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46. We thank S. C. Matthews, University of Bristol, for the gift of topotypes of *Heraultia* and photographs of *Anabarella*; A. A. Öpik, Bureau of Mineral Resources, Canberra, kindly lent important Cambrian rostroconchs. Other figured specimens are deposited at the U.S. National Museum, Washington, D.C.; the British Museum (Natural History), London; the University of Cambridge; and the University of Queensland, Brisbane. Many of the ideas presented here were discussed with E. L. Yochelson, U.S. Geological Survey, N. J. Morris and J. D. Taylor, British Museum (Natural History), E. R. Trueman, University of Manchester, and V. Fretter and A. Graham, University of Reading. We thank them for their help and advice.

Marijuana and Driving in Real-Life Situations

The effect of marijuana on driving is bidirectional and dependent on compensatory ability and dose.

Harry Klonoff

There is a marked paucity of published research dealing with the effects of marijuana on driving in a real-life situation. Le Dain (*1*) was the first to report a study of the effects of two levels of smoked marijuana and a single dose of alcohol on 16 subjects who drove a vehicle in a restricted traffic-free area. All other published studies relevant to marijuana and driving have employed some type of laboratory driving simulator (*2*) or a psychomotor model (*3*). Studies dealing with the monitoring of heart rate during real-life driving conditions have been reported, but infrequently (*4–6*).

The purposes of the present study were to determine: (i) the effects of low and high doses of marijuana on driving performance in both a restricted, traffic-free area—that is, a driving course—and on the streets of Vancouver, including the downtown area, during peak hours of traffic flow; and (ii) the effects of marijuana and driving on heart rate.

Methods

Characteristics of subjects. For the driving course portion of the study, 64 volunteers (43 men and 21 women) were assigned to one of three groups as follows: a group given low doses of the drug, 13 men and 8 women; a group given high doses of the drug, 14 men and 8 women; and a group given a placebo, 16 men and 5 women. Of these volunteers, 38 (25 men and 13 women) also participated in the street driving portion of the study, and were assigned to one of four groups as follows: a group given low doses of the drug prior to the first driving session and then placebo prior to the second session, 5 men and 4 women; a group given placebo first and then low doses of the drug, 7 men and 3 women; a group given high doses of the drug then placebo, 6 men and 2 women; and a group given placebo then high doses of the drug, 7 men and 4 women. Thus the four groups participated in both sessions and in each session they were approximately counterbalanced.

The mean age of the volunteers was 23.89 years (standard deviation, 2.99, range 19 to 31). Their educational level was as follows: 22 percent had finished high school; 12 percent had completed 1 year of university education; 30 percent had completed 2 to 4 years of university education; 30 percent had a bachelor's degree; 3 percent had a master's degree; and 3 percent had a doctorate. Thus the group as a whole was a highly educated one. The volunteers could be classified into six categories according to their occupation: postsecondary students, 38 percent; professional, 20 percent; semiprofessional, 3 percent; service, technical, and clerical, 20 percent; skilled and semiskilled, 11 percent; and housewife, 8 percent. Of the group, 62 percent were single, 32 percent were married, and 6 percent were divorced, separated, or living common-law.

All of the subjects had had prior driving experience; the mean number of years of driving experience was 6.92 (S.D., 3.14 years).

Marijuana and placebo. For the low doses of marijuana, standardized *Cannabis sativa* containing 0.70 percent of Δ^9-tetrahydrocannabinol (Δ^9-THC) was used; for the high doses, 1.2 percent of Δ^9-THC was used. The physical characteristics of the placebo were identical to those of the *Cannabis sativa* plant material, but the placebo was free of cannabinols. When smoked, the placebo

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smelled and tasted like the marijuana cigarettes made from the unextracted plant material.

The marijuana and the placebo were administered in the form of cigarettes of standard size and weight (0.70 gram); a cigarette with a low dose of marijuana contained 4.90 milligrams of Δ^9-THC and a cigarette with a high dose contained 8.40 mg of Δ^9-THC. The way in which the volunteers smoked the cigarettes was standardized as follows. Each subject inhaled smoke for 3 seconds, inhaled air for 1 second, held the breath for 15 seconds, and then exhaled and rested for 15 seconds (*7*).

The driving course: description and scoring method. The driving course was made up of eight road tests arranged in sequence on a T-shaped paved area of about 4620 square meters. The course, in terms of tasks, distances, and cones, is shown in Fig. 1. For the first five driving tasks the subjects had to (i) slalom, (ii) and (iii) drive through two tunnels of different lengths, (iv) drive through a funnel, and (v) assess the risk that would be involved in passing between two rows of cones whose distance apart was either 1.85 or 1.65 meters. The smaller gap was not passable because the outside width of the wheelbase of the vehicle was 1.70 m. The subject was instructed to stop 6.08 m from the cones and decide whether the gap was passable or not. If the subject decided it was passable, he had to drive through the gap, otherwise he had to drive around it. For two of the remaining tasks, the subjects had to (vi) back up; and (vii) negotiate a corner. In task (vii) the subject was instructed to accelerate to 32 kilometers per hour on a straightaway, then slow to 16 km per hour and go through a right curve made up of two rows of cones. For task number (viii) the subjects had to react in an emergency braking situation that was cued by the firing of a .22 caliber paint cartridge. The braking apparatus was attached to the front bumper of the car and triggered by the driving observer. The shot provided the cue to stop as quickly as possible and the paint on the pavement served as a reference point for measuring braking distance. This test was done only when the subject was between other tasks and his speed was 24 km per hour (the speed he was asked to maintain between tasks).

