File Copy

REPORT NO. UM-HSRI-HF-75-1

EFFECTS OF ALCOHOL ON SAFE DRIVING SKILLS

Rudolf G. Mortimer
Samuel P. Sturgis

Highway Safety Research Institute
University of Michigan
Ann Arbor, Mich. 48105

January 1975

Final Report: Grant No. MH20666

National Institute on Alcohol Abuse and Alcoholism
U.S. Department of Health, Education and Welfare
Rockville, Maryland 20852

The contents of this report reflect the views of the Highway Safety Research Institute, which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the National Institute on Alcohol Abuse and Alcoholism.

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle
Effects of Alcohol on Driving Skills

5. Report Date
January 3, 1975

6. Performing Organization Code
010883

7. Author(s)
R.G. Mortimer, S.P. Sturgis

8. Performing Organization Report No.
UM-HSRI-HF-75-1

9. Performing Organization Name and Address
Highway Safety Research Institute
The University of Michigan
Ann Arbor, Michigan 48105

10. Work Unit No.

11. Contract or Grant No.
MH 20666 / AA 00295

12. Sponsoring Agency Name and Address
National Institute on Alcohol Abuse and Alcoholism
U.S. Dept. of Health, Education and Welfare
Rockville, Maryland 20852

13. Type of Report and Period Covered
Final, ~~July 1~~ January 1972- January 5, 1975

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract Tests of sensory, perceptual and motor skills were made. Other tests were carried out in a driving simulator for the study of steering performance, a driving simulator for the study of car-following, and in an automobile on the road.

Alcohol doses of up to 0.10% BAC were used in these tests. The results showed that there were reductions in the left and right lateral horizontal visual fields of red stimuli; mesopic visual acuity; information processing both in a digit-memory task, and when stimulus response compatibility was decreased in a reaction time test; and a reduction in pursuit tracking ability.

The lateral control driving simulator studies showed that drivers changed the cue structure which they used by emphasizing lateral position cues, with a reduction in emphasis on heading angle and yaw rate cues. The drivers under alcohol reduced their responsiveness in manipulation of the steering wheel. The effect was an increase in lateral position and heading angle errors.

The effects of the alcohol doses used on the car-following task were less clear. However, spectral analyses indicated that headway errors were greater under alcohol when the frequencies of changes in lead vehicle velocity were above about 0.06 Hz. Below this frequency there were no detrimental effects of alcohol.

No effects on lateral path error were found in the car driving study. However, speed maintenance and variability in headway were greater in car-following, which confirms the preliminary findings obtained in the car-following driving simulator tests. There were no significant effects in judgments of the speed of overtaking vehicles seen in rearview mirrors or in passing gap judgments with respect to oncoming vehicles, due to alcohol.

These findings are discussed with those of an eye-marker evaluation previously reported. It was concluded that the effect of alcohol was to change the cue structure utilized by the driver for lateral control as well as his responsiveness with the steering wheel to reduce his effectiveness in a manner which mimicked the behavior of a novice driver. This reduction in performance could be expected to lead to an increase in single-vehicle, loss-of-control crashes in which alcohol is often found to be a contributing factor. The car-following tests suggest that drivers at moderate doses of alcohol are likely to introduce perturbations in speed into the traffic stream, thereby increasing the likelihood of rear-end collisions.

The study also indicated that the changes in driving performance at 0.07% BAC during alcohol uptake were less severe than at the same BAC during alcohol elimination, showing residual effects of alcohol and fatigue.

17. Key Words	18. Distribution Statement
Alcohol Driving Steering Car-following Simulators, Road tests	Unlimited

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unrestricted	Unrestricted	123	

Form DOT F 1700.7 (8-69)

TABLE OF CONTENTS

ACKNOWLEDGMENTS

Mr. Irvin Rudolph designed and constructed the TV display driving simulator used in the studies of steering control. Mr. John D. Campbell was responsible for the design and maintenance of the car-following simulator and the test cars.

Dr. Paul L. Olson, Mr. Craig M. Jorgeson and Mr. Corwin D. Moore collected and analyzed the data in the car driving tests.

Mr. Marshall J. Grimm assisted in the collection and processing of data of the TV driving simulator tests.

Mr. Arthur Bernstein carried out some of the analyses of the car-following simulator data.

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

OBJECTIVE

The objective of this research is to obtain an improved understanding of the effects of alcohol upon skills required in the driving task. Concommitant with that requirement is a need to better understand the nature of that task since it is not possible to evaluate the effect of a drug in a particular environment if the features of that environment are not understood. The studies that are described are concerned with visual, cognitive and perceptual factors used in driving and with the driver's manual control of the vehicle.

The driver is viewed as one component in a closed-loop system which also consists of the vehicle, the road and the environment. Conventional data analysis techniques will be supplemented by those of control theory, so that a more detailed understanding of the driver as an input-output element in this system can be obtained. By the same logic the effects of alcohol should become more clearly perceptible in terms of their specificity upon the behavior of the driver.

BACKGROUND

The role of alcohol in degrading highway safety has been clearly documented in many previous studies (McCarrol & Haddon, 1963; Waller, 1968; HSRI, 1969; Filkins et al., 1970; etc.). These findings show that about 50% of drivers involved in fatal collisions have significant levels of alcohol in their blood, and the same is true of pedestrian fatalities (Huelke, 1970). The involvement of alcohol in severe traffic collisions has also been documented in other countries (Schmidt & Smart, 1959; Griep, 1968; Newsweek, 1970; Road Research Laboratory, 1963). Therefore, there is no longer any doubt that the presence

of alcohol in the blood of drivers and pedestrians renders them highly susceptible to highway collisions.

Other studies have sought to determine the nature of the impairment of alcohol upon human behavior. Studies have been conducted to evaluate the effects of alcohol upon sensory abilities such as vision, audition and balance. The effects upon cognitive ability (Rabin & Blair, 1953; Forney & Hughes, 1961; Kalin, 1964) and upon simple perceptual-motor skills (Forney et al., 1964) have been measured. Other studies have been concerned with evaluating the effect of alcohol in a simulation more analogous to the tracking task in driving. Drew et al. (1958) found that performance deteriorated at quite low levels of blood alcohol concentrations, of the order of 30 mg/100 ml (0.03%). Another study (Mortimer, 1963) was concerned specifically with the effects of alcohol in a perceptual-motor task carried out under simulations of day and night driving illumination and headlight glare conditions. This study also found that decrements in tracking performance occurred at quite low levels of alcohol, below 0.02%, and that this decrement was increased, relative to the placebo condition, under the night driving simulation, particularly in the glare effects of simulated headlights of approaching vehicles. These studies, and numerous others, clearly show that perceptual-motor tasks are impaired at very low blood alcohol levels.

Other studies have used automobile driving tasks, such as are employed in some phases of driver license testing and in sports car gymkhanas. Studies such as those carried out by Bjerver & Goldberg (1950), Forney et al. (1961), and Coldwell (1958) have found that tasks involving the conduct of certain driving maneuvers, such as backing or parallel parking, are impaired at blood alcohol levels of less than 0.05%.

Some of these findings have been confirmed in recent studies using an instrumented car by Perrine and Huntley (1971), who found increased frequencies of accelerator pedal movement reversals and coarse steering reversals due to alcohol.

In tests of risk acceptance (Cohen et al., 1958) and passing decision making (Light & Keiper, 1969) it was found that alcohol impairs these behaviors. A recent study by Snapper and Edwards (1972) implies that alcohol impairs the vehicle control task, but not the judgment as to the likelihood of success in a severe handling maneuver.

There is, therefore, a rather clear relationship between the presence of alcohol and behavioral performance as measured in laboratory, simulation and actual driving tasks, and the performance of drivers on the road as measured by the ultimate criterion of collision frequency and severity.

Studies that have been conducted to date, however, shed little systematic information upon those specific aspects of driving behavior which are impaired by alcohol (Carpenter, 1958). Rather, tasks have been used in various studies whose direct relationship to the driving task were not measured. Although impairment has been found at low levels in certain structured driving situations such as those already mentioned, there is a gap in knowledge of the relationship between the skills that are affected by alcohol and collision occurrence. For example, it is difficult to state the effect of alcohol upon the high frequency of fatal, single-vehicle, off-the-road collisions. These incidents suggest a loss of control of the vehicle on the part of the driver. However, there is no understanding, at the moment, concerning where the detrimental effects occurred in the sequence of input-output relationships existing in the traffic system.

The correlations between sensory, perceptual and motor skills and accidents have been found to be low (Goldstein, 1961;

Burg, 1968). However, this may be due to the poor reliability of accidents as a criterion measure. Therefore, an intermediate criterion of driving performance needs to be developed to replace an ultimate criterion, such as collisions. It will then be possible to obtain a better insight into the correlations between various skills used in driving with such an intermediate criterion measure. Previous attempts have focused upon the use of performance in simulators of one type or another as an intermediate measure of driving performance. Because the driving task is a closed-loop task, it is essential that a simulation of the task should, minimally, be based upon that same principle.

Measurements of visual acuity, stereoscopic acuity, brightness discrimination, and simple perceptual-motor tasks, etc., can also be related to aspects of driving performance, so that it can be fruitful to study the effects of alcohol upon them.

Most previous studies concerned with the evaluation of alcohol effects have not shed much light on the manner in which the driver's ability to gather information has been altered. A recent study (Belt, 1969) has reported findings for two subjects, of the effects of blood alcohol levels up to 0.075% upon eye fixations in driving. This study indicated that there was an increase of mean eye fixation duration and a narrowing of the eye movements within the visual field. A study of eye fixations of drivers under alcohol up to 0.10% BAC (Mortimer & Jorgeson, 1972), carried out as part of this program, showed similar results and a reduction in the distance of eye fixations ahead of the vehicle.

In this study, laboratory, driving simulation and driving tests were used so that the specific impairments caused by alcohol might be better understood.

SIMULATOR STUDY OF STEERING PERFORMANCE

OBJECTIVES

One of the objectives of this study was to obtain information of the effects of moderate doses of alcohol (0.07%, 0.10%) on selected sensory, motor and perceptual tasks.

The major objective was to try to discern the effects of these alcohol dose levels upon the components of vehicle steering control behavior.

METHOD

SUBJECTS

Twenty persons (12 male and 8 female) who responded to an advertisement in a local newspaper requesting "persons experienced with alcohol to participate in an experiment concerning simulated driving," served as paid subjects. They were administered the Mortimer-Filkins problem drinker questionnaire and interview protocol (Kerlan et al., 1971; Mortimer et al., 1971) and a driving experience questionnaire prior to testing, to enable quantification of drinking behavior and driving histories.

The subjects were randomly assigned (within sex) to either placebo or alcohol treatment groups. Analyses of variance performed on subjects' ages, years of driving experience and Mortimer-Filkins test scores showed no significant differences between treatment groups (Table 1). Three subjects in each group were diagnosed as problem drinkers or presumptive problem drinkers, a rate higher than estimated to be in the driving population.

APPARATUS

Nine pieces of apparatus were used in the experiment.

TABLE 1. DISTRIBUTION OF AGE, SEX, DRIVING EXPERIENCE, AND MORTIMER-FILKINS TEST SCORES BY SUBJECT GROUP IN THE DRIVING SIMULATOR TEST.

Group	Age (Years)		Sex		Driving Experience (Years)		Mortimer-Filkins Score[1]	
	$\bar{X}$	S. D.	M(f)	F(f)	$\bar{X}$	S. D.	$\bar{X}$	S. D.
Placebo	25.7	3.52	6	4	9.5	3.72	45.5	25.77
Alcohol	29.4	8.38	6	4	11.7	8.79	50.6	28.61
All Ss	27.6	6.69	12	8	10.6	6.83	48.1	26.95

[1]Scores of 85+ are considered indicative of problem drinking; scores of 60-84 indicative of presumptive problem drinking; scores of less than 60 indicate no overt drinking problems.

They were:

1. Foot-Pedal Force Buck. This device (Figure 1) consisted of a vertically adjustable, wooden chair 28 inches wide and 16 inches deep, with a 17-inch high back mounted at an angle of 25° from the vertical; and a foot pedal which could be adjusted longitudinally and vertically. The circular, hard rubber pedal was three inches in diameter and was mounted at an angle of 35° from the horizontal. The pedal incorporated a strain gauge to measure the force applied to it. All pedal force measurements were made with the apparatus adjusted so as to yield thigh angles of 0°, knee angles of 160°, and ankle angles of 90°, as recommended by MacFarland et al. (1942), for maximum pedal force. Pedal force was indicated on a meter calibrated from 0 to 300 pounds. A trial consisted of four measurements: one reading with each foot with subject instructed to press "as hard as possible" (standard motivation); and one reading with each foot with subject instructed to "really press this time - as though your life depends on it" (induced motivation).

2. Hand Dynamometer. A Lafayette Instrument Company model 78010 hand dynamometer, calibrated from 0 to 100 kilograms, was used to measure hand grip strength (Figure 2). Again, one "trial" resulted in four readings; right and left hands with standard and induced motivation.

3. Perimeter. A Lafayette Instrument Company standard perimeter (Figure 3) was used to map color sensitive areas of the retina of the right eye. The perimeter was mounted on a table with uniform overhead fluorescent lighting, two feet from a flat black vertical surface. Stimuli used were 1/8 inch square chips of the colors red, blue, white, green and yellow painted on 1/2 inch diameter neutral cards. The stimuli were kept at a constant distance of 7½ inches from the eye during testing, and thus subtended a visual angle of approximately 30 seconds. The construction of the apparatus enabled movement of the stimuli from 90° to 10° off the longitudinal axis of the eye. One perimeter trial provided four thresholds for each color, made by moving each stimulus inward and outward on each side of the head. Subjects responded verbally when they could definitely report the color, or when the color disappeared on outward moving trials.

4. Portable Rod-and-Frame Test (PRFT). Measurements of perceptual field dependence were made with a Darrow Scientific model RF-3 PRFT (Figure 4). This device is identical to that described by Oltman (1968). The apparatus consists of a rectangular translucent plastic enclosure 24 inches long and 12 inches high and wide, which can be tilted to the left or right at an angle of 28°. The ends of the enclosure are aluminum discs, 22 inches in diameter, with square holes affording an otherwise unobstructed view through the enclosure. The end opposite the subject is covered by a solid, white 22-inch disc, with a 3/8 x 11-inch black plastic strip glued to the center of

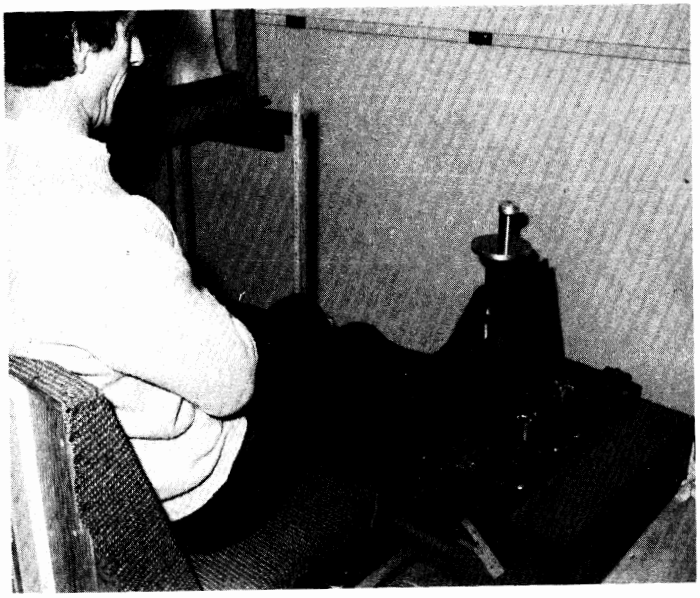


Figure 1. Foot pedal force buck.

