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National Institute on Drug Abuse

CLINICAL AND BEHAVIORAL PHARMACOLOGY RESEARCH REPORT

Effects of Drugs on Driving:

Driving Simulator Tests of Secobarbital, Diazepam, Marijuana, and Alcohol

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
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Alcohol, Drug Abuse, and Mental Health Administration

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FOREWORD

The true impact of drug use on highway safety is relatively unknown. It is only in recent years that the incidence and prevalence of drug involvement in traffic accidents have been studied. Data do exist documenting the role of alcohol as a primary cause of accidental injury; however, the risk of accidents associated with other drugs, whether obtained by prescription, over the counter, or illicitly, is difficult to assess. Clearly, legislators and public health officials are interested in determining the magnitude of drug use effects on our society in terms of highway traffic safety.

As part of a continuing effort to develop information based on research, the National Institute on Drug Abuse (NIDA), in collaboration with the National Highway Traffic Safety Administration (NHTSA), contracted with the Southern California Research Institute (Los Angeles, California) to conduct a series of studies examining the effects of drugs on driving behavior. This report is based on simulated-driving studies designed to assess the effects of three commonly abused drugs: (1) secobarbital--a sedative hypnotic; (2) marijuana; and (3) diazepam--a minor tranquilizer. Marijuana and diazepam were also tested in combination with several levels of alcohol. The logic for studying the drug/alcohol interaction is simply a function of the prevalence of these drug combinations in our society today. The three studies were conducted sequentially over a period of approximately 2 years. The authors have attempted to summarize their data and report their results in a way that provides information scientists and public health officials may use in making sound practical decisions about educational and prevention efforts concerned with drugs and driving and also in directing initiatives for legislation and future research.

A knowledge base in any research area evolves slowly. As studies are completed and questions answered, the process gives rise to new, more focused questions, and further research issues. These studies are no exception. Continued efforts to delineate the nature and extent of the effects of various substances on human performance remain a high priority. The information contained in this document makes a significant contribution toward the establishment of this vitally needed data base.

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INTRODUCTION

This report describes experiments undertaken to examine the effects of commonly used psychoactive drugs on driving performance as measured in a driving simulator. Drugs examined were secobarbital, diazepam, and marijuana. Secobarbital was examined alone while diazepam and marijuana were tested both alone and in combination with alcohol.

Secobarbital

Secobarbital is a widely prescribed "short-acting" barbiturate typically used as a sleeping pill at 100 mg or preoperatively at 200 or 300 mg. It is representative of the barbiturate group which, in 1977, accounted for 19.4 million prescriptions (National Prescription Audit 1977).

Laboratory studies of skills associated with driving or flying have reported evidence of impairment after barbiturate use. McKenzie and Elliott (1965) examined subjects under 200 mg secobarbital on a flying simulator which required subjects to monitor and control four displays simultaneously. Testing began 10 hours after drug administration and continued intermittently for 12 hours. A performance decrement was found throughout the entire testing period, that is, through 22 hours posttreatment. Moskowitz and Sharma (1979) tested the effects of secobarbital using a visual search task, a compensatory tracking task, and a divided-attention task which combined the tracking and visual search tasks. Dose levels of up to 130 mg were used relative to 150 lb bodyweight (bw). Visual search and tracking were impaired individually and, more severely, when performed together in the divided-attention mode. The degree of behavioral impairment was found to be roughly proportional to the treatment dose level. The data as a whole showed impairment for extended time periods, clearly to 6 hours and intermittently beyond that time, especially in the divided-attention situation.

Diazepam

Diazepam is the most frequently prescribed psychotropic drug in the world. Moreover, it often is taken in massive doses by drug abusers (Woody et al. 1975). In 1977, almost 100 million prescriptions were issued for minor tranquilizers in the United States, nearly 60 percent of which were for diazepam (National Prescription Audit 1977).

Epidemiological studies by Bo et al. (1975) in Norway and by Garriott et al. (1977) in Texas found diazepam present in approximately 10 percent of samples of fatally injured drivers. Terhune and Fell (1981) found tranquilizers in the blood of 7.5 percent of 497 injured drivers who came to a hospital emergency room for treatment. Of the drivers who had diazepam in their blood, 32 percent had also been drinking alcohol. The refusal rate (emergency room patients refusing to allow their blood to be assessed for drugs) for this study was 30 percent, which suggests the figures for diazepam and alcohol may be conservative. American surveys show that medical use of tranquilizers is far more common than nonmedical use and that women are more frequent users than men by a factor of about 1.5 (Cooperstock and Parnell 1982). Also, elderly women account for a disproportionate amount of minor tranquilizer use (Stolley et al. 1972). In a survey of 735 persons of driving age (Uhlenhuth et al. 1978), 20 percent reported use of sedatives

and minor tranquilizers in the past year. Low level use (not defined) was reported by 10 percent, medium level use by 4 percent, and high level use (regular use for at least 2 months in the previous year) by 6 percent.

While the tranquilizer-using population is skewed towards females and the elderly, both of whom do less driving than average, the accident fatality population is dominated by young males. Thus, the finding that 10 percent of fatally injured drivers have diazepam in their blood points to a large overinvolvement of tranquilizer users in fatal accidents.

Laboratory studies of the effects of diazepam and of alcohol combined with diazepam clearly demonstrate that diazepam impairs psychomotor skills and that alcohol compounds the impairment (Kleinknecht and Donaldson 1975). Studies have shown diazepam decreases the velocity and accuracy of eye movements (Stein et al. 1974), increases simulator accidents (Linnoila and Häkkinen 1973), and impairs tracking in a divided-attention situation (Moskowitz and Burns 1977).

Marijuana

Marijuana is a potent psychoactive drug in wide use. In 1982, the National Survey on Drug Abuse estimated that roughly 30 percent of the American population had used marijuana at least once, and 11 percent of the population had used marijuana within a 30-day period prior to questioning. These estimates have increased from approximately 20 percent who had used at least once and 6.7 percent current users found in the 1977 survey.

Laboratory studies have shown marijuana to impair perceptual and perceptual-motor functions important to driving. Using a compensatory tracking task, Reid et al. (1973) found significant impairment after a dose of approximately 70 mcg delta-9 tetrahydrocannabinol (THC) per kg bw; using a pursuit meter, Manno et al. (1971) found significant impairment at a dose of 50 mcg delta-9 THC per kg bw. Studies of perceptual functions have shown deficits due to marijuana; detection of intermittent random signals in both central and peripheral vision is impaired (Casswell and Marks 1973; Moskowitz et al. 1972) as is the ability to perform vigilance tasks (Sharma and Moskowitz 1973).