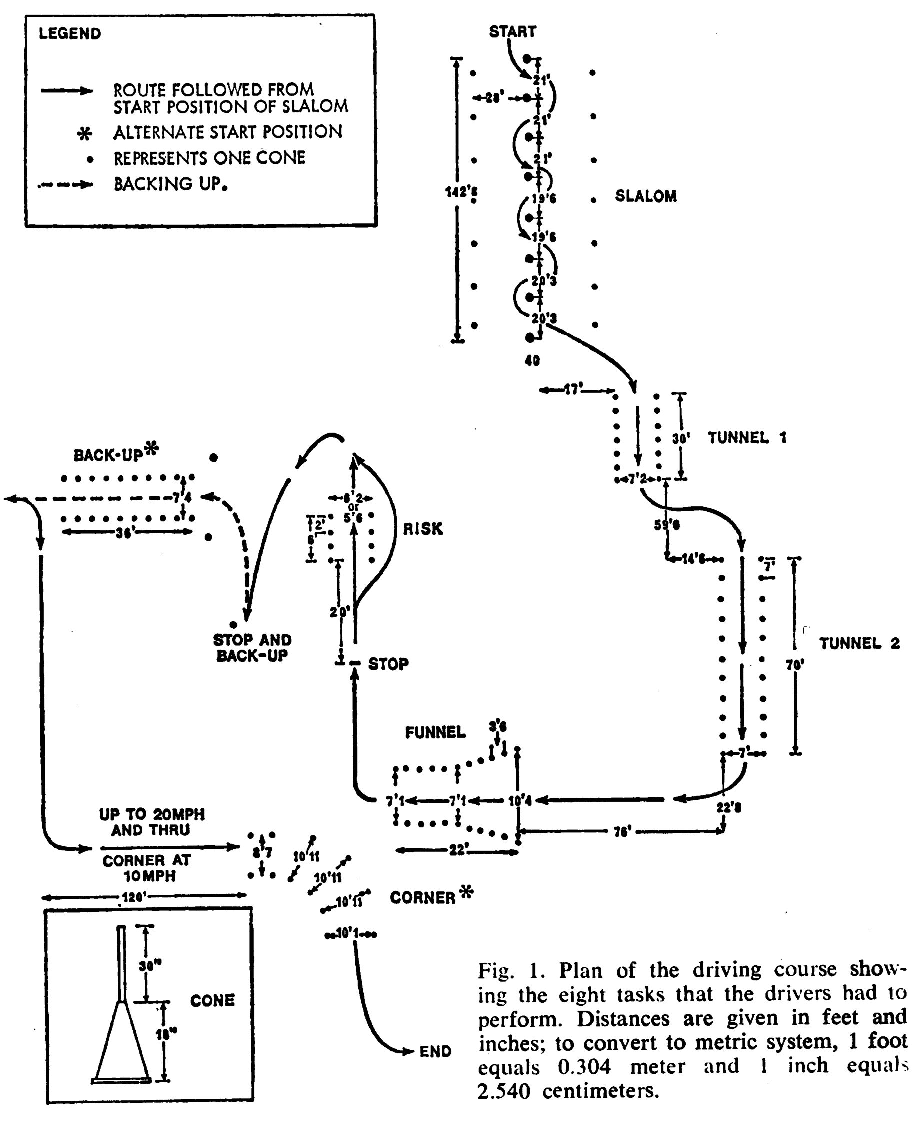

Fig. 1. Plan of the driving course showing the eight tasks that the drivers had to perform. Distances are given in feet and inches; to convert to metric system, 1 foot equals 0.304 meter and 1 inch equals 2.540 centimeters.

Points of entry into the course (slalom, back-up, corner) and the order of the tasks were kept constant for all subjects.

In the scoring for all the tasks except the slalom and risk, each cone hit was recorded as one. For slalom, the scoring was as follows: 1 point for touching a cone; 2 points for a direct hit and knockdown of a cone; and 2 points for backing up to avoid hitting a cone. For risk, the scoring was as follows: for the smaller gap, 0 points for driving around it and 4 points for driving through it; for the larger gap, 4 points for driving around it and, depending on the number of side hits, 0, 2, or 4 points for driving through it. The scoring was done by four persons who were able to count the cones contacted by the vehicle as it traversed the course.

Safety features for the Chevrolet Nova used on the course included dual brakes and an auxiliary ignition, and for the Chevelle Malibu used for the tests on the city streets, dual steering wheel, dual brakes, and an auxiliary ignition.

