*scaber* with a technique of positive reinforcement where the animals were given access to water for a correct turn in a T-maze (*8*).

Eight *P. scaber* were given ten trials per day spaced approximately 20 minutes apart, in a wood T-maze. The arms and stem were 5 cm, internal diameter 0.8 cm, and height 1.3 cm. The floors of both arms were covered with a strip of paper towel (5 by 0.8 cm). Throughout the experiment the maze was kept in a styrofoam chamber (46 by 23 by 31 cm) that contained a heating element, a pan of water, and an Airguide thermometer and hygrometer. The chamber had a top window for viewing and an arm hole in each end to permit access. Conditions in the chamber were kept constant at approximately 32.2°C and 30 percent relative humidity. The chamber was kept in normal room light with care taken to see that no differential shadows were cast on the maze. The subjects were kept in individual environments containing soil, leaves, and a moist sponge, except for the time in the chamber.

Daily sessions began with water deprivation; animals were placed in the chamber for 4 hours in an empty paper cup. They were then given ten trials in the T-maze; a subject was placed at the entrance to the maze and allowed to proceed to the choice point and to turn in either direction. Immediately after a turn the subject was blocked in the arm for 15 seconds and then returned to the paper cup to await the next trial. At the end of ten trials the subjects were returned to their individual environments outside the chamber until the next day's session.

The first ten trials were used to determine any turning preference. A majority of turns in one direction was designated as preference, and on initial training a turn in that direction was counted as an error. A turn in the opposite direction was counted as a correct turn. Subsequently and throughout the experiment, when a correct turn was made and the subject was blocked, one drop of water was applied to the paper towel on the floor of the maze arm. The water spread quickly over the entire towel, permitting absorption by the animal. The subject was then removed, towels were removed, and the maze floor wiped dry and further dried with an electric hair dryer held over the maze for approximately 30 seconds. If an error was made no water accompanied the blocking, and the drying procedures were not used. The subjects were tested until a criterion of nine correct turns out of ten consecutive trials was met. When criterion was met the correct turn direction was reversed. That is, the former error turn became the correct turn, and the former correct turn became the error turn. The animals were tested to criterion, and the correct direction was reversed again. This procedure continued for nine reversals (Table 1).

The mean errors to criterion showed a steady decline. An analysis of variance indicates that this decline is highly significant ($F = 4.78$, d.f. $= 9/63$, $P < .001$). This indicates formation of learning sets in these subjects. It would seem that invertebrates can do this with reasonable efficiency.

In the study of learning capacities of various invertebrate species, it may be particularly important to manipulate variables most relevant to their modes of adjustment. For example, it is unlikely that many invertebrates encounter electric shock in their environment. It is also unlikely that such stimuli played any great role in their phylogeny. Hence the effect of such stimuli on behavior may be too disruptive to allow demonstration of full adjustment capacities. In *P. scaber* dessication and subsequent response-contingent access to water represent a common mode of adjustment to a common environmental event. The similarity of these events to procedures of this experiment may offer a reason why this study was successful in demonstrating learning sets.

Experimental techniques making use of a positive reinforcer are usually associated with a concomitant deprivation procedure. This is more involved than the simple administration or withdrawal of aversive stimulation. Deprivation parameters must be investigated and reliable standards derived. This is particularly difficult with some of the lower species, yet its utility is clearly indicated here. The 4-hour dessication used in our experiment was derived from pilot work. Six-hour periods of lack of access to water at 32.2°C and 30 percent relative humidity seriously impaired the ability of *P. scaber* to run ten trials in a T-maze. Animals not having at least 2 hours of this dessication procedure showed pronounced inferiority at learning an initial position response.

The learning capacities of many species, especially invertebrates, have yet to be adequately delineated. We have attempted to show the fruitfulness of developing reinforcement techniques that are more relevant to the particular ecology of the species studied. When this is accomplished it is possible and even likely that phenomena such as learning sets can be demonstrated in many invertebrate species other than the one studied here.