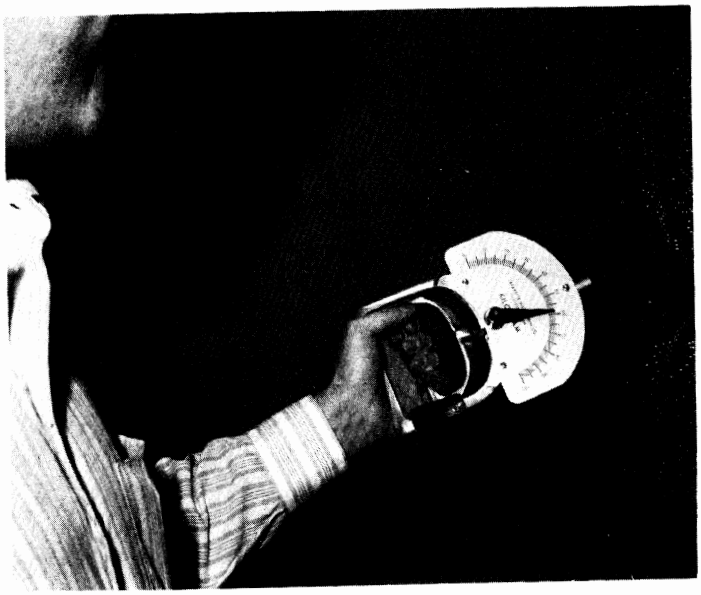


Figure 2. Hand dynamometer.

Figure 3. Perimeter.

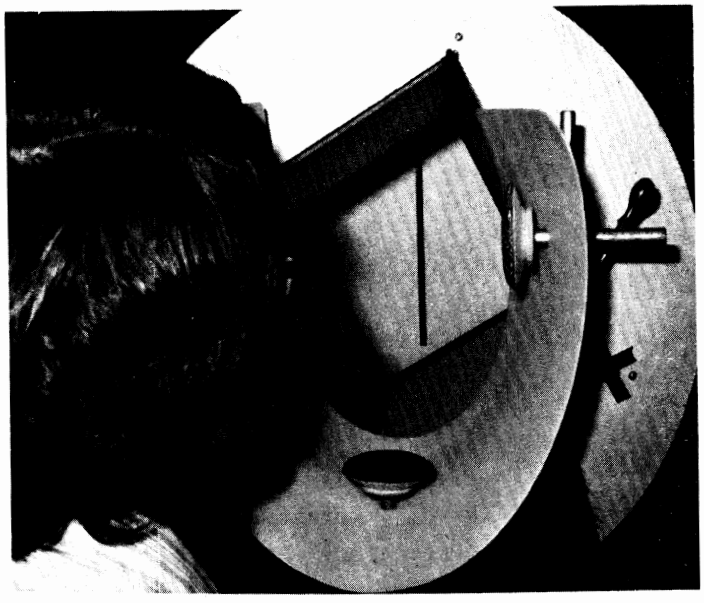


Figure 4. Portable rod and frame test.

the surface. This disc can be rotated independently of the enclosure and is equipped with a pointer and protractor which enable measurement of the deviation of the rod (the black plastic strip) from the vertical (0°). During testing the subject sits at the end of the enclosure opposite the rod with his head in an adjustable headrest, his vision limited to the interior of the enclosure and the rod at the opposite end. Between trials, a curtain is raised in front of his face to obscure his vision of the rod. A trial is begun while the subject's view of the rod is obscured. The rod and frame are each rotated 28° to the right or left, in the same or opposite directions. When the curtain is lowered, subject must tell the experimenter how to rotate the rod to make it perfectly vertical with respect to the real world. The deviation from vertical is noted in degrees, the curtain raised, and the rod and frame reset for another trial. A complete trial consisted of eight measurements; two replications of each of the four possible rod-frame direction combinations.

5. Titmus Industrial-Occupational Vision Tester. This device (Figure 5) was used to measure (1) visual acuity (by Landolt rings) for the left eye, right eye, and both eyes together at effective "far" (20 ft.) and "near" (14 in.) distances; (2) vertical phoria at a 20-foot distance; (3) lateral phoria at 20-foot and 14-inch distances; (4) stereo depth at a 20-foot distance; and (5) color vision (by Ishihara plates) at a 20-foot distance. One measurement of each parameter was made in each trial.

6. AAA Glarometer. Measures of target illumination thresholds with- and without-glare, and glare recovery time were made with this device (Figure 6), which consists of a wooden box, 36" x 12" x 12" painted flat black on the inside

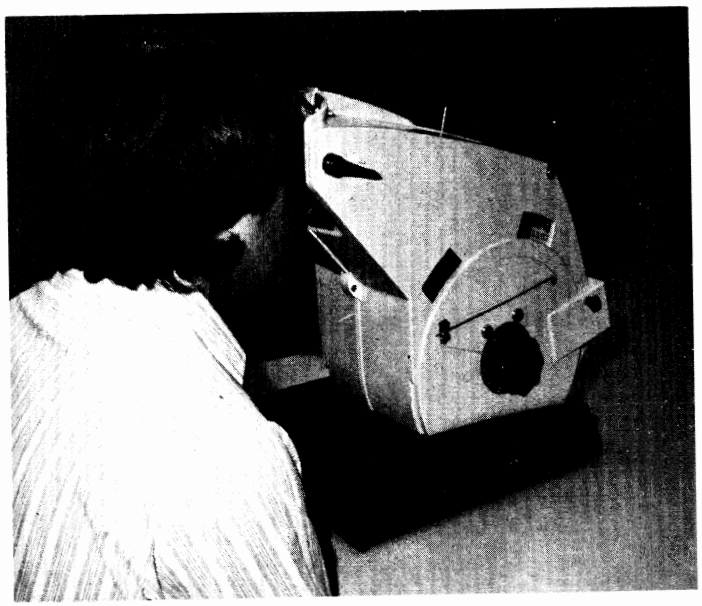


Figure 5. Titmus vision tester.

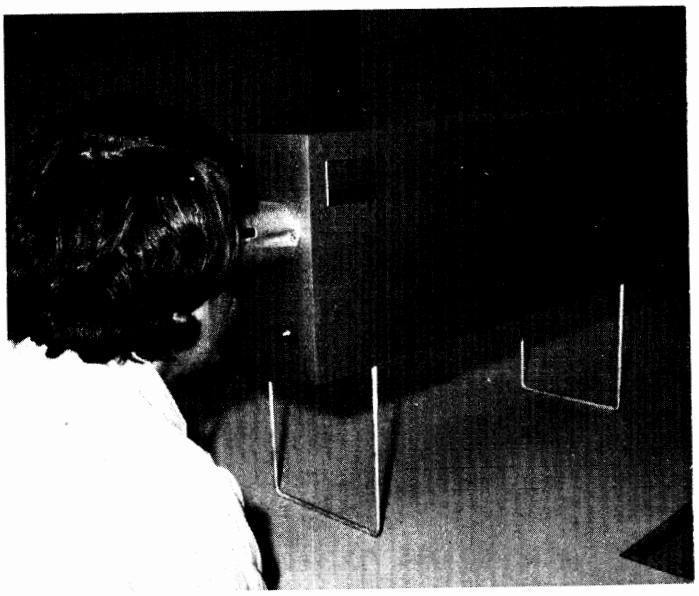


Figure 6. Glarometer.

with a viewing port at one end. At the opposite end, targets consisting of a series of 15 Landolt rings oriented in four directions pass an aperature at a rate of 45/minute. Illumination of the targets is controlled by the experimenter who can also independently operate two 6w 110v lamps which shine in subject's eyes through a 10% transmission filter.

In each test, subject is required to report the orientation of each target passing the aperature. "Glare vision" and "night vision" tests are made by decreasing illumination on the targets until their orientation cannot be determined with and without the glare lights on, respectively. Glare recovery time is obtained by measuring the time it takes subject to begin reporting the orientation of the targets at threshold illumination immediately after observing them under full illumination with the glare lights on. In each trial, four night-vision, three glare-vision and five glare-recovery tests were made.

7. Reaction Time. Simple RT and complex RT with two levels of stimulus-response compatibility were measured with the device pictured in Figure 7. In each task, subject was required to depress the central switch until one of the stimulus lamps was lit. Measurements of simple RT required subject to remove his finger from the central switch only, when the left-most lamp was lit, with latency of response as the dependent variable. (Twenty tests were made per trial.) The complex RT task required subject to respond to the onset of any of the six lamps by releasing the central switch and pressing the appropriately numbered response switch. S-R incompatibility in the complex RT task was introduced by inverting the array of stimulus lamps so that lamp No. 1 was situated above switch No. 6. In both complex RT tasks, decision time (time from the onset of a stimulus lamp to removal of the finger from the central switch) and movement time (time from removal of the finger from the

central switch to depression of the appropriate response switch were measured. Twenty tests were made in each S-R compatibility mode per trial, with random presentation of the stimulus numbers.

8. Digit Memory. A device requiring short-term memory for digits and manual encoding, such as employed in the "Phystester" (Jones, 1972) was used. A stimulus consisted of a 5-digit numeral shown by 1-inch Nixie tubes spaced on 1.5 inch centers (Figure 8). Time delay relays set both stimulus presentation time (2 sec.) and the waiting interval (5 sec.). Responses were made by pressing numbered pushbutton switches mounted on 1.5 inch centers, 2 inches beneath the Nixie tubes. A lamp fitted with a green lens, 1 inch in diameter, was mounted 2 inches above the Nixie tubes and was lighted to signal subject to start responding. Response time from the onset of the lamp to the last correct button press and the total number of response errors per session were dependent variables. One trial consisted of 30 stimulus presentations of randomly selected, non-repeating, 5-digit stimuli. Subjects were instructed to respond as rapidly as possible following the onset of the green lamp.

9. Stylus Tracking. In the stylus tracking task, a curving 0.5 inch wide slot in a metal plate was tracked with a 0.125 inch diameter stylus, 12 inches in length, terminating in a wooden handle. A lamp, fitted with a green lens 1 inch in diameter was lighted to signal subject to begin tracking, while a microswitch mounted across the end of the tracking slot terminated the trial when contacted. Dependent variables were total tracking time and tracking error time, time during which the stylus touched the edge of the slot. One trial consisted of eight tracking tests with subject instructed to complete individual tasks as rapidly as possible without allowing the stylus to touch the edge of the slot.

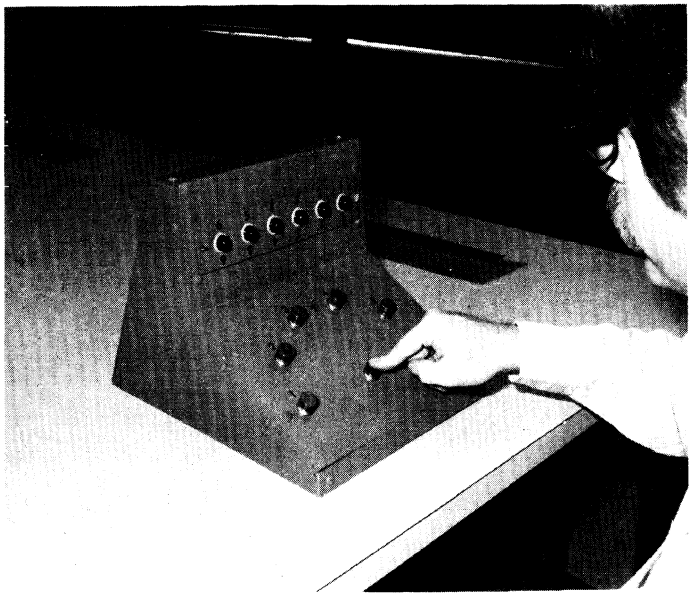


Figure 7. Reaction time test.

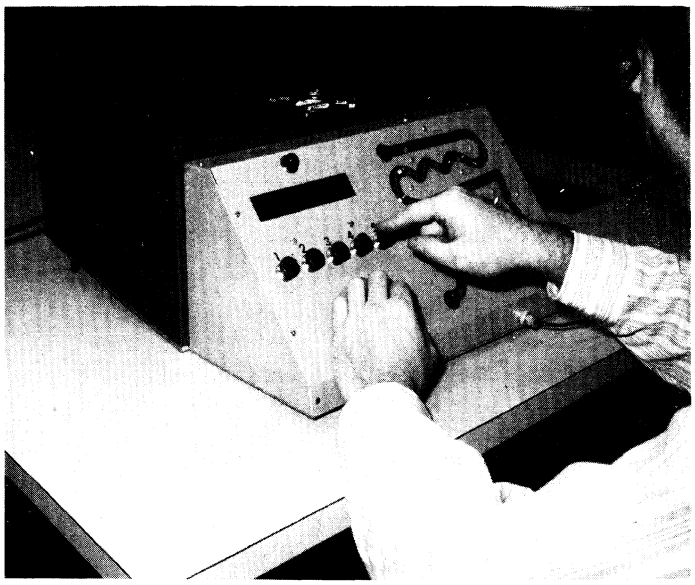


Figure 8. Digit-memory and stylus tracking tests.

10. TV Display Driving Simulator. This HSRI driving simulator provides a video display of the lateral and longitudinal motions of a simulated vehicle which are controlled by steering inputs from a subject-driver. A straight, two-lane roadway is delineated on a 40-foot long, 4-foot wide continuous belt, supported by a wooden table. The belt is roller driven by a variable speed motor. Although velocity of the simulated vehicle can be controlled with brake and accelerator pedals mounted at the driver's position, all simulator tests in this experiment were run at a fixed speed of 40 mph. An Ampex video camera mounted on a gantry at one end of the belt (Figure 9) has two degrees of freedom (about the yaw center of motion of the camera, and perpendicular to movement of the belt), and provides an image of the roadway to the driver on a 25 inch TV monitor (Figure 10).

Driver steering inputs are translated through an electronic control package which outputs appropriate signals to the camera-gantry system, resulting in realistic yaw and lateral movement of the simulated vehicle.

Analog performance data (steer angle, heading angle, and lateral position) are recorded on an FM tape recorder for subsequent digitization and computer analysis. Rates associated with the three measures are digitally produced at the time of analysis. In addition, RMS values of absolute heading angle, absolute lateral deviation, and absolute steer angle can be immediately read out for any selected time interval (Figure 11).

The use of electronic circuitry to control yaw and thus lateral position of the video camera (the simulated vehicle) makes it possible to electronically introduce steer angle errors which produce heading angle and lateral position errors to be controlled by the driver. In this experiment, distur-

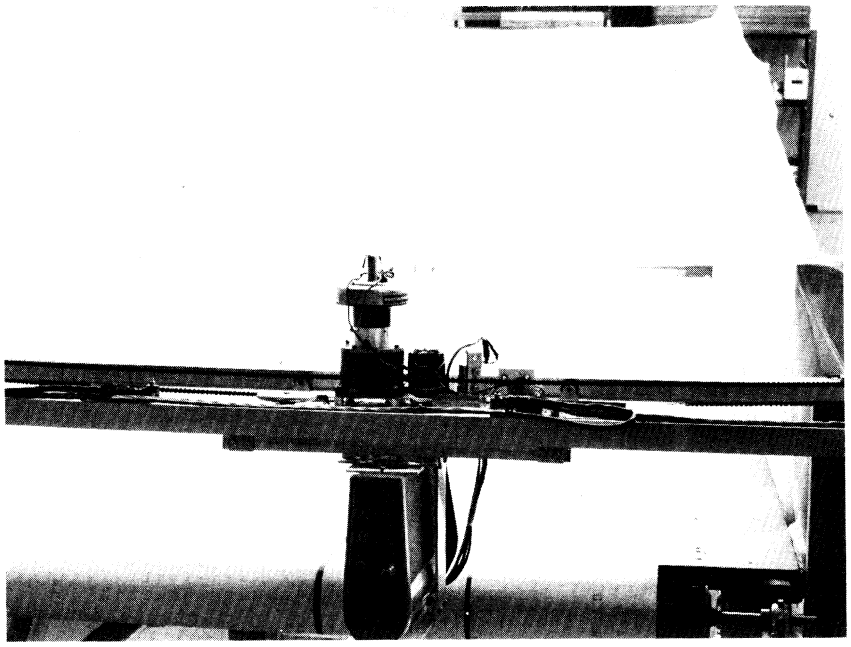


Figure 9. Simulator-camera and road belt.