Driving procedure on the course. The subject, with an observer in the front seat, drove around the course twice to learn about the order of the tasks, the scoring method, and the braking procedure. Trials were given in four blocks of five trials each. Blocks 1 and 2 were given on the same day (first session); blocks 3 and 4 were given, on the average, 7 days later (second session). During the five trials of block 1, the subject was told to drive the course while the driving observer provided cues for improving performance and feedback regarding errors, clearance of cones, and handling of the vehicle. A minimum of two practice braking sequences was allowed. During the five trials of block 2, the only instructions given to the subject were regarding points of entry into the course sequence. Two emergency braking tests were given.

For blocks 3 and 4, the driving procedure on the course was identical to that of block 2. Between blocks 3 (baseline) and 4 (experimental), with the car parked, the subject smoked a cigarette containing marijuana or placebo.

Driving procedure on the city streets. During the first session the subject drove the Chevelle dual control car around the campus for 10 minutes in order to become familiarized with the vehicle. On returning to the laboratory, the subject smoked a cigarette containing marijuana or placebo, and was told that in the next part of the session he or she would be responsible for observing all traffic regulations and should drive as if being examined for a driver's license. The subject was then instructed to drive to a designated intersection in the center of the downtown area. After arriving at this point, the subject was instructed to drive to another designated intersection in a residential area, and after arriving there was instructed to drive back to the university hospital. The approximate distance was 26 km and driving time was on the average 46 minutes.

With the exception of the familiarization period, the procedure was repeated during the second session which took place, on the average, 7 days later. During the pilot phase of the study, two trained driving observers (who had been employed as examiners by the British Columbia Motor Vehicle Department) were in the vehicle to ensure reliability of the scoring system. But, during the study proper, only one of these observers was present in the front seat of the car.

Driving took place on the streets of Vancouver during daylight hours, between 12:00 noon and 8:30 p.m. from Monday through Friday. Because the time of day of the two sessions for each subject was standardized, traffic conditions encountered by individual subjects were more or less controlled. Traffic was light 25 percent of the time, moderate 47 percent of the time, and heavy 28 percent of the time. Road conditions were dry 67 percent of the time, damp 18 percent of the time, and wet 15 percent of the time.

On the course, the subjects smoked a cigarette containing marijuana or placebo only once—before the final block of trials. On the streets, subjects smoked one of these cigarettes before each session, and the drug and placebo were counterbalanced for each subject for each session. The double-blind procedure was maintained on the course and street portions of the driving study,

Table 1. Raw and transformed scores for behavioral components of driving.

Transformed difference scores	Raw difference scores		
	General driving habits	Speed	Remaining categories
1	− 11*	− 4*	− 3*
2	− 7 to − 10	− 3	− 2
3	− 3 to − 6	− 2	− 1
4	± 2	± 1	0
5	3 to 6	2	1
6	7 to 10	3	2
7	11†	4†	3†

* Or less. † Or more.

so that neither the subjects nor the driving observers knew the sequence of the experiments, or which trials were being used for obtaining baseline data, or the format for scoring.

Scoring method on city streets. The format for the driver's examination set by the British Columbia Department of Motor Vehicles served as the basis for measuring driving skills on city streets. Eleven behavioral components involved in driving were selected and quantified. The components reflecting driving skills and their respective raw score ranges were as follows. (i) General driving habits, including: posture (0 to 5); starting and stopping (0 to 5); carelessness with driving regulations (0 to 10); turning (0 to 10); lane changing (0 to 10); regard for traffic signals (0 to 10); poor driving habits, for example, turning the head while talking (0 to 10). (ii) Cooperation (0 to 5). (iii) Attitude (0 to 5). (iv) Irritability (0 to 5). (v) Judgment (0 to 5). (vi) Speed: too fast (0 to 5) or too slow (0 to 5). (vii) Care while driving: careless (0 to 5) or overcautious (0 to 5). (viii) Confidence: overconfidence (0 to 5) or lack of confidence (0 to 5). (ix) Tension: tense (0 to 5) or lethargic (0 to 5). (x) Aggression: aggressive (0 to 5) or passive (0 to 5). (xi) Concentration: fixation (0 to 5) or attention wandering (0 to 5). The driving observer assigned a raw score to each category at the end of each session. To reflect change between the two sessions and to relate changes between sessions to the two conditions (subjects might have received drug first or placebo first), the difference (*d*) scores for each category were always calculated by subtracting the scores obtained by subjects in the undrugged (placebo) condition from those obtained when they were under the influence of marijuana.

In order to compare categories and to provide a meaningful composite (total) score, the raw scores were transformed to an arithmetically weighted scoring system of 1 to 7. Both the transformed score rationale, which was derived from a pilot study, and the format, were decided upon before the study proper began. The driving observer was unaware of the transformed score procedure.

Table 1 indicates the basis for assigning transformed scores (1 to 7) for general driving habits, speed, and the remaining nine categories. For each of the 11 categories a transformed score of 4 indicates no change, transformed scores of 1 to 3 reflect improvement, and transformed scores of 5 to 7, decline. The total transformed score range is, accordingly, 11 to 77; 44 indicates no overall change, less than 44 reflects overall improvement, and more than 44 indicates overall decline.