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## Comparison of the Effects of Marihuana and Alcohol on Simulated Driving Performance

Abstract. *The effects of marihuana, alcohol, and no treatment on simulated driving performance were determined for experienced marihuana smokers. Subjects experiencing a "social marihuana high" accumulated significantly more speedometer errors than when under control conditions, whereas there were no significant differences in accelerator, brake, signal, steering, and total errors. The same subjects intoxicated from alcohol accumulated significantly more accelerator, brake, signal, speedometer, and total errors than under normal conditions, whereas there was no significant difference in steering errors. Impairment in simulated driving performance does not seem to be a function of increased marihuana dosage or inexperience with the drug.*

We have determined the effect of a "normal social marihuana high" on simulated driving performance among experienced marihuana smokers. We compared the degree of driving impairment due to smoking marihuana to the effect on driving of a recognized standard—that is, legally defined intoxication at the presumptive limit of 0.10 percent alcohol concentration in the blood. This study focused attention on the effect of smoking marihuana rather than on the effect of ingesting Δ⁹-tetrahydrocannabinol (Δ⁹-THC), the principal active component.

Weil *et al.* (*1*) have studied the clinical and psychological effects of smoking marihuana on both experienced and inexperienced subjects. They suggest, as do others (*2*), that experienced smokers when "high" show no significant impairment as judged by performance on selected tests; they also establish the existence of physiological changes that are useful in determining whether a subject smoking marihuana is "high." A review of the relation of alcohol to fatal accidents (*3*) showed that nearly half of the drivers fatally injured in an accident had an alcohol concentration in the blood of 0.05 percent or more.

Crancer (*4*) found a driving simulator test to be a valid indicator for distinguishing driving performance; this result was based on a 5-year driving record. Further studies (*5*) indicated that a behind-the-wheel road test is not significantly correlated to driving performance. We therefore chose the simulator test, which presents a programmed series of emergency stituations that are impractical and dangerous in actual road tests.

Subjects were required to be (i) experienced marihuana smokers who had been smoking marihuana at least twice a month for the past 6 months, (ii) licensed as a motor vehicle operator, (iii) engaged in a generally accepted educational or vocational pursuit, and (iv) familiar with the effects of alcohol. The subjects were given (i) a physical examination to exclude persons currently in poor health or under medication, and (ii) a written personality inventory (Minnesota Multi-phasic Personality Inventory) to exclude persons showing a combination of psychological stress and inflexible defense patterns. Seven of the subjects were females and 29 were males (mean age, 22.9).

We compared the effects of a marihuana "high," alcohol intoxication, and no treatment on simulated driving performance over a 4½-hour period. We used a Latin-square analysis of variance design (*6*) to account for the effects of treatments, subjects, days, and the order in which the treatments were given. To measure the time response effects of each treatment, simulator scores were obtained at three constant points in the course of each experimental period. A sample of 36 subjects was determined to be sufficient in size to meet the demands of this experimental design.

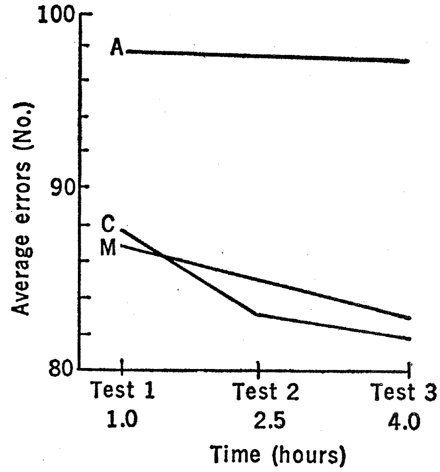


Fig. 1. Display of the effect of each treatment on simulator error scores over a 4-hour period. Alcohol (A), marihuana (M), and control (C).

Three treatments were given to each subject. In treatment M (normal social marihuana "high"), the experimental subject stated that he experienced the physical and psychological effects of smoking marihuana in a social environment comparable to his previous experiences. This subjective evaluation of "high" was confirmed by requiring a minimum consumption of marihuana established with a separate test group, and by identifying an increase in pulse rate (*1*).