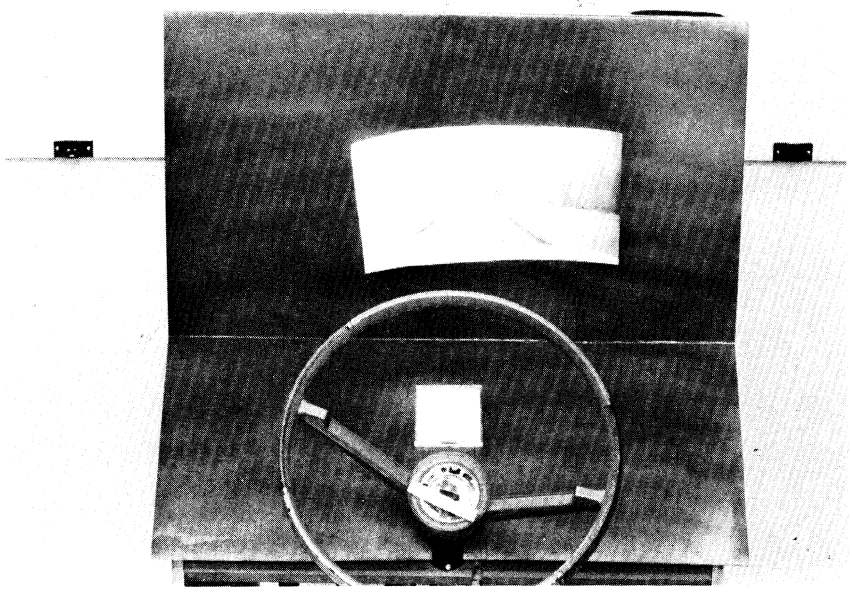


Figure 10. Subject's position in the video display driving simulator.

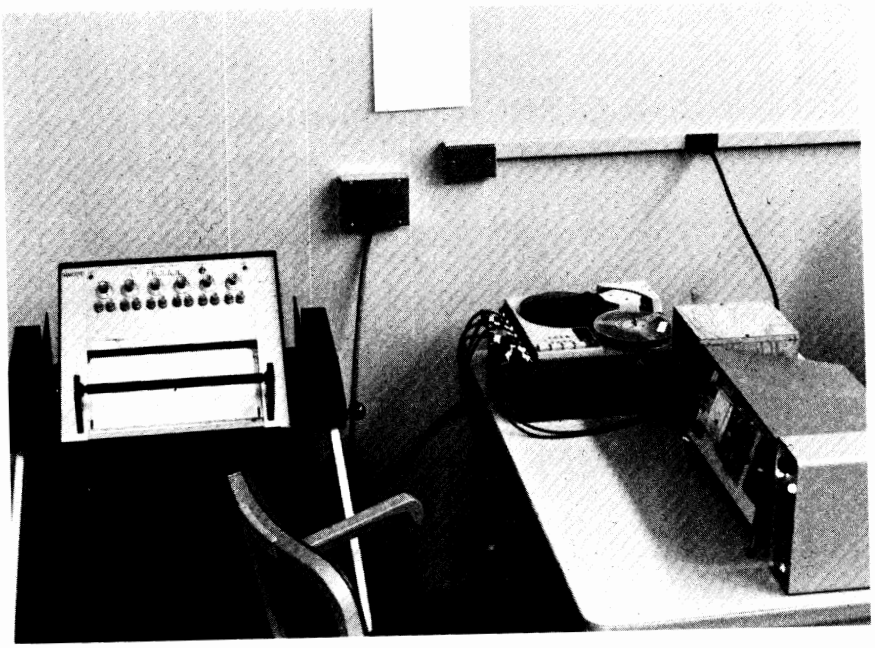


Figure 11. Data recording equipment.

bances in heading angle were introduced in two ways: (a) electronic step-steer angle inputs which simulated sudden, constant crosswinds and (b) continuous, pseudo-randomly varying electronic steer angle disturbances which simulated crosswinds of varying magnitude, frequency, and direction. Three magnitudes of step-steer disturbances corresponding to 20°, 40° and 60° of instantaneous steer angle and two levels of continuous, randomly varying noise of 40 sec. duration were used in this experiment. Examples of each disturbance type and level were demonstrated to all subjects prior to their first simulator trial. They were instructed to maintain a constant lateral position throughout each simulator trial.

Dependent variables measured in the study were:

1. The drivers' response times to the onset and offset[1] of the step disturbances.

2. Values of steer angle, lateral position error, heading angle and yaw rate and their associated rates at the response times described above.

3. Absolute mean values of each of the above six performance measures during five two-second intervals following each step onset-offset.

4. Analog measures of steering angle, lateral position error and heading angle throughout the 40 sec. continuous-disturbance trials.

EXPERIMENTAL DESIGN

Since large learning effects were known to exist for tasks involving RT and/or coordinated motor response (i.e., complex RT, the digit memory, tracking, and simulated driving) subjects were given two practice sessions on each of these tasks prior to receiving treatment doses. One practice session was given on

---

[1]Onset of the step disturbance refers to its application, whereas offset refers to its removal.

each of the remaining tasks to familiarize subjects with the testing procedure and provide control data (pre-treatment) for later statistical comparisons.

The study incorporated a between groups design in that subjects were assigned to either a placebo or alcohol treatment group. Statistical analyses of treatment effects, however, were made through both between and within groups tests of the interaction of test session (practice and treatment) and treatment group (placebo vs. alcohol). Statistical tests performed on simulated driving data were made in the same manner, although five test sessions were used (two practice and three treatment).

PROCEDURE

TASK ADMINISTRATION. Subjects were tested in pairs over periods of two days, with the first day spent in administering questionnaires and interviews and collecting control/practice data on each of the tasks. The second day was spent testing under treatment conditions with each of the paired subjects assigned to an alcohol or placebo treatment condition. Table 2 outlines the testing sequence and shows that a total of five simulator trials, three digit-memory, stylus tracking, and complex RT trials, and two trials on each of the remaining tests were made by each subject. Task order was randomized within each testing period of each subject.

DOSE ADMINISTRATION. The procedure followed on both days of the experiment was identical for placebo and alcohol subjects. Only the contents of the drinks administered on day-2 differed. On both days, subjects were tested during the afternoon. On day-2, after having received instructions to fast for at least an hour and a half prior to reporting to the laboratory, subjects were given 15 minutes to consume a drink containing either orange juice and 200° alcohol or orange juice with a small amount

TABLE 2. TESTING PROCEDURE BY TASK AND TEST DAY.

Day-1	Tests Made	Day-2	Tests Made
SESSION 1	Grip Strength Pedal Force Perimeter Compex RT Simple RT Phystester Tracking PRFT Titmus Tester Glarometer Simulator	SESSION 3†	Drink Administered Simulator* Drink Administered
	Rest Period	SESSION 4	Grip Strength* Pedal Force Perimeter Complex RT Simple RT* Phystester Tracking PRFT Titmus Tester Glarometer Simulator
SESSION 2	Complex RT Phystester Tracking Simulator		
			Rest Period*
		SESSION 5	Simulator*

*Breath test made

†Alcohol group in period 3 targeted for BAC of 0.07%, in period 4 for BAC of 0.10%, in period 5 for BAC of 0.07%.

of alcohol floated on top to simulate the alcohol dose flavor. The first alcohol dose was formulated to provide BAC's of ≈ 0.07% (w/v), the legal cut-off for impaired driving in the State of Michigan. Specific amounts of alcohol contained in the dose were based on both body weight and an estimate of the subject's body build, but averaged 0.7 g alcohol/kg body weight, mixed 1: 6 with a low calorie, carbonated soft drink.

Body build has been found to be an important parameter in determining alcohol doses, as subjects of the same total body

weight but with different amounts of body fat will typically reach different BAC's. This is attributed to the fact that fatty tissue is insoluble to alcohol, resulting in overestimates of total soluble body volume when body weight alone is used (Appendix 1).

Forty-five minutes after finishing the drink, each subject was given a breath test, followed by one session of driving in the simulator. Another breath test was then given, and a second drink administered. The second drink contained ≃ 0.5g alcohol/kg body weight and was formulated to enable subjects' BAC to peak at ≃ 0.11% BAC (mean BAC ≃ 0.10%, the legal cut-off for drunk driving in Michigan) by the middle of the second testing period. Twenty minutes after consuming the second drink, subject was tested on all tasks, administered in a random order. Breath tests were made at the middle and end of this testing period. Approximately two hours after the second testing period (or when the BAC of the subjects in the alcohol group had declined to 0.07%) the third simulator test of the day was made. During the two hour rest period, subjects were allowed to eat a late lunch and relax in a secluded room with casual reading material available. At the conclusion of the experiment, subjects were transported home and cautioned against driving or other potentially hazardous activities.

INCENTIVE STRUCTURE. As an incentive for accurate simulator performance, each subject was told that his performance would be compared with that of the other subject who was participating on the same days, and that the subject who obtained the lowest cumulative lateral position error score in driving the simulator would receive an extra payment of $10.00.

SUBJECTIVE EVALUATION OF DOSE EFFECTS. It was considered of interest to determine the subjective effect of the doses

given. Prior to the second simulator trial on day-2, all subjects were asked to rate their level of intoxication on a 10-point scale which ranged from 1, "completely sober" to 10, "completely intoxicated - on the verge of collapse."

RESULTS

BAC's AND INTOXICATION RATINGS

Table 3 summarizes BAC's attained and intoxication ratings reported for each treatment group in each of the testing periods.

TABLE 3. BAC's AND INTOXICATION RATINGS

Treatment/Session		BAC		Subjects' Intoxication Ratings*	
		Mean	S. D.	Mean	S. D.
Placebo	3	< 0.01%	-	-	-
Placebo	4	< 0.01%	-	2.57	1.18
Placebo	5	< 0.01%	-	-	-
Alcohol	3	0.076%	0.013%	-	-
Alcohol	4	0.098%	0.005%	5.75	1.85
Alcohol	5	0.067%	0.004%	-	-

* 1 = Completely sober
10 = Completely intoxicated

BAC's shown are means of readings taken at the start (or middle in the case of period 4) and end of each of the testing periods. Although BAC's of all placebo subjects were less than 0.01% in all periods, many subjects reported themselves as moderately

intoxicated, showing that the placebos had a meaningful effect. BAC's of individual alcohol subjects varied slightly from the BAC's desired, but mean BAC's were quite close to the target values.

LABORATORY TESTS CONCERNING VISION AND/OR PERCEPTION

Because the procedure followed on these laboratory tests by four male pilot study subjects was identical to that followed by the 20 subjects of this study, their data were included in the following analyses, so that the results are based on a total of 24 subjects.

PORTABLE ROD AND FRAME TEST. Sums of the absolute deviations in the eight trials made in each session (control and treatment) were found for each of the 24 subjects. A three-factor analysis of variance with factors of sessions, subjects, and treatment conditions was performed. No significant effects were found. Decrements due to alcohol were reported in a study by Kristofferson (1968) in a non-alcoholic sample.

Our total subject sample was slightly less field dependent ($\bar{X}$ = 33.9° in the control session) than Oltman's (1968) PRFT validation sample ($\bar{X}$ = 49.2°) when sex is disregarded. When sex is taken into account, the female subjects in this sample were slightly more field dependent than Oltman's (60.5° vs 52.4°), and the males considerably less field dependent (20.5° vs. 45.8°).

GLAROMETER. Means of the several trials of each dependent variable were found for each subject in each session, and each dependent variable was analyzed in a three-factor analysis of variance with test sessions, subjects and treatment conditions as factors.

The analysis of the glare vision data showed no significant

effects although there was an increase in mean target luminance required by alcohol subjects in the alcohol condition. Analysis of the night vision data showed a significant Session x Treatment condition interaction ($p<.05$) which was not detected by Tukey (b) tests performed both on session means within dose treatments and dose treatment means within session. Analysis of the glare recovery time data showed a significant session effect only, with more time required for recovery by both treatment groups in session four ($p<.05$).

VISUAL ACUITY. The analyses used the numerical value of the visual acuity (V.A.) of the most difficult target identified by each subject. Analyses of variance were made on the data from each test with factors of sessions, subjects, and treatment conditions. No significant differences were found in analyses of far V.A., both eyes; near V.A., both eyes; far V.A., left eye; near V.A., left eye; or far V.A., right eye. A significant sessions main effect, showing decrements in right eye near V.A., was found for both treatment conditions in session four ($p<.05$). Thus, no significant effects attributable to alcohol were found.

PHORIA. Data from measurements of lateral and vertical phoria at a 20-foot distance and lateral phoria at a 14-inch distance were reduced to deviations from orthophoria in units of one diopter steps, and analyses of variance performed with factors of sessions, subjects and treatment conditions. Significant sessions main effects were found in both lateral phoria analyses with subjects in both treatment conditions demonstrating less exophoria at both 20-foot ($p<.01$) and 14-inch ($p<.05$) distances in session four. No other significant differences were found. A similar analysis of vertical phoria data at a 20-foot distance showed no significant effects.

STEREO DEPTH. Data from the 20-foot stereo depth test were expressed as percentages of theoretical maximum stereopsis

according to the Shepard-Fry formula as described in the Titmus tester manual. An analysis of variance with factors of sessions, subjects and treatment conditions showed no significant differences. However, a slight decrease in stereopsis was demonstrated by the alcohol subjects under alcohol.

COLOR VISION. No differences in color vision, as measured by Ishihara plates, were found in a three-factor analysis of variance with factors of sessions, subjects and treatment conditions.

PERIMETER. Mean threshold values were found for each direction of stimulus movement for each color stimulus on each side of the head in each session. Analyses of variance with factors of sessions, subjects and treatment conditions were then performed for each stimulus color on each side of the head.

Significant Session x Treatment Condition interactions were found for red stimuli on both sides of the head ($p<.05$, Figure 12).

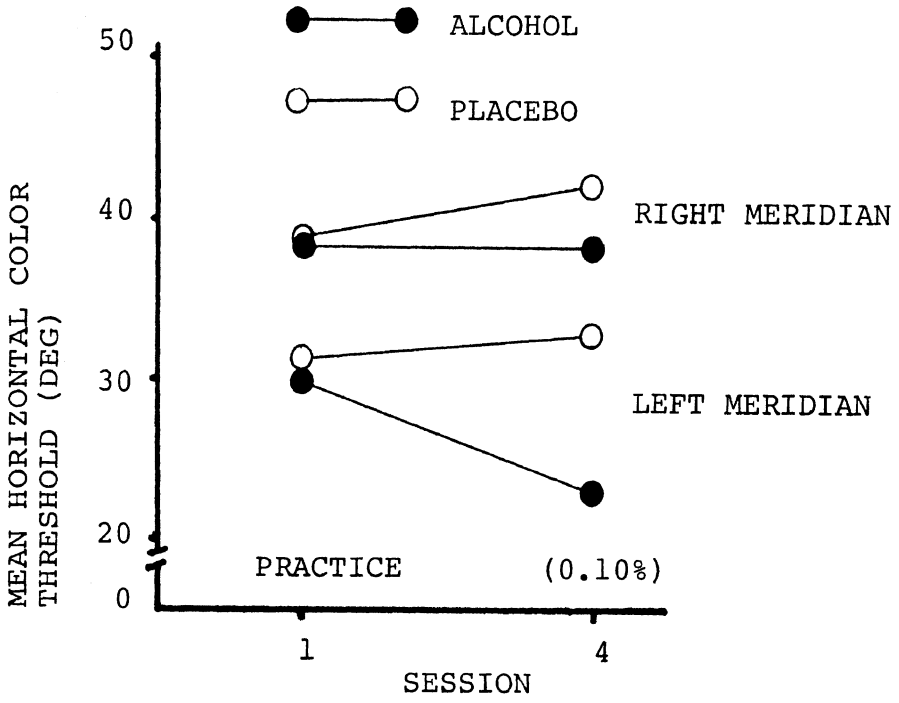


Figure 12. Mean peripheral horizontal thresholds of red stimuli.

Tukey (b) tests performed on session means within treatment conditions and treatment condition means within sessions for the right side data showed that interaction to be due to an increase in threshold angle by the placebo subjects in the treatment conditions. Similar Tukey (b) tests performed on the left side data showed a decrease in threshold angle of the alcohol subjects in the alcohol condition. Thus, alcohol produced a reduction of the left and right horizontal visual field for red.