Simulator and on-the-road studies have also shown impairing effects of marijuana. A film-based car simulator was used by Moskowitz et al. (1973) to study the effects of marijuana at dose levels ranging up to 200 mcg delta-9 THC per kg bw. While none of the car control measures showed any decrement under marijuana, the response to the peripheral signal detection task showed an increasing delay, which was linearly related to the drug dose. It should be noted that the simulator had very crude car dynamics but a rich visual scene.

Another simulator study by Stein et al. (1983) used a graphics display simulator with a sparse visual scene and sophisticated car dynamics. Dose levels of marijuana tested were 0, 100, and 200 mcg delta-9 THC per kg bw. The marijuana treatment significantly reduced speed and increased random steering movements. Tracking per se was not significantly affected. An on-the-road study by the Le Dain Commission (1972) showed that marijuana at 88 mcg delta-9 THC per kg bw was associated with an increase in the number

of overturned cones in a gymkhana course, suggesting that tracking ability was impaired.

Since marijuana is used extensively, both alone and in combination with alcohol, the effects of marijuana were examined under both these conditions. Three epidemiological studies (484 fatally injured drivers in Toronto, Canada; 257 drivers responsible for fatal vehicular accidents in Boston; and 600 operators killed in single-vehicle accidents in North Carolina) suggest that marijuana-alcohol interactions are of greater importance for traffic safety than marijuana alone (Warren 1980; Sterling-Smith 1976; McBay and Mason 1983). In all three studies, 70 percent or more of the fatally injured drivers found with marijuana in their blood also had alcohol in their blood. In the Stein et al. (1983) simulator study, marijuana was studied in combination with alcohol at the 0.10 percent blood alcohol concentration (BAC) level. Marijuana at dose levels up to 200 mcg THC per kg bw was found to reduce speed and increase random steering movements, while alcohol at the 0.10 percent BAC level was associated with increases in simulator accidents, speed, steering control variability, and reaction time. For most variables there was no alcohol-marijuana interaction, suggesting the effects of the drugs were additive.

In the present paper, we report a series of experiments examining the effects on driving behavior of secobarbital, diazepam, marijuana, and the combinations of diazepam with alcohol and marijuana with alcohol.

The results of the three separate studies of drug and alcohol effects are summarized below. In each case, driving performance was examined using a driving simulator with an interactive graphics-generated display and realistic car dynamics. In the first study, secobarbital was examined at dose levels of 0, 1.1, and 2.2 mg drug per kg bw. In the second study, diazepam was examined both alone and with alcohol, at levels of 0, 0.11 and 0.22 mg diazepam per kg bw and 0, 0.425 and 0.85 gm alcohol per kg bw (to achieve target blood-alcohol concentrations of 0, 0.6 and 0.11 percent). In the third study, marijuana was examined both alone and with alcohol at levels of 0, 100, and 200 mcg delta-9 THC per kg bw in combination with doses of 0, 0.425 or 0.68 gm alcohol per kg bw.

METHODS AND PROCEDURES

Subjects

Subjects were selected from male applicants who had been driving at least 3 years, were 21 to 45 years old, 135-200 lbs in weight, had 20/30 vision minimum (corrected or uncorrected), were moderate to light-heavy users of alcohol in terms of the quantity/frequency scale defined by Cahalan et al. (1969) and, for the marijuana study only, used marijuana at least weekly and at most four times weekly. Subjects were screened using a medical examination and the Minnesota Multiphasic Personality Inventory (a standardized personality test) for possible physical or emotional contraindications.

Experimental Design

In each study, each subject was tested on three occasions at each of three dose levels in a repeated-measures design. Thus, drug comparisons were within-subject. Fifteen subjects were tested in the secobarbital study. In the marijuana-alcohol and diazepam-alcohol studies, 45 subjects were divided into three groups, each group receiving one of the three doses of alcohol along with their drug treatments. Consequently, alcohol comparisons were made on the basis of between-group comparisons. Because of dropouts, actual numbers of subjects tested were 15 (0 percent BAC), 15 (0.06 percent BAC) and 12 (0.11 percent BAC) in the diazepam-alcohol study; 15 (0 percent BAC), 10 (0.05 percent BAC), and 10 (0.08 percent BAC) in the marijuana-alcohol study. Thus, 42 subjects were tested at each of three dose levels of diazepam, and 35 subjects were tested at each of three dose levels of marijuana.

In each experiment, the sequence of the three drug treatment sessions and the order of presentation of the driving tasks were counterbalanced across subjects using five replications of a 3x3 balanced Latin square design.

Drug and Alcohol Treatments

Secobarbital and diazepam were administered in capsules. Doses were prepared by a registered pharmacist according to the subjects' weight. Secobarbital doses were 0, 1.1, and 2.2 mg per kg bw; diazepam doses were 0, 0.11 and 0.22 mg per kg bw.

Marijuana was administered by having subjects smoke a cigarette of approximately 1 gram weight composed of cannabis containing 2.0 percent delta-9 THC and/or a placebo cigarette (extracted cannabis containing less than 0.05 percent THC). Three dose levels were used: 0, 100, and 200 mcg delta-9 THC per kg bw. The marijuana was obtained from the National Institute on Drug Abuse.

Alcohol was administered in three drinks consumed over a 30-minute period. The three alcohol dose levels were: 0.0, 0.425, and 0.68 gm alcohol per kg bw (for target BAC's of 0.0 percent, 0.05 percent, and 0.08 percent, respectively) for the marijuana-alcohol study. For the diazepam-alcohol study, dose levels were: 0.0, 0.51, and 1.02 gm alcohol per kg bw (for target BACs of 0.0 percent, 0.06 percent, and 0.12 percent respectively). The active alcohol treatments contained equal parts 80 proof vodka and orange juice.

The placebo alcohol dose had 10 ml of vodka floated on top of each water and orange juice drink.

Apparatus

The subject sat in a cut down car-cab and viewed a roadway scene on a 6-foot x 8-foot screen 6 feet in front of him (see figure 1). The roadway scene was generated by a Megatek 7,000 graphics system in combination with a PDP-11/60 computer and then displayed on a CRT. The CRT display was picked up by a camera and rear projected onto the screen, using an Advent Video Beam projector. The subject thus viewed a roadway scene close to life size. The simulation was interactive; that is, the subjects' use of the steering wheel, accelerator, and brake caused appropriate changes in the roadway scene. Figure 2 illustrates visual scenes as presented to the subject during the simulator drive. Although the driving simulator had realistic car dynamics (unlike film-based simulators), it was limited in its representation of the real world because the visual scene that could be presented was greatly oversimplified.