In treatment M, the subjects smoked two marihuana (*7*) cigarettes of approximately equal weight and totaling 1.7 g. They completed smoking in about 30 minutes and were given their first simulator test 30 minutes later.

Some confirmation that the amount of marihuana smoked was sufficient to produce a "high" is found in Weil's (*1*) study. His subjects smoked about 0.5 g of marihuana of 0.9 percent Δ⁹-THC.

In treatment A, subjects consumed two drinks containing equal amounts of 95 percent alcohol mixed in orange or tomato juice. Dosage was regulated according to subject's weight with the intended result of a 0.10 blood alcohol concentration as determined by a Breathalyzer reading (*8*). Thus, a subject weighing 120 pounds received 84 ml of 95 percent laboratory alcohol equally divided between two drinks. This was equivalent to about 6 ounces of 86 proof liquor. The dosage was increased 14 ml or ½ ounce for each additional 15 pounds of body weight. A Breathalyzer reading was obtained for each subject about 1 hour after drinking began; most subjects completed drinking in 30 minutes.

Treatment C consisted of waiting in the lounge with no treatment for the same period of time required for treatments M and A. The experimental subject stated that his physiological and psychological condition was normal. Subjects were requested to refrain from all drug or alcohol use during the time they were participating in the experiment.

A driver-training simulator was specially modified to obtain data on the effect of the treatments. The car unit was a console mockup of a recent model containing all the control and instrument equipment relevant to the driving task. The car unit faced a 6 by 18 foot screen upon which the test film was projected. The test film gave the subject a driver's eye view of the road as it led him through normal and emergency driving situations on freeways and urban and suburban streets. From the logic unit, located to the rear of the driver, the examiner started the automated test, observed the subject driving, and recorded the final scores.

A series of checks was placed on the 23-minute driving film which monitored driver reactions to a programmed series of driving stimuli. The test variables monitored were: accelerator (164 checks), brake (106 checks), turn signals (59 checks), steering (53 checks), and speedometer (23 checks). There was a total of 405 checks, allowing driver scores to range from zero to 405 errors per test. Errors were accumulated as follows.

1) Speedometer errors: Speedometer readings outside the range of 15 to 35 mile/hour for city portion of film and 45 to 65 mile/hour for freeways. The speed of the filmed presentation is not under the control of the driver. Therefore, speedometer errors are not an indication of speeding errors, but of the amount of time spent monitoring the speedometer.

2) Steering errors: Steering wheel in other than the appropriate position.

3) Brake errors: Not braking when the appropriate response is to brake, or braking at an inappropriate time.

4) Accelerator errors: Acceleration when the appropriate response is to de-

celerate, or deceleration when it is appropriate to accelerate.

5) Signal errors: Use of turn signal at an inappropriate time or position.

6) Total errors: An accumulation of the total number of errors on the five test variables.

Two rooms were used for the experiment. The lounge, designed to provide a familiar and comfortable environment for the subjects, was approximately 12 feet square and contained six casual chairs, a refrigerator, a desk, and several small movable tables. The room was lighted by a red lava lamp and one indirect red light, and contemporary rock music was played. Snacks, soft drinks, ashtrays, wastebaskets, and a supply of cigarettes were readily available. Subjects remained in this room except during simulator tests.

The driving simulator was located in a larger room about 50 feet from the lounge. The simulator room was approximately 20 by 30 feet and was kept in almost total darkness.

Each subject took three preliminary tests on the driving simulator to familiarize himself with the equipment and to minimize the effect of learning through practice during the experiment. Subjects whose error scores varied by more than 10 percent between the second and third tests were given subsequent tests until the stability criterion was met.

The experiment was conducted over a 6-week period. Six subjects were tested each week. On day 1, six subjects took a final test on the driving simulator to assure recent familiarity with the equipment. A "normal" pulse rate was recorded, and each was given two marihuana cigarettes of approximately 0.9 g each. Subjects smoked the marihuana in the lounge to become acquainted with the surroundings and other test subjects, and with the potency of the marihuana. A second pulse reading was recorded for each subject when he reported that he was "high" in order to obtain an indication of the expected rate increase during the experiment proper. They remained in the lounge for approximately 4 hours after they had started smoking.