No differences were found in analyses of yellow, green and blue stimuli on the right side, or white stimuli on the right and left side. Significant session main effects were found for yellow and green stimuli on the left side, with threshold angles smaller for both treatment groups in the second test session, indicating a practice effect.

LABORATORY TESTS CONCERNING STRENGTH

The procedure followed by the four male pilot study subjects was incompatible with that followed by the 20 subjects of this experiment. Data from the pilot study were thus not included in the following analyses.

HAND GRIP STRENGTH. The maximum grip strength for each hand was found for each subject and analyses of variance with factors of sessions, subjects and treatment conditions performed. No significant differences were found for maximum grip strength of either the right or left hands.

MAXIMUM PEDAL FORCE. Maximum pedal forces for each foot of each subject were found, and analyses of variance with factors of sessions, subjects and treatment conditions performed. No significant differences were found for either right or left foot maximum pedal force.

LABORATORY TESTS CONCERNING REACTION TIME (RT)

All analyses in this section include data from the 20 subjects of this experiment only.

SIMPLE RT. All simple RT's were transformed to Log_e to control for skewness in their distributions. An analysis of variance with factors of sessions, subjects and treatment conditions with 20 scores per cell was then performed. No significant differences were found.

COMPLEX RT - COMPATIBLE STIMULUS-RESPONSE ORDER. Separate analyses of variance were performed on decision time, movement time and total time data from both stimulus-response compatibility modes. Analyses of variance with factors of stimulus number, sessions, subjects and treatment condition (with three scores per cell) were then performed.

Decision Time. Analysis of the decision time data in the high stimulus- response compatibility mode showed a significant stimulus number main effect only ($p<.01$). A Tukey (b) test showed that the mean time to initiate responses to stimulus lamp 3, in the center of the display, were significantly longer than mean times associated with stimulus lamps 1, 5 and 6. No other significant effects on decision time were found.

Movement Time. Significant main effects of stimulus number ($p<.01$) and session ($p<.05$) and a significant stimulus Number x Session ($p<.01$) interaction were found in the analysis of movement time in the high stimulus-response compatibility condition. The significant interaction showed that the mean times to complete responses to the various stimulus numbers varied differentially, both across and within sessions.

Total Time. The analysis of the total RT data in the high stimulus-response compatibility mode showed a significant stimu-

lus Number x Session interaction ($p<.01$) and significant treatment groups ($p<.05$) and stimulus number ($p<.01$) main effects. While the significant interaction is due to greatly varying RT's to the different stimulus numbers across sessions, the mean session RT's were nearly equivalent across treatments, but uniformly ≃ 0.1 sec. lower in the placebo condition.

COMPLEX RT-LOW STIMULUS-RESPONSE COMPATIBILITY.

Decision Time. Analysis of decision time data in the low stimulus-response compatibility mode, in which the stimulus display was reversed, showed a significant session main effect ($p<.01$) and a significant Session x Treatment interaction ($p<.05$). Tukey (b) tests performed on session means within treatments and treatment means within sessions showed decision time in the final session of the placebo treatment to be significantly lower than both the first two placebo sessions and the 0.10% alcohol session (Figure 13).

Movement Time. There was a significant main effect of stimulus number ($p<.01$) in the analysis of mean movement times. Mean movement time to stimulus number 2 was significantly greater than mean movement times to stimulus numbers 1, 4, 5 and 6.

Total Time. An identical significant stimulus number main effect was found in the analysis of the total RT data ($p<.01$). Significant main effects of session ($p<.05$) and treatment condition ($p<.05$) and a significant Session x Treatment condition ($p<.01$) were also found. Tukey (b) tests performed on session means within sessions showed total RT's in placebo session 4 to be significantly lower than in alcohol session 4 and the first two placebo sessions (Figure 13), due to the greater decision time.

DIGIT-MEMORY RESPONSE TIME. Median response times were found for each of the five blocks of six digit-memory trials

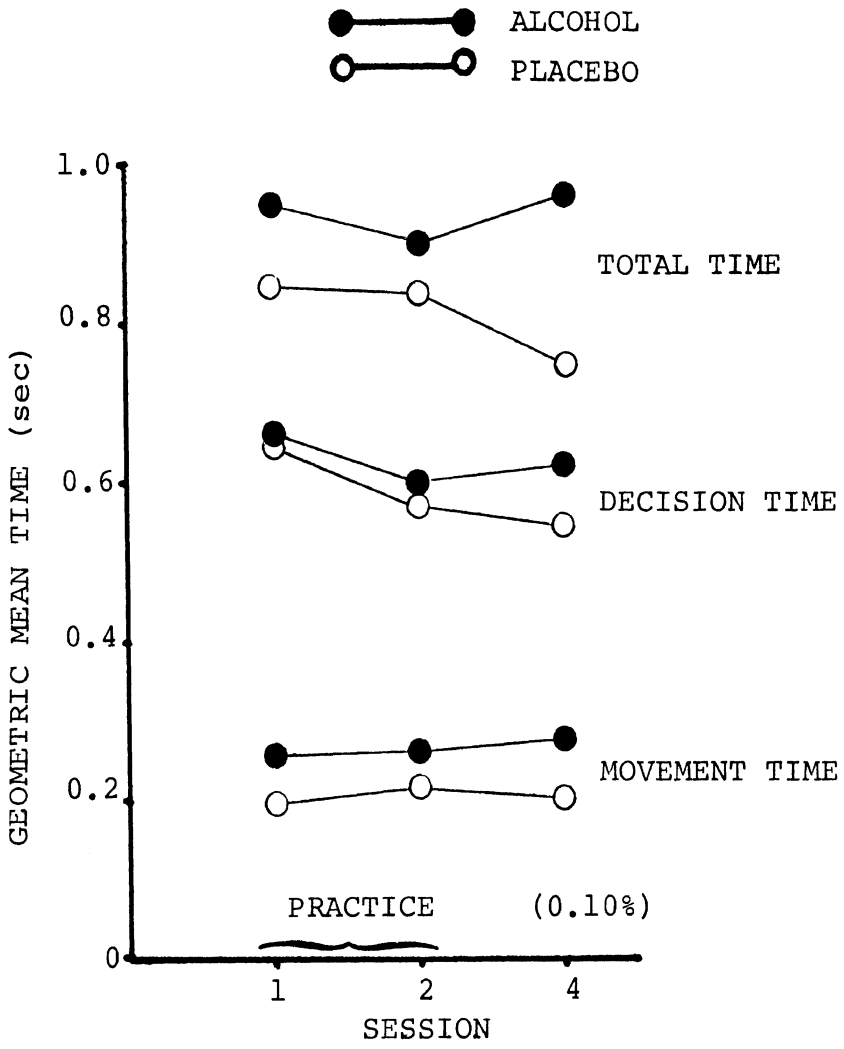


Figure 13. Mean decision, movement and total time in the low stimulus-response compatibility reaction time test.

made in each session. These data were then transformed to Log_e to reduce skewness. A four-factor analysis of variance with factors of trial blocks, sessions, subjects and treatment conditions was then performed. Main effects of trial blocks and sessions, and the Trial Blocks x Sessions interaction were significant ($p<.01$). Thus, there was no effect attributable to alcohol.

Error Frequency. Frequency of response errors was examined in a three-way analysis of variance with factors of sessions, subjects and treatment conditions. An arc-sine transformation was performed on the error frequency data to reduce skewness.

Figure 14 illustrates the significant ($p<.05$) Session x Treatment

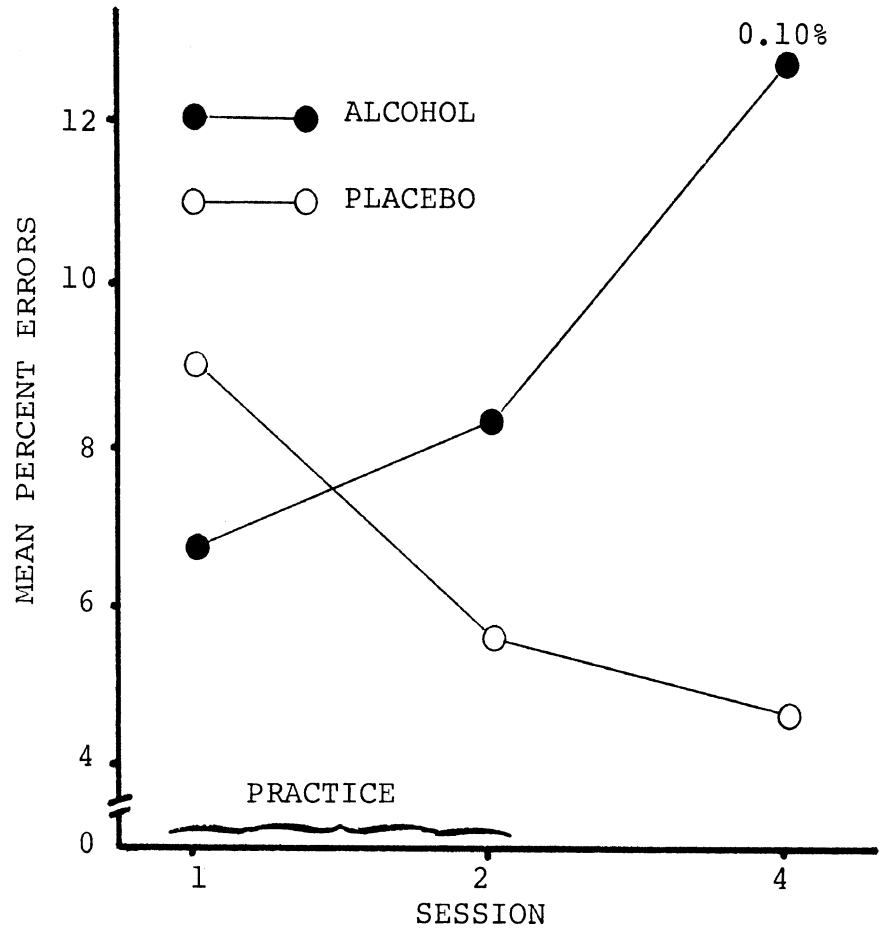


Figure 14. Mean percentage of encoding errors in the digit-memory test.

condition interaction in terms of percent errors. Tukey (b) tests performed on session means within treatment conditions showed no significant differences. However, Tukey (b) tests performed on treatment condition means within sessions showed the alcohol group mean in session 4 to be significantly larger

($p<.05$) than the corresponding placebo group mean. No other significant effects were found.

LABORATORY TEST CONCERNING COORDINATED MOTOR RESPONSE

STYLUS TRACKING TEST. Median tracking error times were found for each of the two blocks of four trials administered in each session. These data were then transformed to square roots to reduce the correlation between the session means and variances. A four-factor analysis of variance with factors of trial blocks, sessions, subjects and treatment conditions was then performed. The only significant effect was the Session x Treatment interaction, illustrated in Figure 15. A Tukey (b)

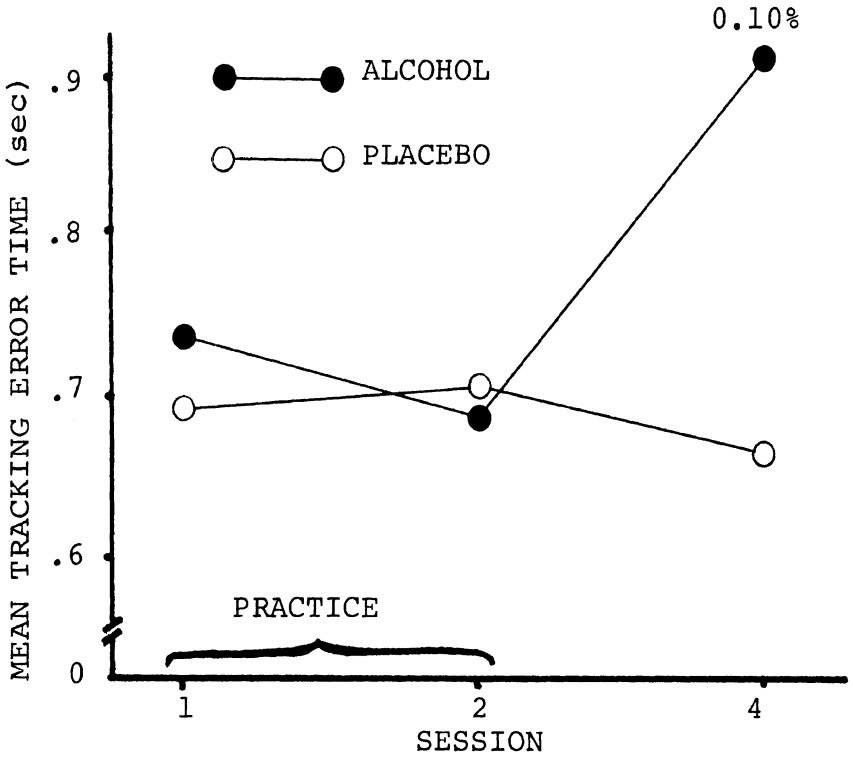


Figure 15. Mean stylus tracking error time.

test performed on session means within treatments showed no differences among the three placebo group means, but significantly more tracking error time in the 0.10% alcohol session, compared with the first two sessions. A Tukey (b) test performed on treatment condition means within sessions showed no difference between treatment conditions in the first two sessions, but significantly greater tracking error times in the alcohol treatment session (BAC ≃.10%).

SUMMARY OF RESULTS OF LABORATORY TESTS

1. PORTABLE ROD AND FRAME TEST. No significant results.

2. GLAROMETER

A. Glare Vision - no significant effects.

B. Night Vision - significant session x dose treatment interaction, not confirmed by Tukey (b) test. (Higher intensity needed under alcohol.)

C. Glare Recovery Time - Significant session effect only.

3. TITMUS TESTER

A. 20-Foot Visual Acuity - Both Eyes - no significant effects.

B. 20-Foot Visual Acuity - Right Eye - no significant effects.

C. 20-Foot Visual Acuity - Left Eye - no significant effects.

D. 14-Inch Visual Acuity - Both Eyes - no significant effects.

E. 14-Inch Visual Acuity - Right Eye - significant session effect only.

F. 14-Inch Visual Acuity - Left Eye - no significant effects.

G. 20-Foot Stereo Depth - no significant effects.

H. 20-Foot Color Vision - no significant effects.

I. 20-Foot Vertical Phoria - no significant effects.

J. 20-Foot Lateral Phoria - significant session effect only.

K. 14-Inch Lateral Phoria - significant session effect only.

4. PERIMETER (RIGHT EYE)

A. Right Lateral Plane

(1) Red Stimulus - session x dose treatment interaction due to increase in visual field of placebo subjects compared to alcohol group.

(2) Yellow Stimulus - no significant effects.

(3) Green Stimulus - no significant effects.

(4) Blue Stimulus - no significant effects.

(5) White Stimulus - no significant effects.

B. Left Lateral Plane

(1) Red Stimulus - session x dose treatment interaction due to decrease in visual field in alcohol subjects under alcohol.

(2) Yellow Stimulus - significant session effect only.

(3) Green Stimulus - significant session effect.

(4) Blue Stimulus - no significant effects.

(5) White Stimulus - no significant effects.

5. MAXIMUM HAND GRIP STRENGTH. Right and left hand - no significant effects.

6. MAXIMUM FOOT PEDAL FORCE. Right and left foot - no significant effects.

7. REACTION TIME

A. Simple RT - no significant effects.

B. Complex RT - normal stimulus order.

(1) Decision Time - significant stimulus number effect only.

(2) Response Time - significant number x session effects. No alcohol effect.

(3) Total Time - significant dose treatment and number x session effects. No alcohol effect.

C. Complex RT - reversed stimulus order.

(1) Decision Time - significant session x dose treatment effect, due to decrease in time in session 4 by placebo subjects.

(2) Response Time - significant stimulus number effect only.

(3) Total Time - significant session x dose treatment effect due to decrease in total time in session 4 by placebo subjects.