Because driving on city streets results in the encountering of emergent situations on a random basis, the number of such situations per session was recorded by the driving observer, who scored each situation on a scale from 0 to 20 according to his assessment of the dangerous nature of the event. For the subjects in this study, the number of emergent situations encountered in one session should be no different from the number encountered in the other session. Significant differences in the incidence of emergent situations between sessions would accordingly be related to whether the subjects had smoked cigarettes containing marijuana or placebo.

Heart rate on course and street. Before each driving session, the heart rate of each subject was recorded for 4 minutes in a laboratory. This rate was used as the baseline. Recording in the automobile was done with a portable FM/FM battery powered telemetry system with FM subcarrier multiplexing.

On the course, heart rate was recorded during the five trials of each of blocks 2, 3, and 4. The approximate recording time for each block of trials was 20 minutes (4 minutes per trial). To score the heart rates, samples of the recordings were used that approximated the time taken to complete each task. Thus the duration of sampling per trial was as follows: 10 seconds each for tunnel 1, tunnel 2, funnel, risk, corner, braking; 20 seconds for back-up; and 30 seconds for slalom. The score was then derived by summing the rates for each task over the five trials for each of blocks 2, 3, and 4 and then converting

Table 2. Linear regression for course scores ($N = 64$). For block 4, the 95 percent confidence interval is shown for the predicted scores.

Task	Actual scores for blocks			Block 4		Slope of line	Actual scores for block 4		
	1	2	3	Predicted scores	Confidence interval		Placebo	Low dose	High dose
Slalom	10.5	9.8	9.0	8.3	± 1.6 (6.7 to 9.9)	− 0.7*	8.9	8.8	10.4‡
Tunnel 1	3.9	2.7	1.5	0.3	± 1.2 (− 0.9 to 1.5)	− 1.2†	1.0	2.6‡	3.0‡
Tunnel 2	8.1	6.6	5.1	3.5	± 1.9 (1.6 to 5.4)	− 1.5†	2.8	5.0	6.9‡
Funnel	2.1	1.9	1.7	1.4	± 1.0 (0.4 to 2.4)	− 0.2	1.2	1.7	2.9‡
Back-up	8.1	7.1	6.1	5.0	± 2.6 (3.4 to 7.6)	− 1.0	6.0	6.0	7.0
Corner	3.5	3.4	3.4	3.3	± 0.7 (2.6 to 4.0)	− 0.1	2.9	4.1‡	3.1
Risk	4.4	3.9	3.4	2.9	± 1.2 (1.7 to 4.1)	− 0.5	4.0	3.8	4.7‡
Composite	40.7	35.4	30.1	24.8	± 5.4 (19.4 to 30.2)	− 5.3†	26.8	31.9‡	38.1‡

* $P < .05$. † $P < .01$. ‡ Beyond upper limits of confidence interval.

these rates to beats per minute and comparing the results for blocks 2 or 3 (or both) with those for block 4.

On the city streets, heart rate was recorded continuously during the two driving sessions; the duration of each session was approximately 46 minutes. Five types of traffic conditions or areas were defined in advance, namely: residential through streets (light traffic and regular traffic flow); residential side streets (light traffic, right of way undefined, school and playground areas); local commercial area (medium traffic and fluctuations in speed); downtown area (heavy traffic conditions and restrictions); and higher speed areas with multiple lanes (medium to heavy traffic and tightness in maneuvering). The score, expressed as beats per minute, was derived from the amount of time spent in each of the five areas, each area being included in the score only if the time spent in that area was greater than 3 minutes. Events were defined in terms of: turns, major intersections, and parking. The total time of the events was scored in terms of beats per minute.

Results

Driving on the course. Because learning was likely to occur while subjects were driving on the course, block 3 was used as the baseline measure and block 4 as the experimental measure. To control for warmup effect, boredom, and fatigue, only the scores for trials 2, 3, and 4 in each of the respective blocks were used in the data analysis.

As a result of learning, total scores improved in the order of 15 percent between blocks 1 and 2, and again between blocks 2 and 3 (with the slope of the linear regression for scores as shown in Table 2 being significant). A comparable rate of improvement (17 percent) was predicted from the linear regression for block 4 (the experimental block). Intake of the drug, however, impeded learning—scores worsened to the extent of 29 percent from predicted for the group smoking low doses of marijuana and 54 percent for the group smoking high doses. These rates of decline are reflected in the regression analysis where two of the tasks and the composite score for the group smoking low doses of the drug and five of the tasks and the composite score for the group smoking high doses were beyond the upper limits of the confidence interval. There was a substantially lesser rate of decline (8 percent) for the group smoking the placebo, and this decline could be explained by the performance of three subjects who were subsequently identified as being sensitive to the placebo.