The simulator presented the following tasks: (1) curve following; (2) controlling a car in wind gusts; (3) following at a constant distance a lead car moving at variable speeds; (4) making a stop or swerve decision within 2 seconds after the appearance of an obstacle (six occurrences); (5) passing a car between obstacles in the adjacent lane (three passes at each of three passing distances); (6) distinguishing between target and nontarget route signs within a 5-second interval and taking a turnoff if appropriate (8 target turnoffs out of 16); (7) maintaining a constant distance behind a lead car which changes speed, while in the presence of heavy wind gusts. In addition to the above, the subject performed a peripheral light cancellation task intended to simulate demands on the driver to attend to other traffic, pedestrians, etc. Red and green lights located on the right and left sides of the car were turned on periodically during the drive (80 occurrences) and had to be cancelled by the subject pressing one of two foot switches within 5 seconds. The simulated drive was 23.6 miles long and took approximately 45 minutes to complete.

Testing Schedule

Subjects attended three training sessions separated by minimum intervals of 2 days and three treatment sessions separated by 2-week intervals. At each training session, the subject drove the simulator twice. Subjects were required to abstain from use of prescription or recreational drugs during the course of the study and to abstain from alcohol use 48 hours prior to each treatment day.

On each treatment day, subjects were given an 8-minute "warm-up" run in the simulator. The specific parameters for each drug study were as follows:

1. In the secobarbital study, the drug dose was administered after the warm-up; 1 hour later the subject began the 23.6-mile, 45-minute simulator run.

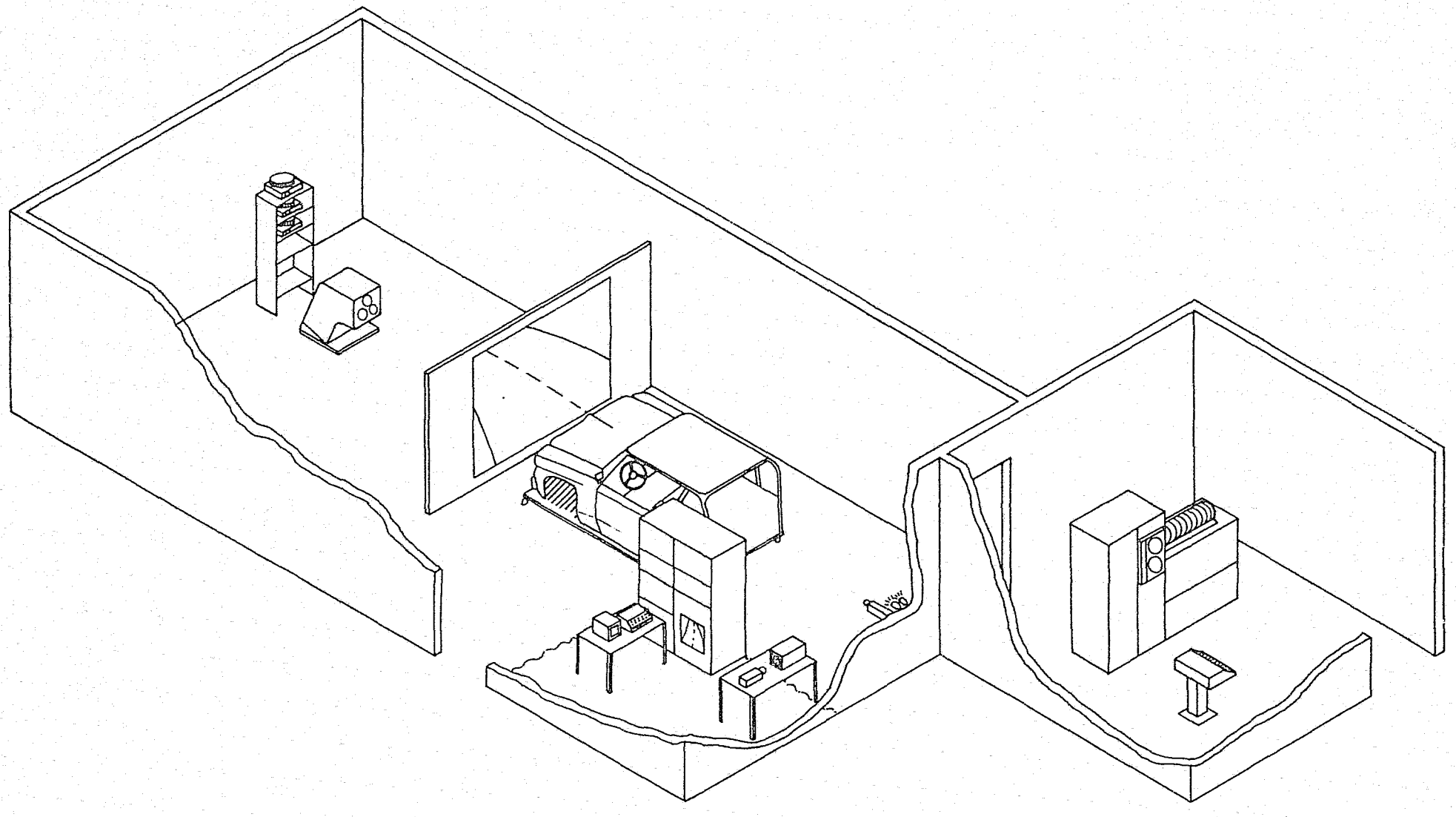
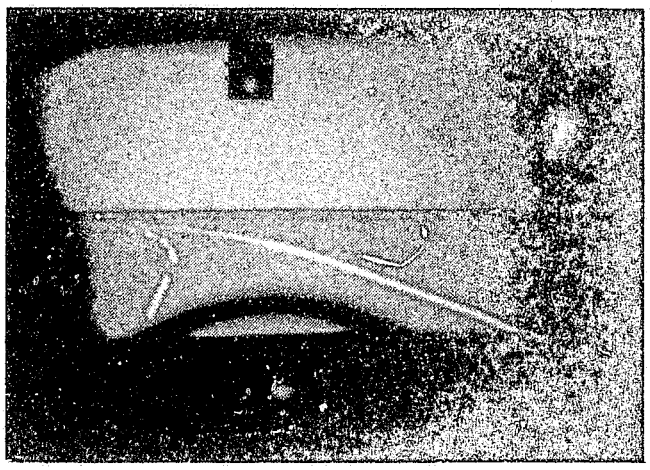
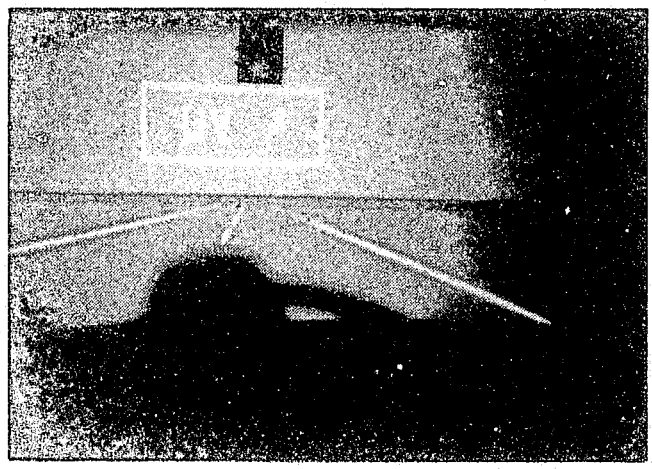