8. DIGIT-MEMORY

A. Response Time - significant trial, session, and trial x session effects. No alcohol effect.

B. Error Frequency - Significant session x dose treatment interaction. (More errors under alcohol.)

9. STYLUS TRACKING ERROR TIME - significant session x dose treatment interaction due to increase in error time demonstrated by alcohol subjects under alcohol.

DRIVING SIMULATOR CONTINUOUS DISTURBANCE ANALYSES

The high level continuous disturbance was used to simulate

the side forces acting on an automobile due to severe, random wind buffeting. The low level continuous disturbance was intended to simulate the translations of the vehicle across the road due to minor road ruts or mild wind gusts.

The data from one male subject in each treatment group was unavailable, due to problems encountered in data recording. Thus, data analyses were made for 18 subjects in all driving simulator continuous disturbance tests.

All continuous disturbance mean and variance data were analyzed in three-factor unweighted means analyses of variance with factors of sessions, subjects and treatment conditions, with subjects nested under treatment condition. Because the high level continuous disturbance was qualitatively different from the low level disturbance, separate analyses were performed on data from each disturbance type. Although cell frequencies were unequal in all analyses (high level disturbance assumed cell frequency = 3.93; low level disturbance assumed cell frequency = 2.67, missing data were randomly distributed across all factors.

LATERAL POSITION MEAN AND VARIANCE ANALYSIS - HIGH LEVEL DISTURBANCE. Significant ($p<.05$) Session x Treatment Condition interactions were found in both lateral position mean and variance analyses. A significant ($p<.05$) sessions main effect was also found in the mean lateral position analysis. Tukey (b) tests performed on session means within treatments showed both mean lateral position and lateral position variance to be significantly ($p<.01$) greater in session 4 (0.10% BAC) than session 2 (0% BAC) in the alcohol condition only. No differences in placebo condition session means were found in either analysis. Further Tukey (b) tests performed on treatment condition means within sessions showed the means of the alcohol

groups in session 4 to be greater ($p<.05$) than the corresponding means of the placebo groups in both analyses (Figures 16 and 17).

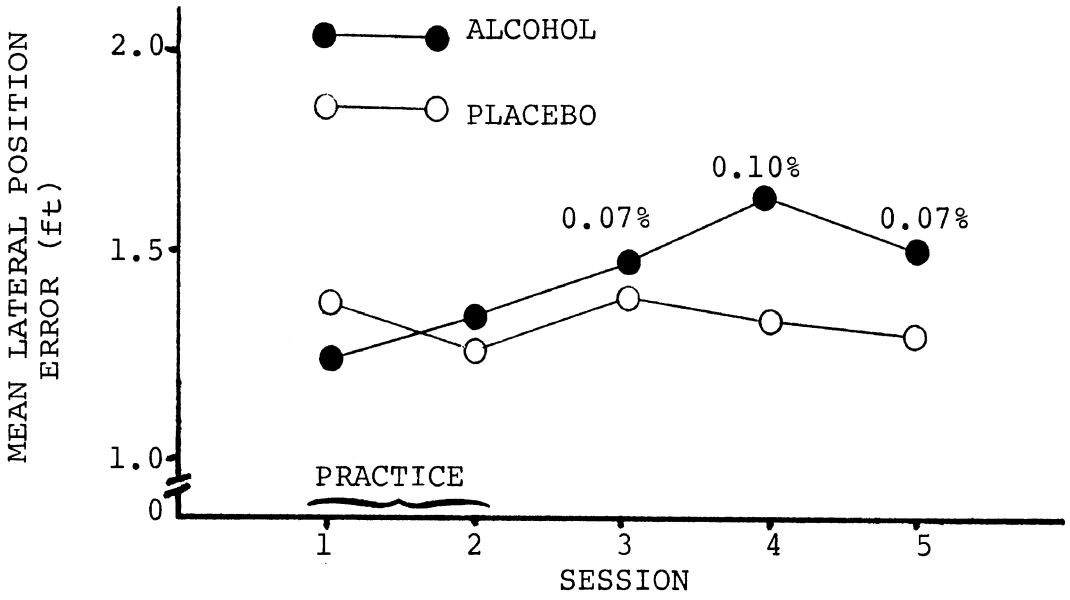


Figure 16. Mean of lateral position error in the high level random disturbance simulator test.

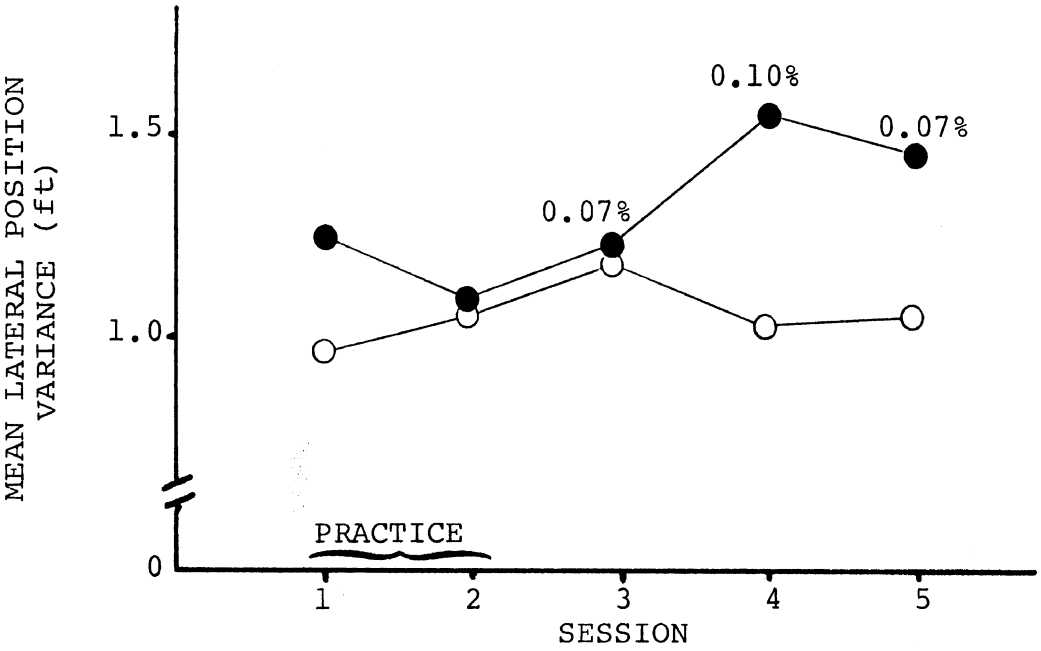


Figure 17. Mean variance of lateral position error in the high level random disturbance simulator test.

LATERAL POSITION MEAN AND VARIANCE ANALYSES - LOW LEVEL DISTURBANCE. Analysis of the mean lateral position data showed a significant ($p<.05$) treatment main effect only, with more lateral position error accumulated by the alcohol group across sessions.

Analysis of the lateral position variance data showed significant ($p<.01$) main effects of sessions and treatment conditions and a significant ($p<.05$) Session x Treatment Condition interaction (Figure 18). Tukey (b) tests performed on session means within treatments and treatment means within sessions

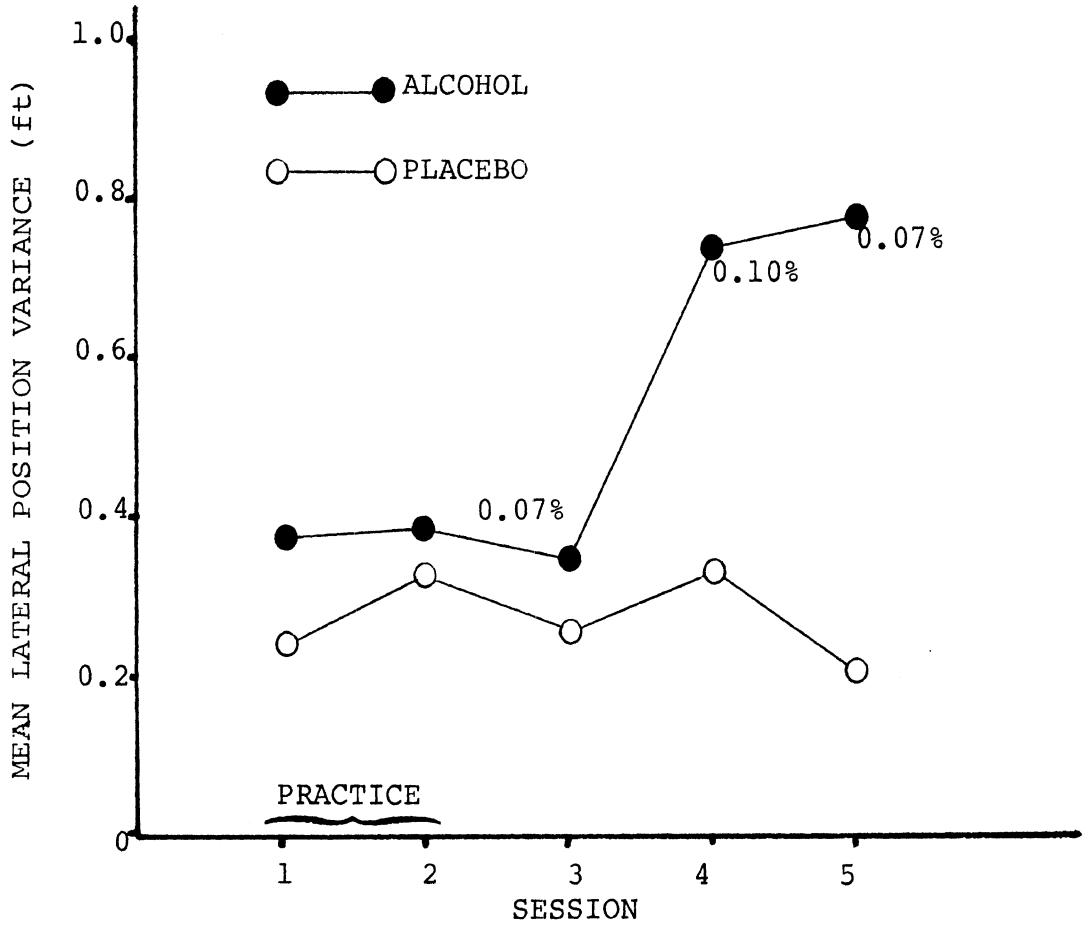


Figure 18. Mean variance of lateral position error in the low level random disturbance simulator test.

showed mean variance in alcohol condition sessions 4 and 5 to be significantly greater than in all other alcohol condition sessions and the corresponding placebo condition sessions ($p<.01$).

LATERAL POSITION RATE MEAN AND VARIANCE ANALYSES - HIGH AND LOW LEVEL DISTURBANCES. No significant effects were found in any analysis.

HEADING ANGLE MEAN AND VARIANCE ANALYSIS - HIGH LEVEL DISTURBANCE. A significant ($p<.01$) Session x Treatment condition interaction was found in the mean heading angle analysis. A Tukey (b) test performed on session means within treatment conditions showed the means of sessions 1, 2 and 3 to be significantly larger ($p<.05$) than the mean of session 5, in the placebo group. No differences were found among session means of the alcohol group. A Tukey (b) test performed on treatment condition means within sessions showed no significant differences.

The analysis of heading angle variances showed a significant ($p<.05$) sessions main effect only. Mean variance in session 1 was found by Tukey (b) test to be greater ($p<.05$) than that in session 5.

Thus, there were no significant effects due to alcohol in either analysis.

HEADING ANGLE MEAN AND VARIANCE ANALYSES - LOW LEVEL DISTURBANCE. Analysis of the mean heading angle data showed a significant Sessions x Treatment Condition interaction only. No significant differences were found, however, in subsequent Tukey (b) tests of session means within treatments and treatment means within sessions.

No significant differences were found in the heading angle variance analysis.

YAW RATE MEAN AND VARIANCE ANALYSES - HIGH LEVEL DISTURBANCE. Analyses of both mean and variance data showed significant ($p<.01$) sessions main effects only. Tukey (b) tests performed on session means showed mean yaw rate to be greater in sessions 1 and 2 than in sessions 3, 4 and 5 and yaw rate variance to be greater in session 1 than in sessions 3, 4 and 5.

YAW RATE MEAN AND VARIANCE ANALYSES - LOW LEVEL DISTURBANCE. No significant effects were found in either analysis.

STEERING WHEEL DISPLACEMENT MEAN AND VARIANCE ANALYSES - HIGH LEVEL DISTURBANCE. The only significant effect found in either analysis was a sessions main effect in the steering wheel displacement variance analysis. Comparisons of session means made by Tukey (b) test showed mean variance in session 1 to be significantly greater than variance in sessions 4 ($p<.05$) and 5 ($p<.01$). The Session x Treatment Condition was not significant in either mean or variance analysis.

STEERING WHEEL DISPLACEMENT MEAN AND VARIANCE ANALYSES - LOW LEVEL DISTURBANCE. Although no significant effects were found in the analysis of the variance data, a significant ($p<.05$) Session x Treatment Condition interaction (Figure 19) was found in the analysis of the mean steering wheel displacement. Session means within treatment conditions and treatment condition means within sessions were subjected to Tukey (B) tests which showed session 5 of the placebo group to be significantly smaller than all other placebo group means ($p<.05$) and significantly ($p<.01$) smaller than the corresponding alcohol group mean.

STEERING WHEEL DISPLACEMENT RATE MEAN AND VARIANCE ANALYSES - HIGH LEVEL DISTURBANCE. Significant sessions main effects ($p<.05$) were the only significant effects found in either analysis. The mean of session 1 was significantly

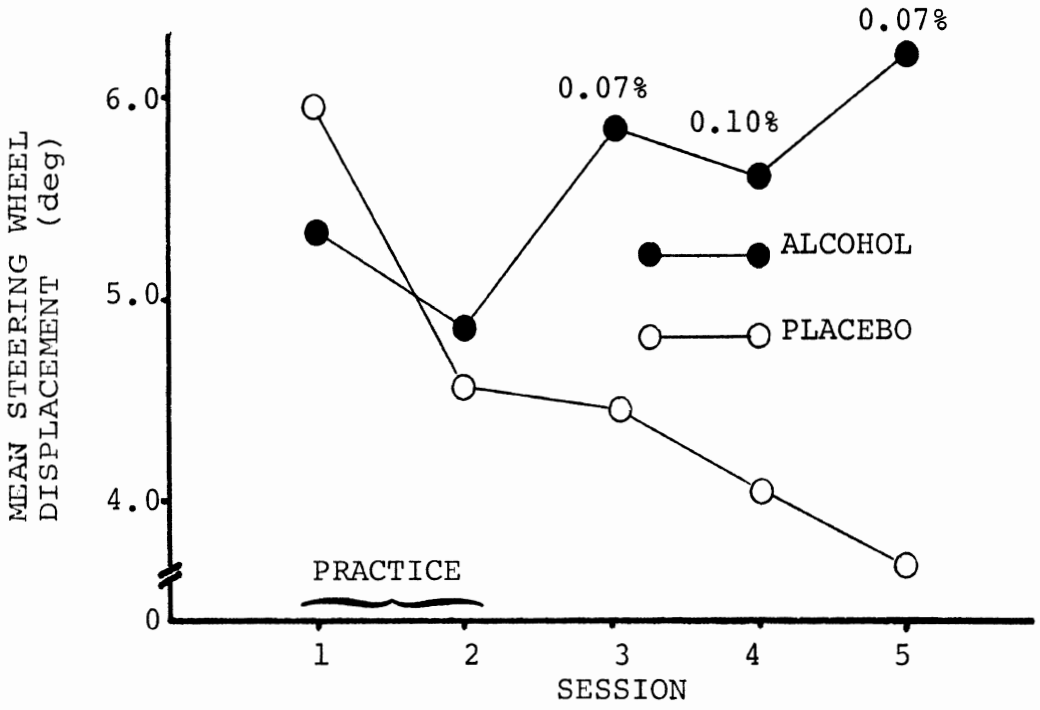


Figure 19. Mean steering wheel displacement in low level random disturbance simulator test.

larger ($p<.01$) than means in sessions 3, 4 and 5 in both mean and variance analyses. In addition, the mean of session 2 in the mean steering rate analysis was significantly larger ($p<.05$) than that of session 5.

