 2 provide an X,Y pair for Figure 5. If the 2-dimensional point fell closer to the alcohol ellipse than to any other, we would declare the driver drunk. Likewise, if the point fell closer to the placebo ellipse we would declare him unimpaired; or closer to the marihuana ellipse, under the influence of marihuana, etc.

Velocity-Maintenance: 80 kph. The alcohol-sensitive function is given by:

\[ D_{80: ALC} = -0.73 V_{23} + 17.53 V_{19} + 0.16 V_{27} \]  \((3)\)

where:

- \( V_{23} \) = Steering-wheel reversals (1.0-1.5 degrees) per minute
- \( V_{19} \) = Lane position: Interquartile range
- \( V_{27} \) = Steering-wheel reversals (0.5-2.5 degrees) per minute

The marihuana-sensitive function is given by:

\[ D_{80: MAR} = 0.61 V_{28} - 2.30 V_{26} - 1.07 V_{22} + 236. V_{2} \]  \((4)\)

where:

- \( V_{28} \) = Steering-wheel reversals (0.5-5.5 degrees) per minute
- \( V_{26} \) = Steering-wheel reversals (2.5-3.0 degrees) per minute
- \( V_{22} \) = Steering-wheel reversals (0.5-1.0 degrees) per minute
- \( V_{2} \) = Velocity: Standard deviation

Figure 6 plots the results of evaluating equations 3 and 4 for each subject under each drug condition. The ellipses, which plot the 95 percent confidence limits along each axis, overlap more for the 80 kph task than for the 60 kph task. In spite of this, the relative location of the ellipses suggests that equations 3 and 4 are also correctly classifying drug-related behaviour.

Car Following. The alcohol-sensitive function is given by:

\[ D_{CF: ALC} = -408.1 V_{17} + 2.77 V_{61} - 3.45 V_{44} + 28 V_{7} \]  \((5)\)

where:

- \( V_{17} \) = Longitudinal acceleration: Median
- \( V_{61} \) = Accelerator pedal: Reversals (17% < X) per minute
- \( V_{44} \) = Relative velocity: Range
- \( V_{7} \) = Relative velocity: Standard deviation

946
The marihuana-sensitive function is given by:

\[ D_{CF:MAR} = 1.19 V_1 - 0.98 V_{59} + 1.24 V_{60} + 3.29 V_{48} + 2.04 V_{31} + 3.83 V_9 \]  

(6)

where:

- \( V_1 \) = Velocity: Standard deviation
- \( V_{59} \) = Longitudinal acceleration: Reversals (total) per minute
- \( V_{60} \) = Accelerator pedal: Reversals (<11%) per minute
- \( V_{48} \) = Brake Force: Total seconds BF > 2.77 kg
- \( V_{31} \) = Headway: 25th Percentile
- \( V_9 \) = Brake Force: Maximum

Figure 7 plots the 95th percentile confidence ellipses that result from evaluating equations 5 and 6 with the data from each subject under each drug treatment. The graph indicates that although the placebo and alcohol-only ellipses are well separated from each other and from the marihuana-related ellipses, there is a substantial overlap in the marihuana data. It is likely, therefore, that equations 5 and 6 would not discriminate well between the marihuana-only and the marihuana-plus-alcohol conditions. However, the functions appear to be able to correctly classify unimpaired performance, alcohol-intoxicated performance, and marihuana-related performance.

**DISCUSSION**

There are many logistical problems associated with repeated sampling of blood or breath for drug analysis during a driving experiment and subsequent adjustment of drug doses. Because of this, the decision was made to calculate drug doses which might be expected to achieve desired plasma levels or effects prior to their administration and to simply monitor the plasma levels achieved to verify the success (or not) of the dosing strategy.

In the case of marihuana a somewhat "standard" dose of 150 ug, delta-9-THC per kg body weight (or half this amount when marihuana and alcohol were to be given together) was chosen. The levels achieved in our subjects of the parent compound and its 11-hydroxy metabolite, while somewhat variable (given the difficulty of enforcing a standard smoking technique) are in keeping with those reported in the literature (Rosenfeld, 1976; and Agurell et al, 1973).

The strategy for achieving the desired blood concentrations of alcohol also appears to have been successful. However, we are not able to explain the discrepancy between the breath analysis and that of venous blood. The higher initial levels obtained in this study with the breath analysis may represent residual oral alcohol, even though breath samples were not taken until 10 minutes following the completion of a given drink. The higher BACs seen with venous blood analysis for subsequent samples is a consistent finding in studies we have done using both methods in the past. The blood alcohol samples have been analyzed by an experienced reference laboratory, and it therefore seems reasonable to use these in interpreting our data. There is considerably less chance of systematic error in the sampling, collection and transportation of blood specimens, and in their analysis, than in the conduct of
the breath analysis. The reader should note, however, that the Breathalyzer used was serviced and calibrated by a Government Laboratory prior to use in this study and that instrumentation error, per se, is unlikely.