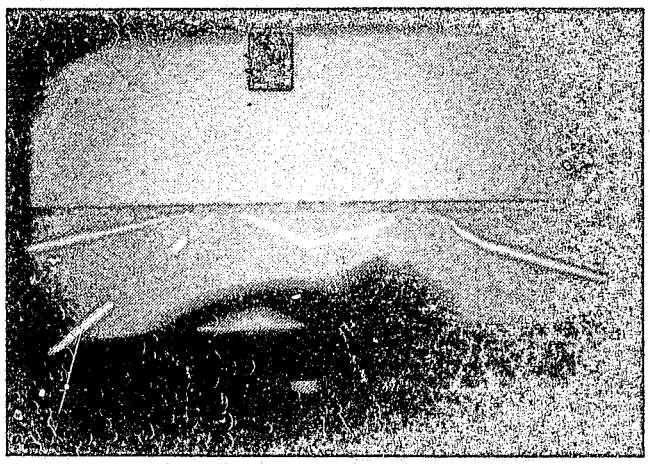
Figure 1. Simulator Laboratory



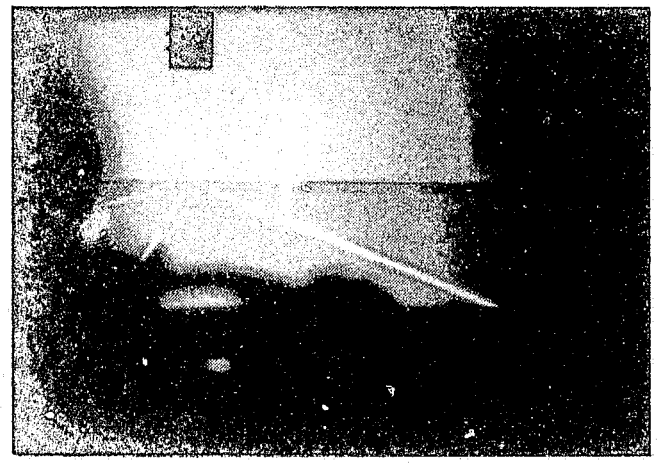
Curved Road



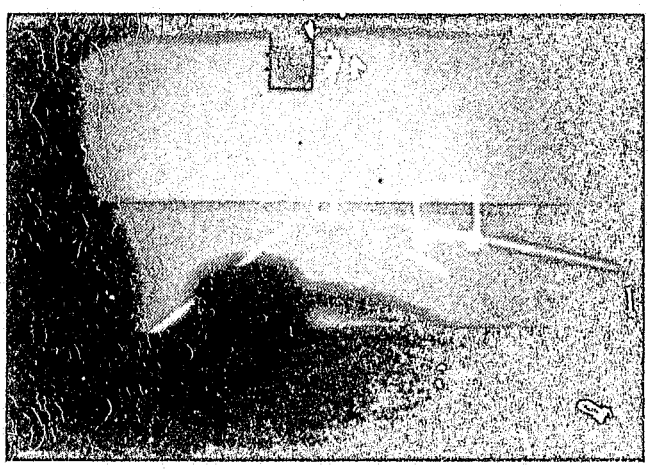
Route Sign



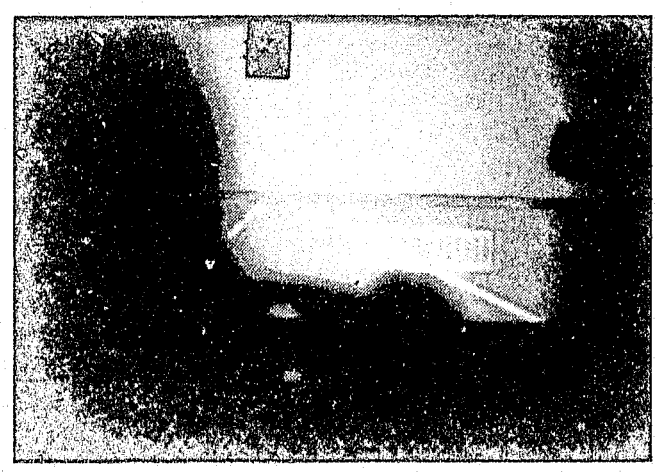
Turn-Off



Speed Sign



Passing Lead Car
(obstacle in background)



Emergency Stop Obstacle
(moving off road after stop)

Figure 2. Roadway Scenes for Simulator

2. In the diazepam-alcohol study, the drug dose was also administered immediately after the warm-up, and at the same time, the first of three drinks (placebo or containing alcohol). The three drinks were consumed over a half-hour period. Testing began 30 minutes after the end of the drinking period, that is, 60 minutes after diazepam administration.

3. In the marijuana-alcohol study, the alcohol was again administered in three drinks over a half-hour period, the first drink being consumed immediately after the subject had completed the warm-up. The marijuana cigarette was administered 15 minutes after the last drink had been consumed. The cigarette was smoked through a glass tube which cooled the smoke and allowed the entire joint to be smoked. The cigarette was consumed within 10 minutes and was smoked according to the following regimen: 10 seconds, inhale; 15 seconds, hold; 10 seconds, exhale. Five minutes after the cigarette was finished, the subject began the 23.6-mile simulator run. The testing times were chosen so that peak drug and alcohol effects would occur during the runs.