STEERING WHEEL DISPLACEMENT RATE MEAN AND VARIANCE ANALYSES - LOW LEVEL DISTURBANCE. No significant effects were found in either analysis.

DRIVING SIMULATOR STEP DISTURBANCE RESPONSE TIME COMPONENT ANALYSES

The time to respond to the onset and offset of the step disturbances was measured in terms of the estimated time required to detect the error in path keeping (detection time), the time to decide on the direction of the disturbance and the lag to initiate a muscular response (reaction time), and to accomplish a

sufficiently large response by movement of the steering wheel to counteract the disturbance (movement time).

The total response time (T_T) consisted of the following variables:

$$T_T = DT + RT + MT$$

where,

DT is the detection time

RT is the decision time and the neuromuscular lag time

MT is the time to move the steering wheel the angular distance equal to the effect of the wind gust disturbance (40°, 60°).

Thus, T_T was the amount of time following the application or removal of the wind gust disturbance, which the subject required to respond with a steering wheel movement equal to the effective magnitude of the disturbance and in the opposite direction to it. The movement time was calculated by dividing the step magnitude by the mean steering wheel rate at ±10° of half the magnitude. The reaction time (RT) was taken as 0.2 sec. for on-steps and 0.1 sec. for off-steps. Detection time was obtained by subtraction of RT and MT from Total Time, T_T.

These variables (DT and T_T) were computed for step inputs equivalent to 40° and 60° of steering wheel displacement. The 20° tests were omitted from this analysis because of difficulty in consistently separating steering responses to the continuous low level random inputs from those to the 20° step disturbances which were superimposed upon the continuous input. Steering responses to the 40° and 60° steps could be detected clearly.

Data recording problems made it necessary to omit data from two male subjects in each treatment group, making a total of 16 subjects for the following analyses.

Analyses of both decision and total response time data were made in five-factor unweighted means analyses of variance with factors of step initiation (on vs. off), step magnitude (40° vs. 60° step steer disturbance input), session, subject and treatment condition with subjects nested under treatment condition. Assumed cell frequencies were 5.7 in each analysis. Missing data were randomly distributed across cells. Cell RT's were transformed to $\log_e$ prior to analysis to correct for skewness.

DETECTION TIME TO STEP DISTURBANCES. Significant ($p<.01$) main effects of step initiation and sessions, and a significant ($p<.01$) Session x Treatment Condition (Figure 20) interaction,

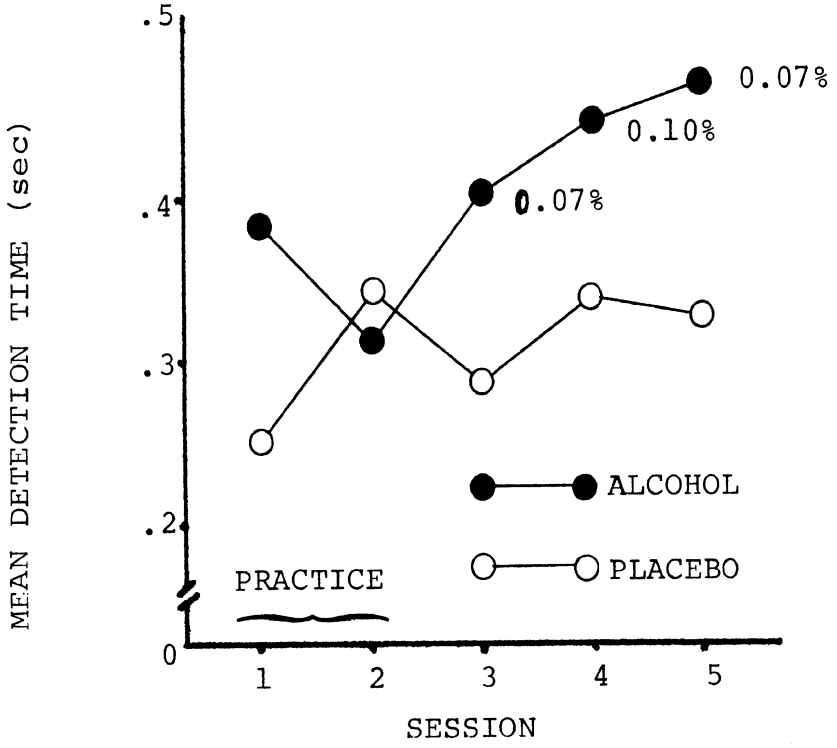


Figure 20. Detection time to step disturbances by alcohol and placebo groups.

were found. Detection times to off-steps were found to be approximately 0.1 seconds lower than those to on-steps (0.323 sec. vs. 0.437 sec.) across all other factors. The significant interaction was examined by performing Tukey (b) tests on session means within sessions. Differences in session means were found in both treatment conditions: the mean of session 1 was significantly ($p<.05$) smaller than means of sessions 2 and 4 in the placebo condition, while the mean of session 2 was significantly ($p<.01$) smaller than means of sessions 4 and 5, and the mean of session 1 significantly ($p<.05$) smaller than session 5, in the alcohol condition. Placebo condition means were found significantly ($p<.05$) smaller than corresponding alcohol means in sessions 1, 3 and 5, indicating greater mean detection times at a BAC of 0.07% than without alcohol. While detection time was also greater with a BAC of 0.10% than the corresponding placebo condition (session 4, Figure 20), the difference was not statistically significant.

TOTAL RT TO STEP DISTURBANCES. Significant step initiation ($p<.01$), magnitude ($p<.01$), and treatment condition ($p<.05$) main effects and Session x Treatment Conditions ($p<.01$) and Step Initiation x Magnitude x Session Interactions ($p<.05$) were found. Since all main effect differences were contained in interactions, only the interactions were analyzed further.

Differences in treatment condition means within sessions and session means within treatment conditions were analyzed by Tukey (b) tests. No differences in session means were found in the placebo condition, while the mean of session 5 was significantly ($p<.05$) greater than means of sessions 1, 2 and 3, and the mean of session 4 significantly ($p<.05$) greater than the mean of session 2 in the alcohol condition. Means of the alcohol group were significantly larger than corresponding placebo group means in sessions 3 ($p<.05$), 4 ($p<.01$), and 5 ($p<.01$), as shown in Figure 21.

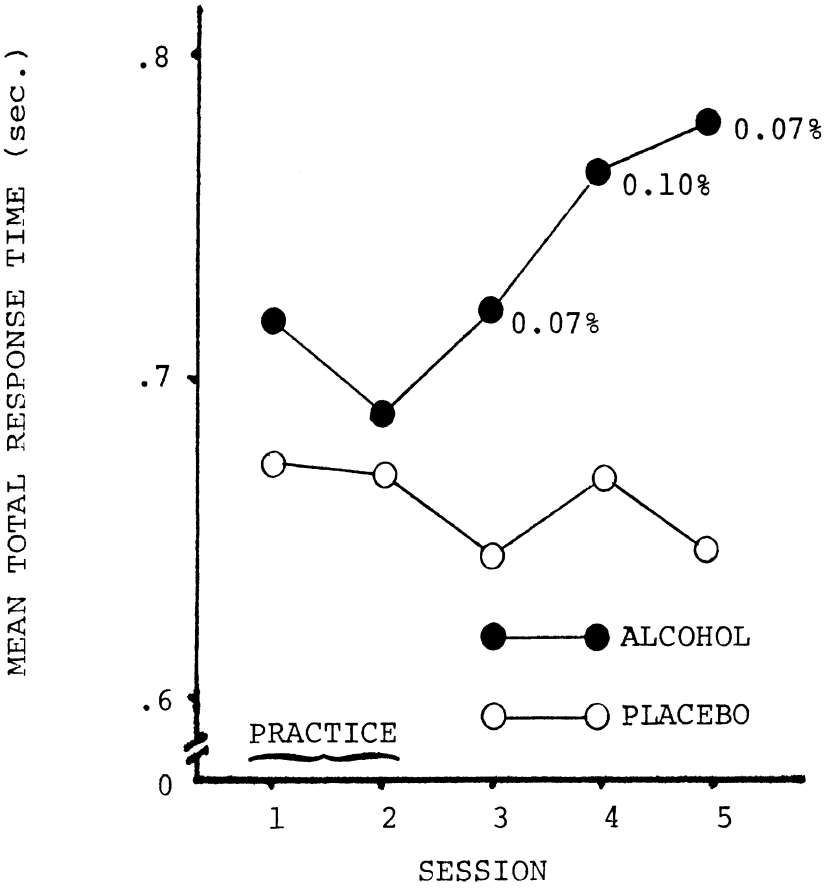


Figure 21. Response time to step disturbances by alcohol and placebo groups.

The significant Step Initiation x Magnitude x Session interaction was examined by performing Tukey (b) tests on step initiation means and magnitude means within levels of the other interacting factors. Significantly greater mean RT's to on- than off-steps were found in sessions 2, 3 and 4 at the 60° magnitude and session 5 at the 40° magnitude ($p<.05$). Greater mean RT's were found to 40° than 60° disturbances in all sessions and step initiation modes except sessions 1 and 2, on-step, and session 5, off-step.

DRIVING SIMULATOR STEP DISTURBANCE SETTLING TIME ANALYSES

Means and variances of the dependent measures were found in five, two-second, intervals following the onset and offset of each step disturbance presented. These data were then analyzed in six-factor unweighted means analyses of variance with factors of time intervals (five levels), step initiation

(on- and off-steps), magnitudes (20°, 40° and 60°), sessions, subjects and treatment conditions, with subjects nested under treatment conditions. Data from two male subjects were unavailable, so that the analyses are for 18 subjects. The steering wheel displacement variance data were not analyzed because a disproportionate amount of the data were missing due to problems in data recording.

In each analysis, the effects of major interest are the Interval x Session x Treatment Condition and Session x Treatment Condition interactions which reflect differences in settling times within sessions between treatments or differences across sessions between treatments, respectively. Although a considerable number of other interactions were found significant in many of the above analyses, only the two mentioned were analyzed further.

LATERAL POSITION MEAN AND VARIANCE SETTLING TIME ANALYSES. Analysis of the mean data showed a significant Session x Treatment Condition interaction. Tukey (b) tests performed on treatment means within sessions showed lateral position means of the alcohol group to be significantly larger across intervals in sessions 4 and 5 (Figure 22), indicating a greater mean lateral position error at 0.10% BAC, and 0.07% BAC during alcohol elimination.

A significant Interval x Session x Treatment Condition interaction was found in the analysis of the lateral position variance settling time data. Tukey (b) tests showed variances in the alcohol condition to be significantly greater in interval 1, sessions 3, 4 and 5 and interval 2, session 5 only (Figure 23). The step magnitude factor also interacted with intervals, sessions and treatment conditions, indicating that the above results may not hold true for all magnitudes employed.

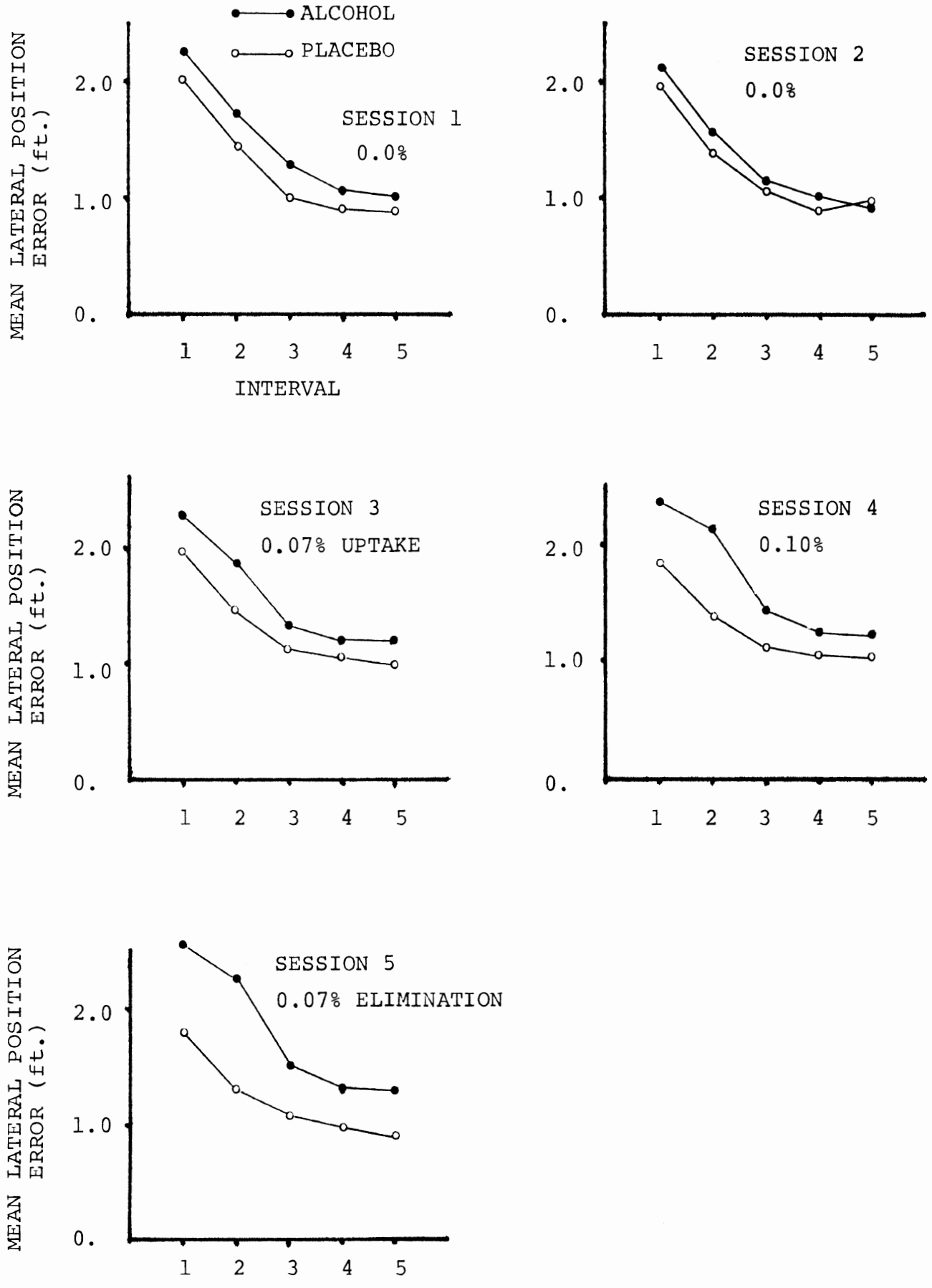


Figure 22. Mean lateral position error in the five two-second intervals after the step disturbance.