Learning can also account for the differential rate of change in scores between block 3 (baseline) and block 4. Scores for the group smoking the placebo continued to improve significantly (mean improvement, 5.5; $t = 2.41$, $P < .05$); scores for the group smoking low doses of marijuana indicated some impairment in learning (mean decline, 1.0), while scores for the group smoking high doses of the drug indicated significant impairment in learning (mean decline, 8.2; $t = 2.85$, $P < .01$). Also, both groups that smoked marijuana (low or high doses) showed significant mean declines in learning of 6.5 and 13.7 compared to the group smoking the placebo. Furthermore, there was a dose-related response, in terms of comparisons within and between conditions: according to Duncan's multiple range test, $F = 11.99$, $P < .01$; placebo versus low dose of marijuana, $P < .05$; placebo versus high dose, $P < .01$; low dose versus high dose, $P < .05$ (8).

Braking distance was analyzed separately within and between conditions. Braking distance decreased significantly between blocks 3 and 4 for the placebo group ($t = -2.41$, $P < .05$) but not for the groups on low or high doses of marijuana. In comparing the braking distance of the placebo group with the group on low doses of the drug and then with the group on high doses, neither difference was significant.

Statistical tests permit one to make inferences about differences between groups, and in this study, differences between the groups smoking the placebo and marijuana. But this is a generalization that requires qualification in terms of the number of subjects within each group that changed, the direction of their change, and the extent of change.

Table 3 provides information regarding absolute change in performance in terms of decline, no change, and improvement of driving skills. But absolute scores overstate the nature of change, and a criterion measure was accordingly used to determine significant change in performance. From the linear regression (Table 2), it may be noted that the confidence interval for the total score was ± 5.4, and ± 5 was accordingly used as a cutoff point for determining significant decline and improvement (Table 3).

Driving on the city streets. Data for the group given high doses of marijuana prior to the first session were combined with those for the group given high doses prior to the second session. Likewise, data for the groups on low doses of marijuana in the two sessions were combined. For the groups on the high dose the mean score was 47.5; for the combined group on the low doses it was 45.1. An analysis of the scores as they differed from the cutoff point of 44 revealed significant findings for the combined group on high doses of marijuana ($t = 2.33$, $P < .05$) but not for the combined group on low doses. The scores were then categorized in terms of: decline (above the cutoff score of 44); no change (score of 44); and improvement (below the cut-off score of 44). Table 3 also summarizes the distribution of scores for the groups on low and high doses of marijuana, respectively (9).

As with the data for the driving course, absolute scores for the street driving tests overstated the nature of change; the 95 percent confidence interval was thus again used as a basis for inferring significant change. The 95 percent confidence interval was ± 1.99 for the scores of all subjects, and this interval was related to the cutoff score of 44 in order to determine categories of significant change. The findings regarding significant change for the two conditions are summarized in Table 3.

The behavioral components of driving were also analyzed (see Table 4). There was no appreciable difference between the subjects below and above the cutoff point for cooperation and attitude, some difference in general driving skills, irritability, speed, confidence, tension, and aggression, and considerable difference in judgment, care while driving, and concentration.

For the 38 volunteers, the number of emergent situations recorded during the placebo session was 8, and during the drug session (unrelated to dose) 18. With the placebo session being used as the criterion, the probability of emergent situations occurring in the drug session was significant beyond the .01 level. Whereas there was a significant difference between the placebo and drug sessions regarding the frequency of emergent situations, the mean magnitude of situations during the drug session (5.5) was slightly but not significantly higher than during the placebo session (5.2).

Driving scores and other variables. A number of variables which may produce differential effects on driving were also included in the data analysis. For the course, difference scores for trials 2, 3, and 4 between blocks 3 and 4 were again used as the basis for comparison. The first variable considered was sex, and there were no significant differences for the three groups. The second variable analyzed was driving experience, and this was defined in terms of: at least 5 years of driving on a more or less daily basis, and less than 5 years of driving. There were no significant differences for the three groups. The third variable examined was previous experience of driving while under the influence of marijuana, and this was defined in terms of: never or infrequent, and frequent (more than 50 times). There were no significant differences in this variable.

These same variables were analyzed with respect to scores obtained by those subjects who drove on the street. There were again no significant differences attributable to sex, driving experience, or experience of driving while under the influence of marijuana.

Unusual behavior and emergent situations. When subjects were driving on the course after they had smoked marijuana, the observers noted behavior that may have reflected transient episodes of preoccupation and possibly confusion. Such behavior included: loss of set regarding the order of tasks to be followed; loss of discrimination between internal and external course markers; driving off the course; and forgetting to change into the appropriate gear during the back-up task.

Unusual driving behavior noted by the observer during the street portion of the project included the following: the missing of traffic lights or stop signs; engagement in passing maneuvers without sufficient caution; poor anticipation or poor handling of vehicle with respect to traffic flow; unawareness or inappropriate awareness of pedestrians

Table 3. Frequency (*f*) and percentage of decline, no change, improvement, significant decline (+ 6 or more for course and 47 or higher for street), no change (+ 5 to − 5 for course and 42 to 46 for street), and significant improvement (− 6 or less for course and 41 or lower for street) in driving performance on the course and on city streets.