Three of the subjects were scheduled for testing in the early evening on days 2, 4, and 6; the remaining three subjects for days 3, 5, and 7. A single treatment was given each evening. Within a given week, all subjects received treatments in the same order. Treatment order was changed from week to week to meet the requirements of a Latin-square design. Procedure for each evening was identical except for the specific treatment.

Table 1. Analysis of variance of total driving simulator error scores for three treatments; marihuana (M), control (C), and alcohol (A).

| Source of variation | Sum of squares | Degrees of freedom | Mean square | Mean square ratios |
|---|---|---|---|---|
| Treatments | 2,595.1 | 2 | 1,297.5 | 6.7* |
| M versus C | (11.7) | (1) | 11.7 | 0.1 |
| A versus M and C | (2,583.4) | (1) | 2,583.4 | 13.3† |
| Days | 738.5 | 2 | 369.3 | 1.9 |
| Subjects | 40,872.5 | 24 | 1,703.0 | 9.7† |
| Squares | 13,708.5 | 11 | 1,247.2 | 6.4† |
| Pooled error | 13,253.8 | 68 | 194.9 | |
| Total | 71,168.4 | 107 | | |

* $P < .05$. † $P < .01$.

Subject 1 arrived at the laboratory and took the simulator warm-up test. Treatment A, M, or C was begun at zero hour and finished about ½ hour later. One hour after treatment began, subject 1 took simulator test 1, returning to the lounge when he was finished. He took simulator test 2 2½ hours after treatment began, and test 3 4 hours after treatment began. Pulse or Breathalyzer readings, depending on the treatment, were taken immediately before each simulator test.

Subject 2 followed the same schedule, beginning ½ hour after subject 1. Time used in testing one subject each evening was 4½ hours, with a total elapsed time of 5½ hours to test three subjects.

The three simulator tests taken after each treatment establish a time response effect for the treatment. For each treatment the total error scores for each time period were subjected to an analysis of variance. Table 1 presents the analysis of variance for period 1 scores; results comparable to these were obtained for scores in periods 2 and 3.

The simulated driving scores for subjects experiencing a normal social marihuana "high" and the same subjects under control conditions are not significantly different (Table 1). However, there are significantly more errors ($P < .01$) for intoxicated than for control subjects (difference of 15.4 percent). This finding is consistent with the mean error scores of the three treatments: control, 84.46 errors; marihuana, 84.49 errors; and alcohol, 97.44 errors.

The time response curves for "high" and control treatments are comparable (Fig. 1). In contrast, the curve for alcohol shows more total errors ($P < .01$). These higher error scores for alcohol persist across all three time periods with little evidence of the improvement shown under the other two treatments.

A separate Latin-square analysis of variance was completed for each test variable to supplement the analysis of total errors (Table 2). In comparison of intoxicated and control subjects, significant differences ($P < .05$) were found for accelerator errors in periods 1 and 2, for signal errors in periods 1, 2, and 3, for braking errors in periods 2 and 3, and for speedometer errors in period 1. In the comparison of marihuana smokers and controls, a significant difference ($P < .05$) was found for speedometer errors in period 1. In all of these cases, the number of errors

Table 2. Significant treatment differences from Latin-square analysis of variance ($P < .05$). Accelerator, signal, and total errors are significantly correlated with driving performance for normal drivers. No correlation was found for brake, speedometer, and steering errors; A > C, M > C indicate that error scores for alcohol (A) or marihuana (M) treatment are greater than control (C).

| Simulator test | Test variable errors | | | | | |
|---|---|---|---|---|---|---|
| | Accelerator | Signal | Total | Brake | Speedometer | Steering |
| Period 1 | A > C | A > C | A > C | None | A > C<br>M > C | None |
| Period 2 | A > C | A > C | A > C | A > C | None | None |
| Period 3 | None | A > C | A > C | A > C | None | None |

for the drug treatments exceeded the errors for the control treatment.