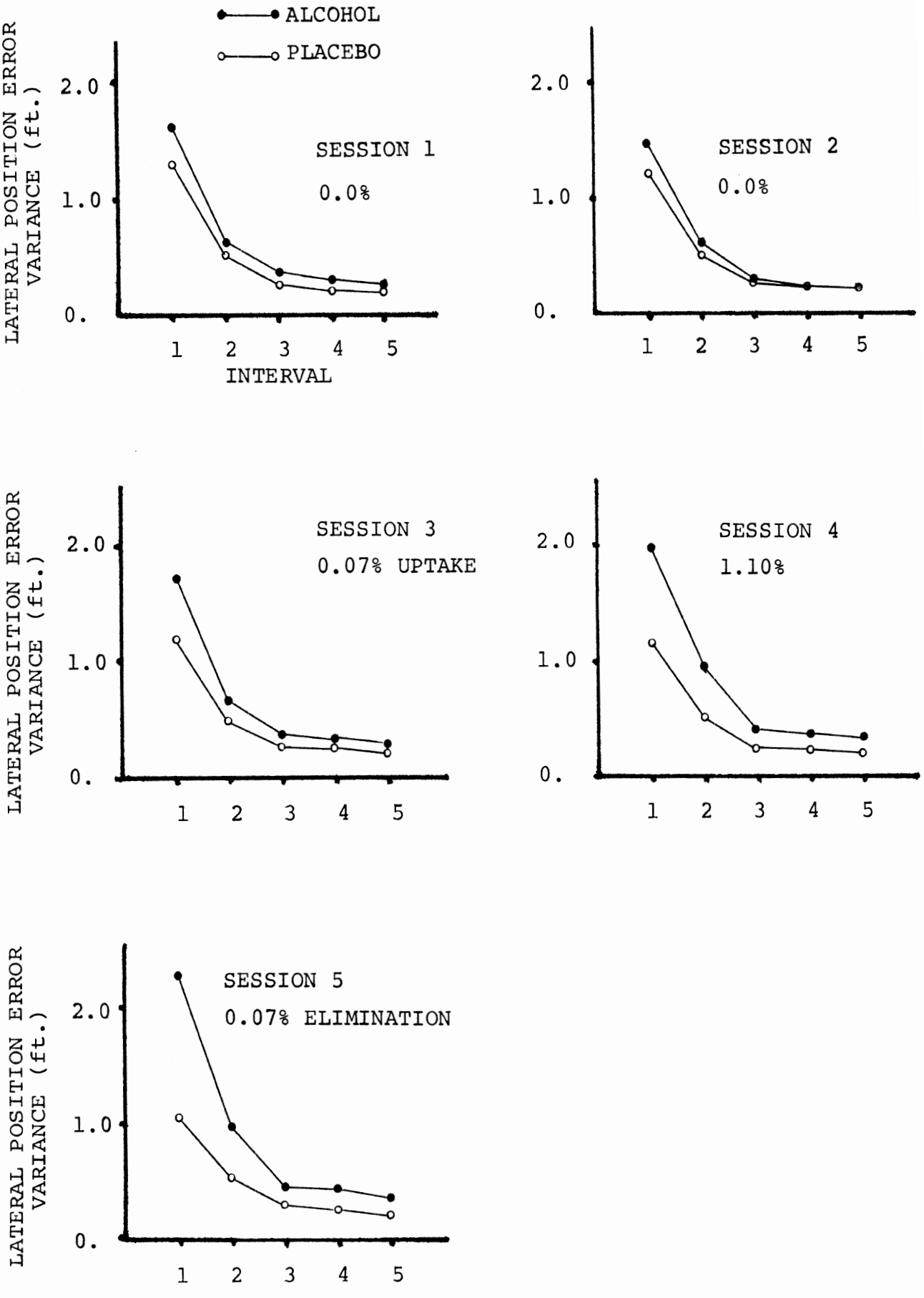


Figure 23. Mean variance of lateral position error in the five two-second intervals after the step disturbance.

LATERAL POSITION RATE MEAN AND VARIANCE SETTLING TIME ANALYSES. Neither the Interval x Session x Treatment Condition or Session x Treatment Condition interactions were found significant in either analysis.

HEADING ANGLE MEAN AND VARIANCE SETTLING TIME ANALYSES. Both analyses showed significant Interval x Session x Treatment Condition interactions. These interactions were examined as between groups effects only, by performing Tukey (b) tests on treatment means within interval and session. No differences between groups were found in either mean or variance analysis in intervals in sessions 1 and 2. The mean heading angle of the alcohol group was greater than the placebo group ($p<.01$) in interval 1, sessions 3, 4 and 5: interval 2, sessions 4 and 5; and interval 3, session 5. No differences in group means were found in intervals 4 and 5 in any sessions (Figure 24).

Significantly greater ($p<.01$) variances were found in the alcohol group in interval 1, sessions 3, 4 and 5; and interval 2, session 5. No differences in variances were found in intervals 3, 4 and 5 in any session (Figure 25).

It should be noted that the above effect was also found to interact with the magnitude factor (Interval x Magnitude x Session x Treatment Condition), in both mean and variance analyses, indicating that the above results may not be applicable to all step magnitudes employed. Analysis of the four-factor interaction was not pursued.

YAW RATE MEAN AND VARIANCE SETTLING TIME ANALYSES. No interactions were found involving treatment conditions, sessions, and/or intervals. Significant effects involved interactions of intervals, step initiation, and magnitude which were not further examined.

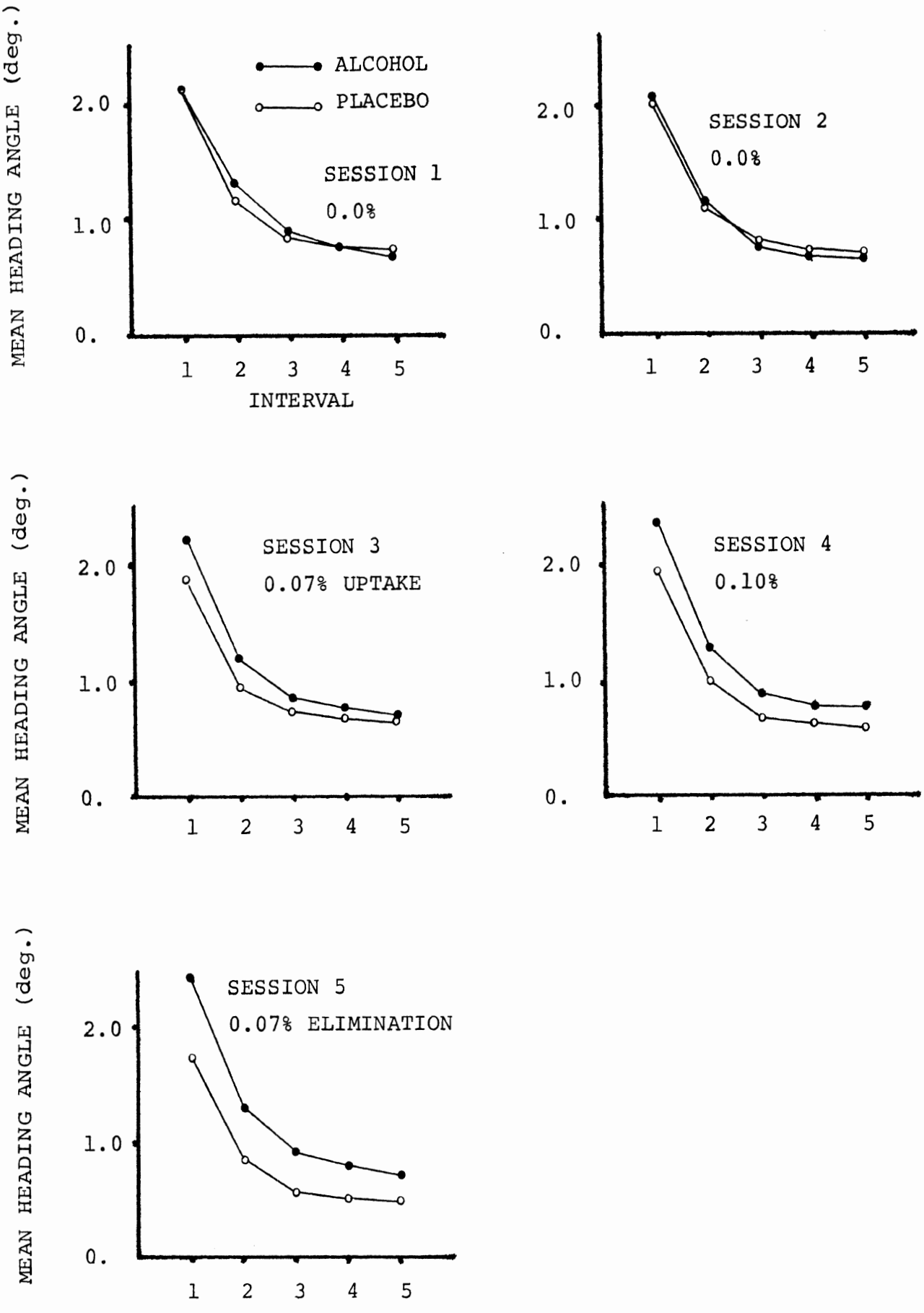


Figure 24. Mean heading angle in the five two-second intervals after the step disturbance.

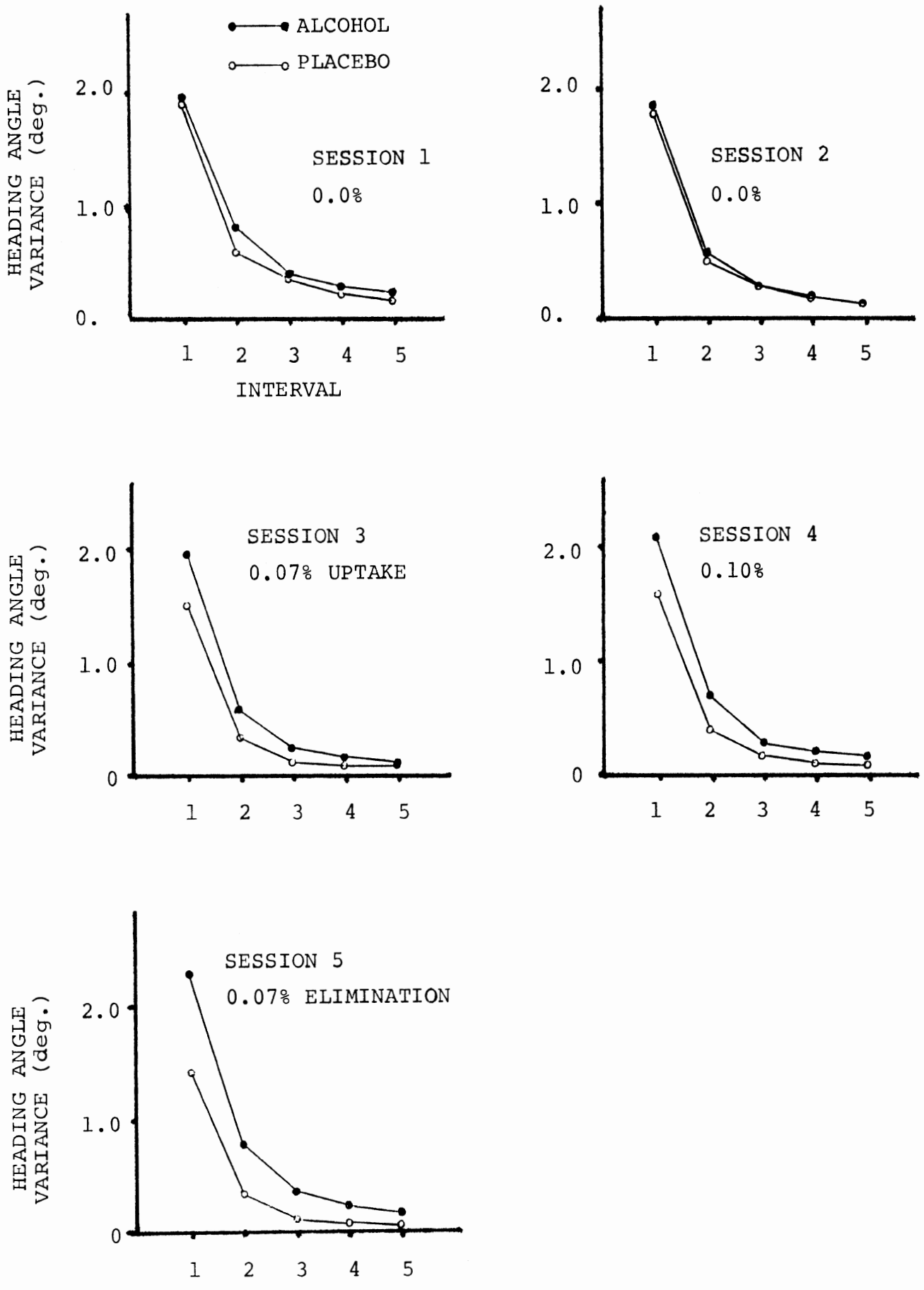


Figure 25. Mean variance of heading angle in the five two-second intervals after the step disturbance.

STEERING WHEEL DISPLACEMENT MEAN SETTLING TIME ANALYSIS. Neither interaction of interest was significant.

STEERING WHEEL DISPLACEMENT RATE MEAN AND VARIANCE SETTLING TIME ANALYSES. Analyses of both sets of data showed significant Interval x Session x Treatment Condition interactions. In the analysis of means, treatment conditions differed in interval 1, session 5 only, with a greater steering rate mean in the placebo condition (Figure 26).

Analysis of the variance data showed placebo condition variance means of steering rates to be significantly larger in interval 1, sessions 2, 4 and 5 only (Figure 27). As the Interval x Magnitude x Session x Treatment Condition interaction was also significant in the variance analysis, the above results may not be valid for all step magnitudes employed.

DRIVING SIMULATOR SPECTRAL ANALYSES

Steering control performance in the continuous, high-level disturbance condition was analyzed by means of time-series analyses for 18 subjects, 9 in each of the placebo and alcohol groups.

For lateral position error, heading angle (same as the path angle in the simulator[1]), yaw rate and steering wheel displacement, the power spectrum of each signal was obtained in each trial. The power spectrum of the signal is the fourier transform of the autocorrelation of the signal. From the power spectra the frequency bandwidths of these signals and the RMS values were derived for the test trials to which the placebo and alcohol group subjects were exposed.

---

[1]Since heading angle is the difference between path angle and slip angle, with slip angle ignored in the simulator.

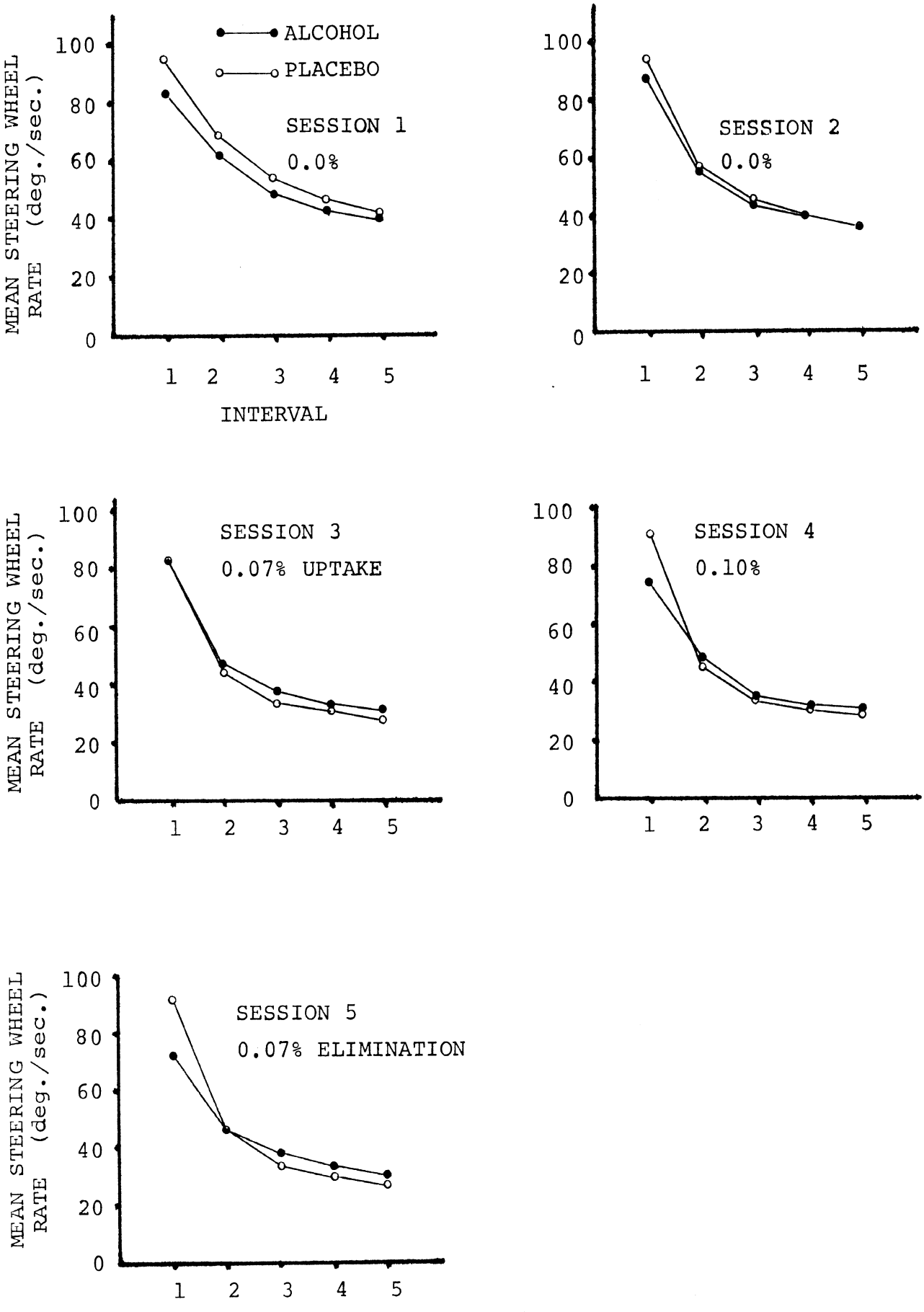


Figure 26. Mean steering wheel rate in the five two-second intervals after the step disturbance.