On treatment days, before any drugs or alcohol were administered, each subject provided a urine specimen to be screened for drug use and a breath sample to ensure an initial 0.0 percent BAC. Breath samples to determine BAC levels after treatment were taken immediately before the simulator run and at 1 hour and 4 hours later. Several blood samples were taken to measure the drug blood levels. These data are reported in detail elsewhere (Smiley et al. 1984a,b).

Analysis

Seventeen measures of driving performance generated by the simulator were analyzed. Four measures, numbers of successful passes and crashes in the passing task, and numbers of incorrect decisions and crashes in the emergency stop task, were analyzed using chi square techniques (Dixon and Massey 1957). Due to small frequency counts, data for all three alcohol groups were combined to examine the marijuana and diazepam effects, and data for the three diazepam treatments were combined to examine the alcohol effect.

All other measures were analyzed using analysis of variance or covariance techniques (Winer 1971). (See table 1.) Analysis of variance was used for secobarbital data. Analysis of covariance was used for the marijuana-alcohol and diazepam-alcohol studies. For each measure, the covariate used was the value of that measure on the last training run. The use of a covariate does not affect the analysis of the drug effect because drugs were a within-subject measure. Where measures were significant, the difference between pairs of means was tested using the Newman-Kuhls test (Winer 1971).

Table 1. Summary of Analysis of Covariance

Performance Measure	Significance Levels							
	Secobarbital		Diazepam		Marijuana		Alcohol	
Lane Position Variability								
Curve Following	***	L,H	**	L,H	***	L,H	***	L,H
Wind Gust Control	***	H	**	L,H	**	H	***	H
Lead Car Following	***	H	***	L,H	*	H	b	
Wind Gust and Lead Car	b		**	L,H	**	H	***	H
Speed Variability								
Curve Following	*	H	***	L,H	**	H	b	
Wind Gust Control	*	H	***	L,H	*	H	b	
Headway Variability								
Lead Car Following	**	H			***	L,H	b	
Wind Gust and Lead Car					b			
Emergency Decisionmaking: Room to Spare	b		*	H			b	
Turnoffs: Number Correct	**	H			*	L,H		
Mean Reaction Time			b					
Peripheral Lights: Detected	*	L,H	b				b	
Mean Reaction Time					**	H		

* = $p<0.05$, ** = $p<0.01$, *** = $p<0.001$
b = $p<0.1$
L = Newman-Kuhls test significant for placebo vs. low dose and placebo vs. high dose
H = Newman-Kuhls test significant for placebo vs. high dose

RESULTS

Breath Alcohol Levels

In the diazepam-alcohol study, the 0.51 and 1.02 gm alcohol per kg bw doses produced mean peak BACs of 0.055 percent ± 0.016 percent and 0.113 percent ± 0.022 percent, respectively, just prior to simulator testing. Differences in BAC levels as a function of diazepam dose were minimal.

In the marijuana-alcohol study, the 0.425 and 0.85 gm alcohol per kg bw doses produced mean peak BACs of 0.045 percent ± 0.011 percent and 0.076 percent ± 0.013 percent, respectively, just prior to simulator testing. Blood alcohol concentrations were reduced when alcohol was combined with active marijuana treatments. This effect, although not statistically significant, has also been noted in other studies, suggesting possible alteration of alcohol metabolism in the presence of THC (Burns and Moskowitz 1980).

Performance Results

The performance results are discussed below with variables grouped according to particular driving task requirements. (See tables 2 - 5.) To simplify the reporting of results, the alcohol treatment effects discussed are drawn from the diazepam-alcohol study which used a larger number of subjects (42 vs. 35) and tested alcohol at higher dose levels (see breath alcohol levels above) than did the marijuana-alcohol study.

Lane Position Maintenance and Velocity Control. Variability in lane position was measured during the curve following, lead car following, wind gust control, and combined lead car following and wind gust tasks. Each of these tasks represents an increasing level of tracking difficulty. All four drugs significantly impaired lane position control in all four tasks in which it was measured ($p<0.05$), with the exception of a trend ($p<0.10$) for secobarbital to impair performance only in the combined lead car following and wind gust task. (See table 2 for secobarbital, table 3 for diazepam,and table 4 for marijuana.) Newman-Kuhls comparisons indicated that marijuana and secobarbital significantly impaired lane control at the lower dose level in the curve following task; in other tasks, impairment was significant only for the higher dose. Diazepam, however, had significant effects on lane control for all four tasks at both active dose levels. The percentage differences from placebo were averaged for the low and high doses of each drug over the four driving tasks and are shown in figure 3.

The ability to maintain a posted speed was measured during the curve following and wind gust control tasks. Speed variability increased significantly during both tasks under the secobarbital, diazepam, and marijuana treatments ($p<0.05$). The increase observed under alcohol treatment was of borderline significance ($p<0.10$).

Lead Car Following. Two tasks measured the ability of the driver to react quickly to changes in the speed of a car he was following. In the easier of the tasks, the simulator car followed at a constant distance a lead car which was speeding up and slowing down. In the more difficult of these tasks, the simulator car followed a lead car at a constant distance while also being buffeted by wind gusts. Marijuana, secobarbital, and alcohol

Table 2. Secobarbitol Study: Mean Values

Performance Measure		Drug Dose mg/kg bw 0	1.1	2.2
Lane Position Variability:	Curve Following	0.94	1.07	1.40
	Wind Gust Control	1.48	1.59	1.96
	Lead Car Following	0.40	0.50	0.86
	Wind Gust and Lead Car	2.33	2.33	2.58
Speed Variability:	Curve Following	1.09	1.26	1.48
	Wind Gust Control	1.47	1.48	1.89
Headway Variability:	Lead Car Following	7.9	8.0	12.3
	Wind Gust and Lead Car	24.0	16.8	26.6
Emergency Decisionmaking:	Room to Spare	26.4	25.0	23.4
Turnoffs:	Number Correct	5.73	4.87	3.87
	Mean Reaction Time	2.46	2.53	2.60
Peripheral Lights:	Number Detected	54.2	49.5	49.2
	Mean Reaction Time	1.78	1.86	1.90