Change in performance	Course (*N* = 64)						Streets (*N* = 38)			
	Placebo		Low		High		Low		High	
	f	Percent	*f*	Percent	*f*	Percent	*f*	Percent	*f*	Percent
Decline (+)	5	24	12	57	16	73	10	53	15	79
No change (0)	1	5	1	5	1	4	1	5	1	5
Improvement (−)	15	71	8	38	5	23	8	42	3	16
Significant decline	3	14	7	33	12	55	8	42	12	63
No change	10	48	9	43	7	31	5	26	4	21
Significant improvement	8	38	5	24	3	14	6	32	3	16

Table 4. Behavioral components of driving performance for those subjects who showed no change or significant improvement (below cut-off point) compared to those who showed significant decline (above cutoff point) (*f*, frequency).

Driving categories	Change*	Subjects below cutoff point (*N* = 19)†		Subjects above cutoff point (*N* = 19)†	
		f	Percent	*f*	Percent
General driving	+	17	45	12	32
	−	2	5	7	18
Cooperation	+	18	47	19	50
	−	1	3	0	0
Attitude	+	19	50	18	47
	−	0	0	1	3
Judgment	+	13	34	5	13
	−	6	16	14	37
Irritability					
Less irritable	+	14	37	12	32
More irritable	−	5	13	7	18
Speed					
Closer to speed limit	+	17	45	12	32
Unduly slow or fast	−	2	5	7	18
Care					
Appropriately careful or cautious	+	16	42	5	13
More careless or hypercautious	−	3	8	14	37
Confidence					
Appropriately confident	+	15	39	9	24
Overconfident or lacking confidence	−	4	11	10	26
Tension					
Less tense or less lethargic	+	15	39	9	24
More tense or more lethargic	−	4	11	10	26
Aggression					
Less aggressive or less passive	+	15	39	11	29
Unduly aggressive or unduly passive	−	4	11	8	21
Concentration					
More attention or less fixation	+	9	24	3	8
More fixation or less attention	−	10	26	16	42

* Plus signs indicate no change or an improvement; minus signs indicate a decline in performance.
† Frequencies are different from those for Table 3 (9).

or stationary vehicles; and preoccupation at traffic signals and lack of response to green lights. The observer intervened rarely while the subjects were driving on city streets; in fact he intervened on only three occasions, once when a subject was driving in the placebo condition and twice when two different subjects were driving after they had smoked marijuana.

Measurements of heart rate. Because the effects of marijuana on heart rate were not consistently related to the dosage, data for the two groups of subjects on high and low doses of the drug were combined.

Table 5 summarizes the data on the heart rate of subjects driving on the course. Compared with the laboratory baseline, heart rate increased significantly during the baseline trials ($t = 7.26$, $P < .01$) and increased further during block 4 trials conducted after the subjects had smoked marijuana, but not after they had smoked the placebo. For the group that had smoked marijuana, the increases in heart rate were significant during block 4 trials for the composite score and for all tasks including braking.

Table 6 summarizes the data on the heart rates of subjects driving on the street. Compared with the baseline rate obtained in the laboratory, the heart rates of subjects driving after they had smoked the placebo did not increase significantly. After subjects had smoked marijuana, however, their heart rates increased significantly. Heart rates during the drug compared with the placebo condition increased significantly for the composite score and for all types of traffic patterns and events. With the exclusion of the scores for parking (which can be explained in terms of expended effort), the range of scores was much more restricted when subjects were on the placebo than when they were on the drug, suggesting that the significant increase in heart rate caused by the drug was reinforced by arousal. Dose-related responses occurred with two types of traffic patterns, one event, and the total score for events.

Table 5. Heart rate of subjects driving on the course. Values for Student's t-tests were derived from d scores.

Task	Mean (beats per minute)		t-Test for placebo versus baseline	Drug mean ($N = 29$)	t-Test	
	Baseline* ($N = 42$)	Placebo ($N = 13$)			Drug versus baseline†	Low versus high dose
Slalom	99.9	102.9	0.12	122.8	9.62	− 0.68
Tunnel I	97.3	99.8	0.22	122.5	9.93	− 0.77
Tunnel II	95.2	96.3	0.80	119.2	8.77	− 0.65
Funnel	95.9	97.1	0.23	120.1	9.18	− 0.92
Back-up	100.9	101.0	1.63	122.5	9.57	− 0.86
Corner	99.9	100.8	1.22	122.2	8.04	− 0.66
Risk	97.0	97.9	0.29	119.2	8.94	− 0.97
Composite	98.0	99.4	0.72	121.2	9.38	− 0.81
Braking	99.9	105.3	0.03	121.9	8.38	− 1.04

* Mean baseline heart rate in the laboratory was 76.2. † All t's significant at $P < .01$.

Table 6. Heart rate of subjects driving on city streets. Values for Student's t-tests were derived from d scores.