Other sources of variation are Latin squares, subjects, and days. In all of the analyses, the effect of subjects and Latin squares (representing groups of subjects) were significant ($P < .05$). In contrast, the effect of days was not significant, thus indicating that no significant amount of learning was associated with repeated exposure to the test material.

For normal drivers, Crancer (*4*) found a significant correlation ($P < .05$) between the three simulator test variables (signals, accelerator, and total errors) and driving performance. An increase in error scores was associated with an increase in number of accidents and violations on a driving record. In the same study, error scores for brake, speedometer, and steering were not correlated with driving performance.

It may not be valid to assume the same relationship for persons under the influence of alcohol or marihuana. However, we feel that, because the simulator task is a less complex but related task, deterioration in simulator performance implies deterioration in actual driving performance. We are less willing to assume that nondeterioration in simulator performance implies nondeterioration in actual driving. We therefore conclude that finding significantly more accelerator, signal, and total errors by intoxicated subjects implies a deterioration in actual driving performance.

Relating speedometer errors to actual driving performance is highly speculative because Crancer (*4*) found no correlation for normal drivers. This may be due in part to the fact that the speed of the filmed presentation is not under the control of the driver. However, speedometer errors are related to the amount of time spent monitoring the speedometer. The increase of speedometer errors by intoxicated or "high" subjects probably indicates that the subjects spent less time monitoring the speedometer than under control conditions.

This study could not determine if the drugs would alter the speed at which subjects normally drive. However, comments by marihuana users may be pertinent. They often report alteration of time and space perceptions, leading to a different sense of speed which generally results in driving more slowly.

Weil *et al.* (*1*) emphasize the importance and influence of both subject bias (set) and the experimental environment (setting). For this study, the environmental setting was conducive to good performance under all treatments.

Traditional methods for controlling potential subject bias by using placebos to disguise the form or effect of the marihuana treatment were not applicable. This is confirmed by Weil *et al.* (*1*); they showed that inexperienced subjects correctly appraised the presence or absence of a placebo in 21 of 27 trials.

The nature of selection probably resulted in subjects who preferred marihuana to alcohol and, therefore, had a set to perform better with marihuana. The main safeguard against bias was that subjects were not told how well they did on any of their driving tests, nor were they acquainted with the specific methods used to determine errors. Thus, it would have been very difficult intentionally and effectively to manipulate error scores on a given test or sequence of tests.

A further check on subject bias was made by comparing error scores on the warm-up tests given before each treatment. We found no significant difference in the mean error scores preceding the treatments of marihuana, alcohol, and control. This suggests that subjects were not "set" to perform better or worse on the day of a particular treatment.

In addition, an inspection of chance variation of individual error scores for treatment M shows about half the subjects doing worse and half better than under control conditions. This variability in direction is consistent with findings reviewed earlier, and we feel reasonably certain that a bias in favor of marihuana did not influence the results of this experiment.

A cursory investigation of dose response was made by retesting four subjects after they had smoked approximately three times the amount of marihuana used in the main experiment. None of the subjects showed a significant change in performance.

Four additional subjects who had never smoked marihuana before were pretested to obtain control scores, then given marihuana to smoke until they were subjectively "high" with an associated increase in pulse rate. All subjects smoked at least the minimum quantity established for the experiment. All subjects showed either no change or negligible improvement in their scores. These results suggest that impairment in simulated driving performance is not a function of increased marihuana dosage or inexperience with the drug.

A significant difference ($P < .01$) was found between pulse rates before and after the marihuana treatment. Similar results were reported (*1*) for both experienced and inexperienced marihuana subjects. We found no significant difference in pulse rates before and after drinking.

Thus, when subjects experienced a social marihuana "high," they accumulated significantly more speedometer errors on the simulator than under control conditions, but there were no significant differences in accelerator, brake, signal, steering, and total errors. The same subjects intoxicated from alcohol accumulated significantly more accelerator, brake, signal, speedometer, and total errors than under control conditions, but there was no significant difference in steering errors. Furthermore, impairment in simulated driving performance apparently is not a function of increased marihuana dosage or inexperience with the drug.

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