Table 3. Diazepam-Alcohol Study: Mean Values

Performance Measure	BAC Level / Drug Dose mg/kg bw	0.0 Percent 0	0.0 Percent 0.11	0.0 Percent 0.22	0.6 Percent 0	0.6 Percent 0.11	0.6 Percent 0.22	0.11 Percent 0	0.11 Percent 0.11	0.11 Percent 0.22
Lane Position Variability:	Curve Following	0.94	1.03 (1.22)[1]	1.08	1.18	1.26 (1.19)	1.62	1.44	2.00 (1.77)	2.02
	Wind Gust Control	1.36	1.42 (1.54)	1.55	1.60	1.66 (1.65)	1.92	1.86	2.17 (2.03)	2.16
	Lead Car Following	0.41	0.52 (0.61)	0.67	0.69	0.71 (0.68)	0.89	0.59	0.87 (0.78)	0.82
	Wind Gust and Lead Car	2.10	2.18 (2.34)	2.35	2.51	2.59 (2.58)	3.06	2.77	3.42 (3.12)	3.15
Speed Variability:	Curve Following	1.04	1.27 (1.51)	1.40	1.50	1.94 (1.82)	2.35	1.46	1.82 (2.08	2.01
	Wind Gust Control	1.25	1.72 (1.59)	2.10	1.69	2.17 (2.07)	2.52	1.79	2.03 (2.05)	2.30
Headway Variability:	Lead Car Following	6.5	6.9 (7.9)	6.6	10.1	9.6 (10.2)	12.3	10.6	10.2 (9.6)	10.9
	Wind Gust and Lead Car	18.3	19.0 (18.3)	20.4	19.7	30.9 (27.2)	32.3	26.1	27.5 (29.1)	32.5
Emergency Decisionmaking:	Room to Spare	27.5	25.2 (25.3)	22.6	24.8	24.2 (22.4)	21.6	23.9	20.1 (22.3)	21.2
Turnoffs:	Number Correct	4.13	4.40 (4.19)	4.27	4.13	4.33 (4.07)	3.33	3.67	3.83 (3.58)	3.50
	Mean Reaction Time	2.38	2.83 (2.72)	2.50	2.78	2.84 (2.63)	2.99	2.60	2.79 (2.69)	2.42
Peripheral Lights:	Number Detected	49.9	48.3 (48.6)	49.0	51.2	51.3 (48.4)	46.5	43.9	37.4 (43.4)	41.8
	Mean Reaction Time	1.98	2.09 (2.01)	2.03	1.97	1.99 (2.01)	1.97	2.05	2.05 (1.98)	1.97

1. Means for each alcohol group were calculated across all diazepam groups and adjusted using values obtained during the subject's last training run.

Table 4. Marijuana-Alcohol Study: Mean Values

Performance Measure	BAC Level / Drug Dose mg/kg bw	0.0 Percent 0	0.0 Percent 0.11	0.0 Percent 0.22	0.05 Percent 0	0.05 Percent 0.11	0.05 Percent 0.22	0.08 Percent 0	0.08 Percent 0.11	0.08 Percent 0.22
Lane Position Variability:	Curve Following	0.93	0.98 (1.02)[1]	1.16	1.09	1.28 (1.20)	1.31	1.17	1.30 (1.31)	1.40
	Wind Gust Control	1.41	1.42 (1.50)	1.68	1.36	1.55 (1.58)	1.47	1.70	1.59 (1.63)	1.69
	Lead Car Following	0.54	0.54 (0.54)	0.60	0.46	0.59 (0.56)	0.55	0.60	0.58 (0.63)	0.69
	Wind Gust and Lead Car	2.28	2.26 (2.36)	2.80	2.10	2.15 (2.27)	2.44	2.41	2.59 (2.55)	2.65
Speed Variability:	Curve Following	1.17	1.23 (1.26)	1.41	1.07	1.13 (1.18)	1.25	1.40	1.29 (1.36)	1.57
	Wind Gust Control	1.58	1.46 (1.63)	2.09	1.22	1.27 (1.51)	1.30	1.42	1.40 (1.34)	1.59
Headway Variability:	Curve Following	7.9	12.0 (10.1)	11.9	6.3	9.4 (9.0)	9.2	7.5	10.0 (10.9)	15.3
	Wind Gust and Lead Car	16.7	27.8 (19.5)	24.7	17.5	21.7 (21.7)	19.2	14.7	15.8 (17.6)	26.7
Emergency Decisionmaking:	Room to Spare	24.0	26.9 (25.2)	22.5	27.5	27.4 (26.3)	25.9	27.7	25.4 (26.6)	25.8
Turnoffs:	Number Correct	4.86	4.14 (4.41)	4.57	5.20	3.90 (4.59)	4.40	5.22	4.33 (4.73)	4.56
	Mean Reaction Time	2.83	2.80 (2.75)	2.59	2.77	2.77 (2.93)	2.60	2.47	2.51 (2.82)	2.64
Peripheral Lights:	Number Detected	51.5	46.5 (49.6)	47.8	63.2	60.1 (56.3)	59.4	51.9	49.2 (52.2)	49.4
	Mean Reaction Time	1.86	1.92 (1.93)	2.01	1.82	1.91 (1.93)	2.00	1.98	2.00 (1.99)	2.06

1. Means for each alcohol group were calculated across all marijuana groups and adjusted using values obtained during the subject's last training run.

Table 5. Mean Values and Summary of Chi-Square Results

Performance Measure	Secobarbital mg/kg bw			Diazepam mg/kg bw			Marijuana mcg THC/kg bw			Alcohol percent blood alcohol concentration		
	0	1.1	1.2	0	0.11	0.22	0	100	200	0	0.06	0.11
Emergency Decisionmaking Task:												
No. of Incorrect Decisions	1.13	1.20	1.73	1.19	0.93	1.19	0.86	0.83	0.83	0.78	1.20	1.25*
No. of Crashes	0.13	0.07	0.60a	0.43	0.67	0.86b	0.29	0.31	0.77**	0.36	0.60	1.08***
Passing Task:												
Mean No. of Crashes	0.67	0.67	0.73	0.83	1.17	1.45*	1.06	0.80	0.80	0.77	1.11	1.67**
No. of Passes	4.27	4.33	3.34	3.71	3.86	4.02	5.14	5.17	4.77	3.62	4.18	3.78

a. There were too few crashes to calculate a chi-square value for the secobarbital treatment.

Note. Results for marijuana, diazepam, and alcohol were calculated by combining all marijuana or diazepam treatments regardless of alcohol treatment and all alcohol treatments regardless of marijuana or diazepam treatment.