Traffic patterns and events	N	Mean (beats per minute)*		t-Test	
		Placebo	Drug	Drug versus placebo†	Low versus high dose
		Types of traffic conditions			
Residential through streets	27	79.2	96.0	8.56	− 1.03
Residential side streets	16	80.8	93.9	6.02	− 2.54‡
Local commercial area	26	80.5	98.9	8.39	− 2.14‡
Downtown	26	81.3	99.5	8.91	− 1.27
Higher speed area	28	81.8	103.9	9.12	0.20
Total		80.3	98.8	10.16	− 1.11
		Events			
Turns	27	84.4	101.5	8.54	− 1.90
Major intersections	27	82.4	100.3	8.48	− 1.08
Parking	13	91.4	102.9	2.48	− 2.34‡
Total		84.8	101.6	9.12	− 2.13‡
Composite		82.3	100.0	9.92	− 1.60

* Mean baseline heart rate in the laboratory was 77.7. † All significant at $P < .01$ except for parking which was significant at $P < .05$. ‡ Significant at $P < .05$.

Discussion

Driving ability as it was measured on the course was a composite of skill, judgment, and shifting set. The subjects responded in a competitive manner to the challenge of driving in an experimental context. Although boredom and fatigue had to be taken into account, these seemed to be of secondary importance. When the experiments were being planned, it was considered possible that unconscious if not conscious bias might induce many of the volunteers to demonstrate that marijuana does not affect driving; this they might have done by hitting cones on purpose during the preliminary trials. To offset this possibility, none of the volunteers nor the observers were aware of which block of trials would be designated as the baseline. Furthermore, before the trials began, 61 percent of the volunteers reported on a questionnaire that marijuana slightly detracts from or impairs driving, thus indicating that bias was not an important factor in these experiments.

Although the driving skills measured on the course and on the city streets might not on the surface appear to be similar, and although the scoring systems used for the two experimental situations were certainly conceptually different, there was nonetheless a striking relationship between the percentages of decline, no change, and improvement for the respective groups driving on the course and on the streets.

How does one explain these findings? First, there are individual differences regarding the effects of a drug, and such differences are not exclusively related to dosage. Second, a change in a subject's sensorium is most apt to result in his making an effort to compensate, particularly if he is driving, a task that requires a high degree of alertness. But as with the effects of a drug, there are individual differences in ability to compensate; this is well demonstrated by those volunteers whose scores did not change significantly when they were under the influence of marijuana. And there are individual differences in ability to overcompensate, as shown by those subjects who showed improvements in scores after they had smoked the drug.

The association between autonomic arousal and emotion, as well as stress, is well accepted (*10*). Of vital functions affected during stress, the most dramatic and readily measurable changes occur in heart rate. The significant and consistent changes in heart rate recorded in this study could most readily be related to an interaction model of stress-habituation and the effects of the drug. The mere act of driving caused differential changes in heart rate depending on whether the subjects were on the course or the city streets. Specifically, heart rate increased by 29 percent (beats per minute) during baseline (practice driving) trials on the course compared with the laboratory measure. A directly comparable measure of heart rate was not available for driving on the street because of the nature of the experimental design. But with an indirect measure, namely, the difference in rate between the laboratory and the placebo condition, heart rate on the course increased 30 percent (to 99.4 beats per minute; see Table 5) and on the streets increased only 6 percent (to 82.3 beats per minute).

If one began with the premise that driving on the street as well as on the course was stressful and would have resulted in autonomic activation, and predriving baseline differences (76.2 and 77.7 beats per minute for those subjects on the course and streets, respectively) can be ruled out, then the significant increase in heart rate noted on the course (30 percent) compared with the negligible (6 percent) increase on the street could be explained in terms of the monitoring procedure and habituation. The physiological monitoring on the course was done on a sampling basis, and in fact was designed to document the stress induced by the course tasks which followed in very quick succession. The monitoring on the street was continuous, so that increases in heart rate during stressful moments were counterbalanced by a more normal heart rate that characterizes the more nonstressful periods of driving. In Taggart and Gibbons' study (*5*), the sampling of the driving experience, as well as the driving site, which was Trafalgar Square in London, England, might have accounted for their finding significant increases in heart rate. The same explanation might apply to the study of Simonson *et al.* (*6*) in which distinct increases in heart rate with critical driving situations were noted.

The smoking of marijuana potentiated the stress of driving, and subjects who drove on the streets and those who drove on the course showed almost identical tachycardia (increases in the order of 22 percent). The finding that tachycardia occurred soon after the smoking of marijuana was consistent with previous electrophysiological investigations in our laboratory in which the doses of marijuana used were the same as in this study (*11*). In contrast, the effect of the placebo on heart rate was negligible, and this has also been demonstrated previously in our laboratory. The design of the study described here permitted a measure of internal validation in that the heart rates for the discrete tasks on the course could be compared with the heart rates for the different types of traffic patterns and for the events on the street. Such analyses revealed that heart rate measures were amazingly consistent between the tasks on the course and, to a lesser extent, between types of traffic and events on city streets. A dose-related response occurred only on the street and for two of the five types of traffic, one of the three types of events and for the total score for events.