The results of the driving task analyses suggest that alcohol and marihuana, when taken in quantities normally associated with social use, adversely affect performance on tasks that are typical of everyday driving situations. That is, no exaggerated courses on manoeuvres had to be employed to demonstrate the effects. Moreover, the data obtained from the driving tasks suggest that the effects of alcohol and marihuana are additive when the drugs are taken together.

Having said this, however, it is necessary to qualify the term 'adverse'. At no time during this experiment was the driving performance of our eight subject drivers so poor that we were forced to cancel a run. Drivers did not weave down the road under the influence of drugs, or brake and accelerate in an erratic manner. The differences in behaviour between the drug and placebo conditions that we were able to isolate were so subtle that they would hardly be noticed by observation. Only when the outputs from a number of sensitive transducers are combined and analyzed with the aid of multivariate techniques do the differences between drug conditions become evident.

Notwithstanding the lack of observable performance changes under the effects of drugs, performance does vary in a measurable manner. The technique developed to quantify performance and isolate the effects of one drug from another (as shown in Figures 5, 6, and 7) could permit us to extend the number of drugs that can be considered at one time. To illustrate this point, Figure 8 displays a hypothetical, 3-dimensional distribution of driving performance that could result from a three-drug experiment. The graphic extends the 2-dimensional results given above. Confidence ellipses, for example, have become confidence ellipsoids. The figure suggests that the performance of drivers under the predominant influence of Drug A would fall near the Drug A ellipsoid which has high values on the Drug A-sensitive axis and low values on the B- and C-sensitive axes. In a similar fashion, performance under the Drug B treatment would be concentrated around the B-sensitive axis. Combinations of the three drugs would result in behaviour that would fall between the major axes as illustrated by the ellipsoid labelled "Drugs A+B+C".

In conclusion, this experiment suggests that performance of typical driving tasks under placebo conditions can be differentiated from performance obtained under the effects of moderate doses of alcohol and marihuana, both alone and in combination. But, the differentiation could only be achieved with a high degree of confidence by combining the data from each drug condition and analyzing them using multivariate methods. It is expected that the results of this study will lead to research that will attempt to refine the hardware and analysis techniques to develop an on-line monitoring device that will be able to detect driver impairment.
REFERENCES


Table 1: Summary variables calculated from the data collected in the Velocity-maintenance (L) tasks and the Car-following (F) tasks.

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<th>VEL (kph)</th>
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<th>ACC POS'N³</th>
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<td>F</td>
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<tr>
<td>IQR⁵</td>
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<tr>
<td>MDN/R</td>
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<tr>
<td>MDN/IQR</td>
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<td>F</td>
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<tr>
<td>Reversals/min⁶</td>
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<td>F⁷</td>
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<tr>
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<tr>
<td>Brake Stats⁷</td>
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Footnotes:

1 Degrees relative to center
2 Distance (metres) of left-hand wheels from centerline
3 Percent full-scale deflection
4 SD = Standard Deviation
5 IQR = Interquartile Range
6 See text for explanation.
7 Only the rates for the three largest reversals were calculated owing to reduced sensitivity of transducer.
Figure 1

Blood alcohol concentration (BAC) using both blood and breath analyses as a function of time into the experiment for the full and half dose conditions. (Shaded areas indicate periods when subjects drove vehicle.)

Figure 2

Velocity maintenance: 60 kph fine steering reversal (<5 deg.) rate as a function of drug condition.

Figure 3

Velocity maintenance: 60 kph lateral position: mean/standard deviation as a function of drug condition.

Figure 4

Car following: interquartile range (IQR) as a function of the standard deviation of longitudinal acceleration for each drug condition.
Figure 5

VELOCITY-MAINTENANCE: 60 kph
Alcohol versus marihuana discriminant functions evaluated for each drug condition. Ellipses outline 95% confidence intervals for each axis.

Figure 6

VELOCITY-MAINTENANCE: 80 kph
Alcohol versus marihuana discriminant functions evaluated for each drug condition. Ellipses outline 95% confidence intervals for each axis.
Figure 7

CAR-FOLLOWING
Alcohol versus marihuana discriminant functions evaluated for each drug condition. Ellipses outline 95% confidence intervals for each axis.

Legend
- placebo
- alcohol
- marihuana
- alcohol + marihuana

Alcohol Function (arbitrary units)
Marihuana Function (arbitrary units)

Figure 8

Hypothetical 3-Dimensional distribution of driving performance. Each axis represents a discriminant function emphasizing one of three different drugs. Ellipsoids represent arbitrary confidence intervals for the 3 axes.