* = $p<.05$
** = $p<.01$
*** = $p<.001$
b = $p<.10$

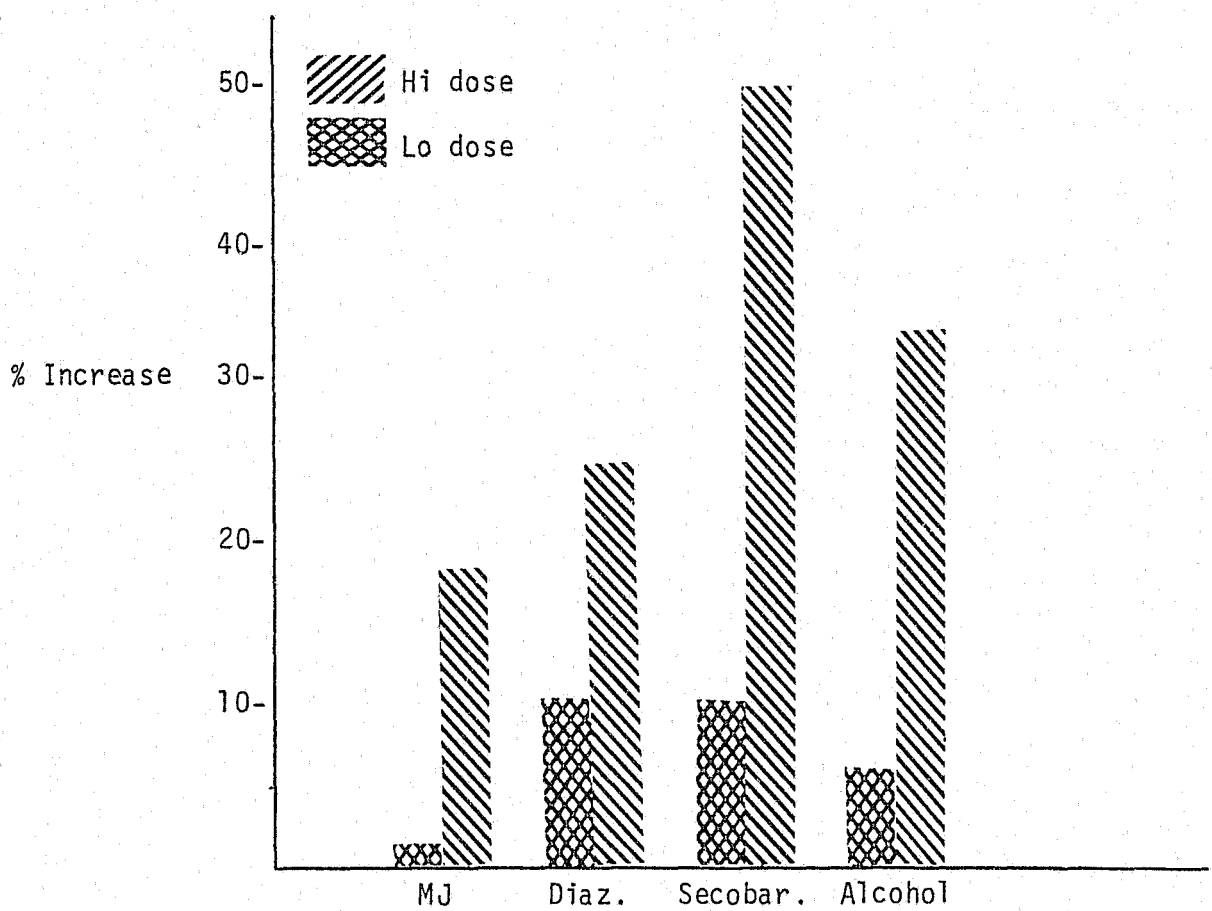


Figure 3. Changes in Lane Position Variability

were all associated with increased headway variability in the less difficult task ($p<0.001$, $p<0.01$ and $p<0.10$, respectively). Both dose levels of marijuana impaired ability to follow a lead car, whereas only the high doses of alcohol and secobarbital did so. Diazepam did not appear to affect ability to maintain a constant headway. In the more difficult car-following task, drivers treated with marijuana and alcohol showed trends towards impaired performance.

Emergency Decisionmaking. The ability to respond quickly in an emergency was measured by having subjects avoid an obstacle which unexpectedly appeared in their lane. Subjects were required to stop as quickly as possible unless they saw headlights behind them. In that case, they were instructed to swerve to avoid the obstacle. For those cases in which the driver stopped, the room to spare between the obstacle and the car was a measure of the decision and response time, with less room to spare meaning longer response times. Diazepam and alcohol were associated with decreased room to spare ($p<0.03$, $p<0.07$ respectively). Marijuana and secobarbital did not appear to affect room to spare. All four drugs increased the number of crashes; marijuana and alcohol showed significant increases ($p<0.05$); and diazepam showed a trend in that direction ($p<0.10$). Because of the secobarbital study design, there were too few crashes to apply a chi-square test. However, the number of crashes increased as a function of dose, from one on placebo to two at the low dose to nine at the high dose of secobarbital. Only alcohol significantly increased the number of incorrect decisions made ($p<0.05$). At 0.11 percent blood alcohol concentration, the number of incorrect decisions was double that in the placebo-alcohol condition.

Passing. The passing task tested the driver's ability to complete a successful pass of a lead car for three different passing distances. Passing distances were established by means of obstacles in the adjacent lane. At the shortest distance, passing was very difficult; at the longest distance, it was relatively easy. Each passing distance was presented three times. Mean number of crashes (into the lead car and/or the obstacles) increased in a dose-related fashion under both the alcohol and diazepam treatments ($p<0.05$). None of the substances tested appeared to affect the number of successful passes made. (See table 5.)

Data for the shortest passing distance (three replications per subject) were examined further. Because there were 80 fewer passes made or attempted at the shortest distance, data for all alcohol groups were combined and examined for the effect of marijuana and diazepam only.

It was possible, but unusual, to record more than one crash for each attempted pass; thus an exact measure of attempted passes cannot be determined. Bearing this in mind, the data suggest that at the highest marijuana level fewer of the most difficult passes were attempted: 27.6 percent compared to the low-dose rate of 36.2 percent or the placebo rate of 35.2 percent. For the high-dose marijuana condition, a greater percentage of the attempted passes resulted in crashes: 41 percent versus 27 percent crashes for placebo and 29 percent crashes for the low dose.

For the diazepam treatment the trend was very different in that the number of passes attempted increased as dose increased: 4 percent, 16.7 percent,

and 25.3 percent for the placebo, low, and high doses respectively. Of the attempted passes, none resulted in a crash on the placebo treatment whereas 52.4 percent resulted in crashes at the low dose and 53.1 percent at the high dose.

Visual Search and Route Sign Recognition. Drivers' skills at search and recognition of route signs were tested in the route-sign-following task. Number of correct turnoffs taken decreased significantly under marijuana and secobarbital treatment ($p<0.05$). Only in the diazepam treatment was there a trend towards increased response time to the turnoffs. (See tables 2 - 4.)