Conclusion

It is evident that the smoking of marijuana by human subjects does have a detrimental effect on their driving skills and performance in a restricted driving area, and that this effect is even greater under normal conditions of driving on city streets. The effect of marijuana on driving is not uniform for all subjects, however, but is in fact bidirectional; whether or not a significant decline occurs in driving ability is dependent both on the subject's capacity to compensate and on the dose of marijuana. For those subjects who improved their performance, the explanation may lie in overcompensation and possibly the sedative effect of the drug.

Whereas the street portion of this study approximated normal driving conditions, it should be emphasized that the context of the driving experience even on city streets was experimental. The design of this study provided maximal safeguards in terms of a dual control vehicle and a driver observer; in addition, the subjects were professionally screened and, with rare exception, they were emotionally stable. Given the experimental setting and set, the safeguards, and the nature of the study sample, idiosyncratic behavior that might occur under normal driving conditions would be less likely to occur in a study such as this.

Other identified factors might lead to more stringent conclusions regarding the effects of marijuana on driving. The first is night driving, which may be more stressful. But an even more important unanswered question is the cumulative effect of alcohol and marijuana on driving (64 percent of the study sample reported using alcohol in combination with marijuana before driving). Third, the doses of marijuana used in this study were within the range of social marijuana usage (*1*); more heroic doses might be taken before driving. Fourth, the effect of marijuana on reactions and decisions during high speed is still another unknown.

What are the recommendations that emerge from this study? Driving under the influence of marijuana should be avoided as much as should driving under the influence of alcohol. More investigation is urgently required—and high priority should be given to studies that approximate normal conditions of driving and in which alcohol and marijuana are administered to the same subjects.

References and Notes

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University Research and the New Federalism

Interactions with state governments pose problems and opportunities for university scientists.

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The President's budget for fiscal year 1975 continues to place emphasis on the philosophy of the "new federalism" which calls for strengthening the role of state and local governments. Between fiscal 1970 and 1973, federal research and development funds directed to state and local governmental bodies increased from $99 million to $250 million (*1*). As a consequence, major public and private universities are becoming increasingly involved with state and local governments in both research and service activities. Table 1 shows expenditures for selected institutions for sponsored programs from state governments for 1970 and 1973.

As a result of this shift some universities and their faculties are operating in a new environment, one that affects many aspects of their teaching, research, and service. Some of these new relationships are healthy and result in new vigor for academic programs; others are not and lead universities and their faculties into value-laden political arenas, into contractual restrictions which can erode academic freedom, and into fiscal arrangements that potentially could alter university priorities. These issues need to be discussed more thoroughly in the academic community. For example, we hear with great concern that an official of a state agency has told a professor that his research project, which is important to the state, will not be funded because the professor belongs to the wrong political party. In another situation, a state agency refuses to allow a social scientist to publish his findings without prior approval of the agency because an official feels that "he who pays the piper calls the tune," and that the university owes first allegiance to the agency rather than to the general public. In yet another situation agencies are willing to pay only partial costs for university involvement in service operations that are somewhat peripheral to its academic programs. Thus some universities are finding themselves in the position of hammering out anew, with a myriad of state, local, and regional agencies, policies relating to such matters as peer review, freedom to publish, copyrights, and cost reimbursement policies that were already carefully worked out with federal agencies 20 years ago.

Background

Although the implementation of much of the "new federalism" (*2*, *3*) is attributed to the present national administration, its roots can be seen much earlier. In 1958 Melvin Laird (at that time R–Wis.) introduced the first revenue sharing bill in the House of Representatives. Economists Walter Heller (University of Minnesota) and Joseph Pechman (Brookings Institution) also developed plans for redistribution of federal funds in the early 1960's, and recommendations of the Advisory Commission on Intergovernmental Relations in 1967 called for a redress of the general power imbalance that worked in favor of the federal government and against states and localities, and hence against a strong decentralized form of government (*4*). The result of these recommendations, even though they were directed toward revenue sharing, has been to send a much larger flow of federal money into the states for numerous categorical programs that often involve university faculty. Among them are funds for research on water resources, housing and urban development, community education, vocational training, career education, occupational safety, and energy conservation. In addition there are the two major programs of block grants in law enforcement assistance and health planning created by the Omnibus Crime Control and Safe Streets Act of 1968 and the Partnership for Health Act of 1966.

The state agencies that are recipients of these funds have tended to develop counterpart regional organizations at the substate level, creating a layerism that results in more red tape, and more overlapping of political boundaries between municipal, county, and multicounty governmental units. Often the staffs of the organizations do not have the professionalism and objectivity that the academic community has come to expect in its relationships with staffs at the federal level. Having been committed to a "nationally dominated system of shared power and shared functions" (*2*, p. 145), we are witnessing an increasing amount of bureaucracy to make operational the rhetoric of the movement, a movement in which relatively few faculty members have yet involved themselves or realize what the implications of that involvement will be.

Another new development relates to the State Commissions for Postsecondary Education—"1202" commissions, as they are often called—that

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