Peripheral Signal Detection. In real driving situations, while performing the primary driving task, the driver must also monitor the environment for other approaching traffic, parked cars, pedestrians, etc. In the simulator, this skill was tested by the peripheral light detection task. Secobarbital treatment significantly reduced the number of peripheral lights detected ($p<0.05$), while diazepam and alcohol treatments showed trends in the same direction ($p<0.10$). A significant increase in reaction time was found only for marijuana ($p<0.005$).

Drug-Alcohol Interactions

In both the marijuana-alcohol and the diazepam-alcohol studies, the addition of alcohol to the drug resulted in greater impairment than was present when the drug was used alone. In the marijuana study, few effects due to alcohol were significant, and any found were mainly at the highest dose level used, 0.08 percent BAC. In the diazepam study, however, numerous measures showed significant impairment due to alcohol.

The difference in findings is thought to be due to the larger dose levels of alcohol used in the diazepam-alcohol study as compared with the marijuana-alcohol study (0.06 percent and 0.11 percent BAC vs. 0.05 percent and 0.08 percent BAC) as well as the greater number of subjects used (groups of 15, 15, and 12 vs. groups of 15, 10, and 10). Both factors would increase chances of finding significant impairment due to alcohol. As was mentioned previously, it is the alcohol effects from the diazepam-alcohol interaction study that are presented in this paper. The lack of significant diazepam-alcohol interactions or marijuana-alcohol interactions suggested that, for both drugs, the effects of alcohol were additive.

DISCUSSION

Secobarbital, diazepam, marijuana, and alcohol, at the dose levels used in these experiments, impaired performance on a wide range of simulated driving tasks including perceptual-motor tasks and strictly perceptual tasks.

In examining the test results, one must keep in mind that the analysis of the alcohol effect was statistically less powerful than the test of secobarbital effect, which was in turn less powerfully tested than the effects of diazepam or marijuana. Therefore, fewer instances of significant differences would be expected for the alcohol variable. The alcohol effect was based on between-group comparisons using groups of 15, 15, and 12 subjects. In contrast, the other drug comparisons were made with a repeated-measures,

within-subject design using 15 subjects for the secobarbital study, 35 subjects for the marijuana study, and 42 subjects for the diazepam study.

Secobarbital, diazepam, marijuana, and alcohol all impaired the perceptual-motor tasks measured by the simulator. Lane position control was significantly impaired by all four substances on nearly every task in which it was measured. Under diazepam treatment, impairment was found at both dose levels. For the other substances, impairment was significant only at the highest dose tested. The percentage increase from placebo in lane position variability was highest for secobarbital, followed by diazepam, alcohol, and marijuana in that order. The ability to maintain a posted speed was impaired by all four substances. Headway control was significantly impaired by secobarbital and marijuana.

Perceptual tasks, as opposed to perceptual-motor tasks, showed fewer impairments for all substances tested. However, it must be kept in mind that the simulator used for the study traded off excellent car dynamics for a visually impoverished scene. The real-world visual scene is vastly more complex than the red and green lights used to simulate other visual stimuli in the environment. In the real-world environment an enormous variety of stimuli are present which must be processed by the driver to determine their importance. Background casual noise can make it difficult to detect the relevant stimuli. Thus, the perceptual tasks were much less demanding than they would be in a normal driving environment. Clearly, one would expect that individuals under the influence of these drugs would be more impaired in a real-world environment.

Not only were there fewer cases of significant impairment on the perceptual tasks than on the perceptual-motor tasks, but impairments were inconsistent. Mean reaction time in the turnoff (16 instances) and peripheral light tasks (80 instances) and mean stopping distance in the emergency stop task (3 instances) are all reaction time measures. All drugs showed at least borderline impairment on one or more of these measures; however, no drug consistently impaired all three.

Number of crashes in the emergency stop task, number of turnoffs taken, and number of peripheral lights detected are all measures of detection ability. Secobarbital was the only drug associated with impairments on all three measures. Marijuana, diazepam, and alcohol all increased the number of crashes in the emergency stop task ($p<0.05$, $p<0.10$, and $p<0.05$, respectively). The number of turnoffs taken significantly decreased only under marijuana treatment; however, diazepam and alcohol treatments were associated with trends towards decreased peripheral light detections ($p<0.10$).

In summary, all substances that were tested impaired response time and detection ability; however, the pattern of impairments are not as consistent as might be expected.

Decisionmaking abilities were measured in the passing task and in the emergency stop task. The decision in the first task was related to the degree of risk the driver took. While drivers were rewarded for successful passes, they were also penalized for crashes. The decision to pass depended on how capable the driver felt, as well as which of the three passing distances was presented. A number of drivers chose not to make any passes at

all. The optional nature of the task as well as the fact that only nine passing situations (three at each passing distance) were presented may account for the fact that number of passes was not significantly affected by the drug and alcohol treatments. Despite these limiting factors, however, both alcohol and diazepam were associated with significant increases in numbers of crashes.

Under the high-dose marijuana treatment, fewer of the most difficult passes were attempted, and a greater percentage of these resulted in crashes when compared to the low-dose or placebo treatment. Under diazepam treatment the number of difficult passes attempted increased as dose increased. While none resulted in a crash on the placebo treatment, over half resulted in crashes on the low- and high-dose treatments.

The second decisionmaking task, the emergency stop, was not an optional task. Drivers had to check whether or not they were being followed by another car (as indicated by headlights in the rear view mirror) and stop in front of or swerve around the obstacle accordingly. In this situation, all four substances were associated with increased crashes. Since only three emergency stop situations requiring a stop were presented, the finding of significance ($p<0.01$ for marijuana combined with alcohol) indicates marked impairment.

For both marijuana and secobarbital, only the high doses of the drug were related to increased crashes in the emergency stop task. In the case of alcohol and diazepam treatments, there appeared to be a dose-related increase in number of crashes.

CONCLUSIONS

Secobarbital, diazepam, marijuana, and alcohol were all found to impair performance of a variety of simulated driving tasks. Drug levels tested for secobarbital and diazepam were therapeutic doses; the marijuana doses were considered moderate to strong by the subject population used; the alcohol effects were reported for levels up to and slightly above the legal limit. No clear-cut differences in the pattern of effects were found among the drugs tested. All drugs impaired perceptual-motor skills (e.g., tracking, speed, and headway control), perceptual tasks where response time and detection ability were measured, and decisionmaking tasks.

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