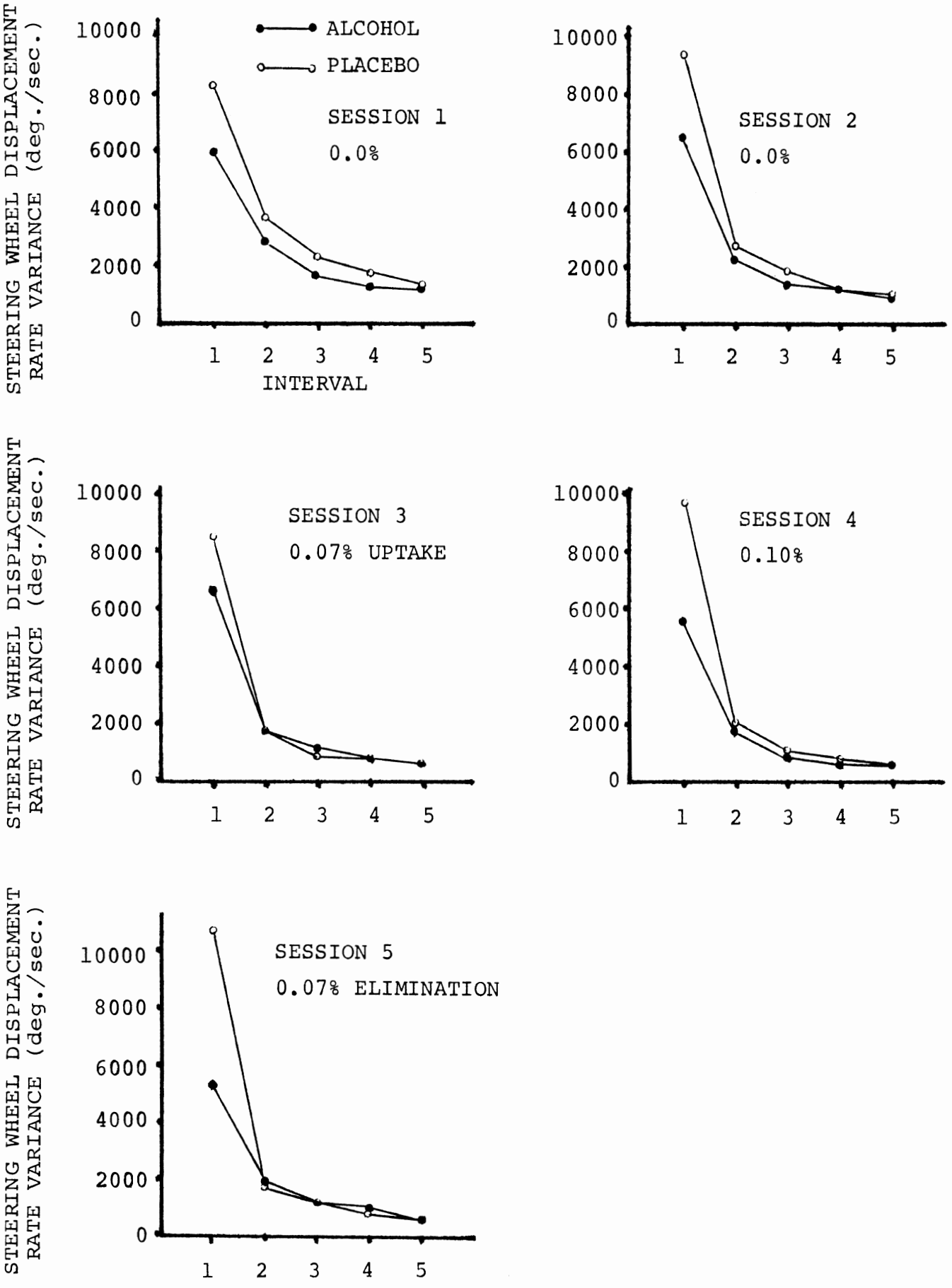


Figure 27. Mean variance of steering rate in the five two-second intervals after the step disturbance.

Figure 28 shows an example of the steering wheel displacement power spectra of a subject in the placebo group and in the alcohol group in test sessions 2 and 4. Session 2 indicates the performance on the last practice series of trials on the first day, and session 4 shows performance on the second day under 0.10% mean BAC for the subject in the alcohol group and the equivalent trial, without alcohol, for the placebo subject. It will be noted that the steering wheel displacement spectral density of the placebo group subject peaked at about the same value (i.e., 0.3 Hz) in both sessions, and that the bandwidths in both trials are about the same. Also, the curves show that the RMS of steering wheel displacement (the square root of the area under the curve), was less in session 4 than session 2, showing a reduction in steering wheel activity attributable to practice between sessions 2 and 4.

The subject in the alcohol group used a peak steering wheel frequency of about 0.28 Hz in practice session 2. In session 4, subject F carried out the same task at 0.10% BAC, resulting in a reduction of the peak steering wheel frequency to about 0.20 Hz, as well as a reduction in the steering wheel frequency bandwidth compared to session 2.

There was also a change in the RMS of the steering wheel displacement, with an increase in steering wheel displacement used by the subject under alcohol.

This example shows that the behavior of the placebo and alcohol subjects was changed by alcohol, which reduced the steering wheel response peak frequency and the frequency bandwidth, while increasing the total extent of steering wheel movement relative to performance without alcohol.

Figures 29, 30 and 31 show similar comparisons, for these two subjects, for the lateral position error, heading angle and

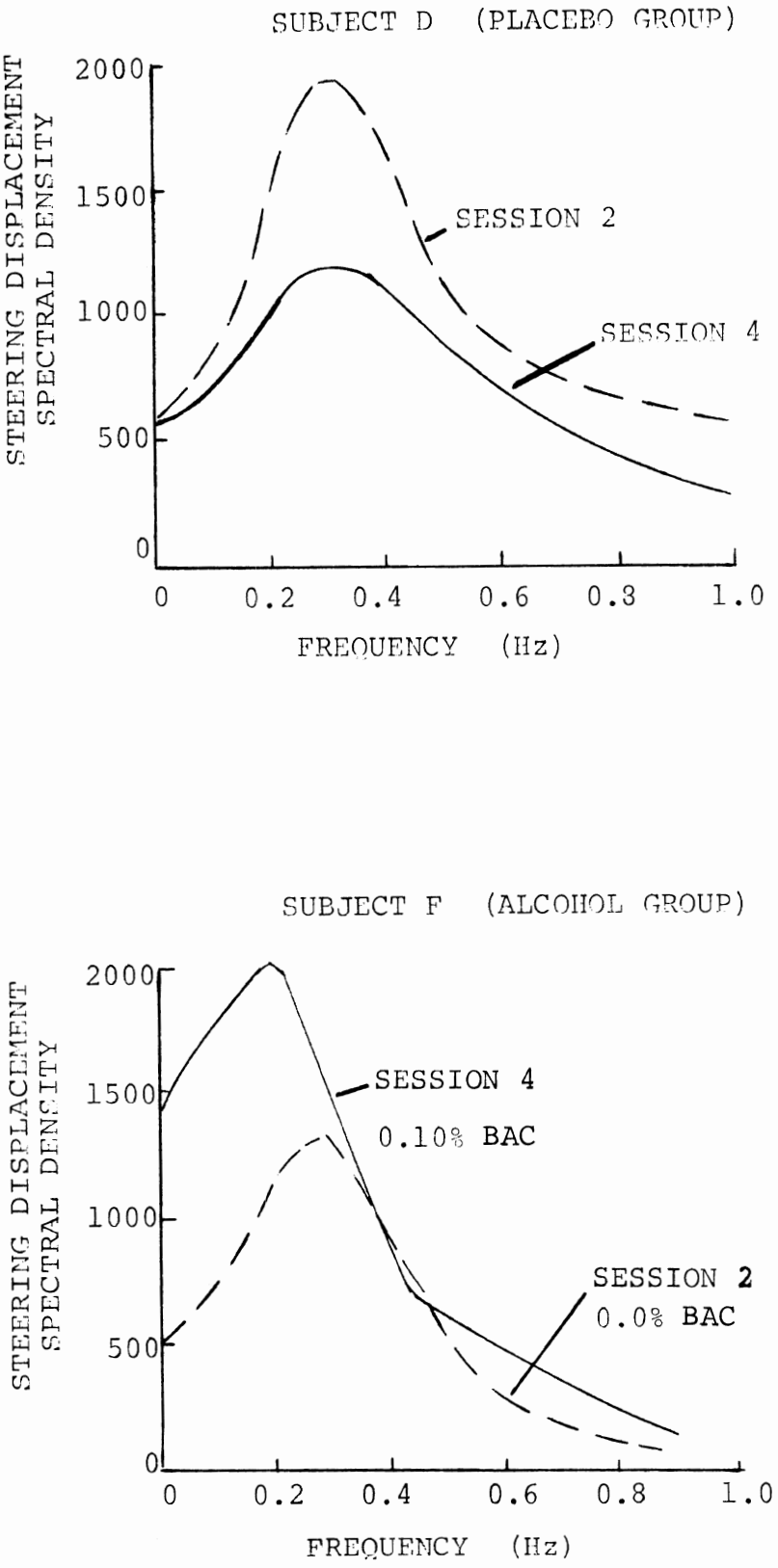


Figure 28. Steering wheel displacement power spectra of a placebo and alcohol group subject in sessions 2 and 4.

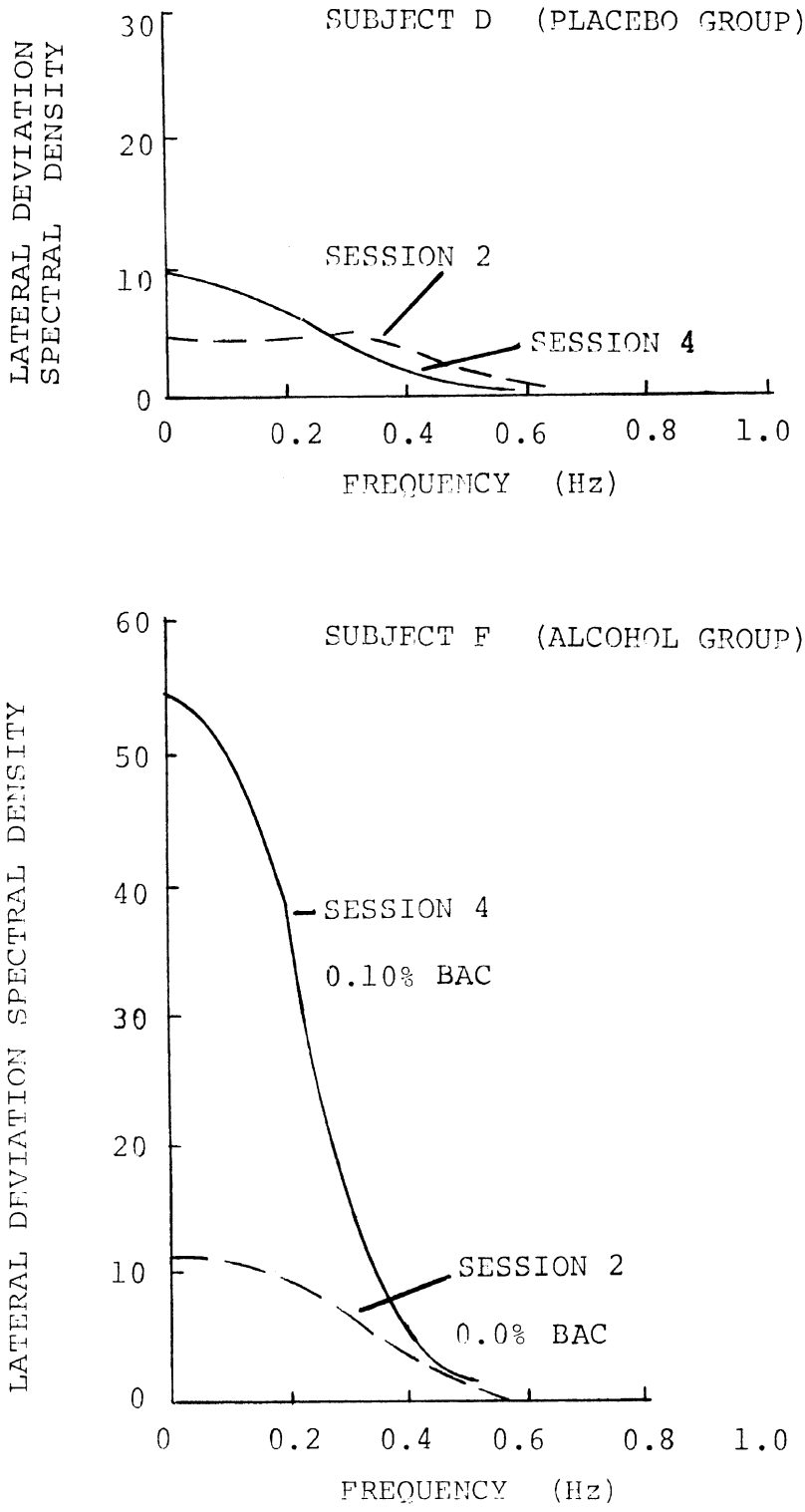
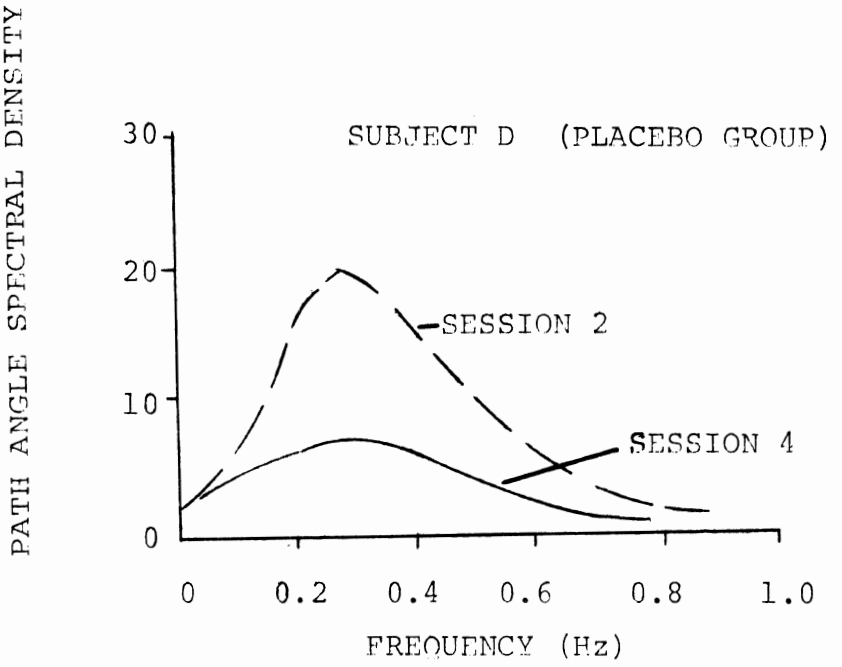


Figure 29. Lateral position error power spectra of a placebo and alcohol group subject in sessions 2 and 4.



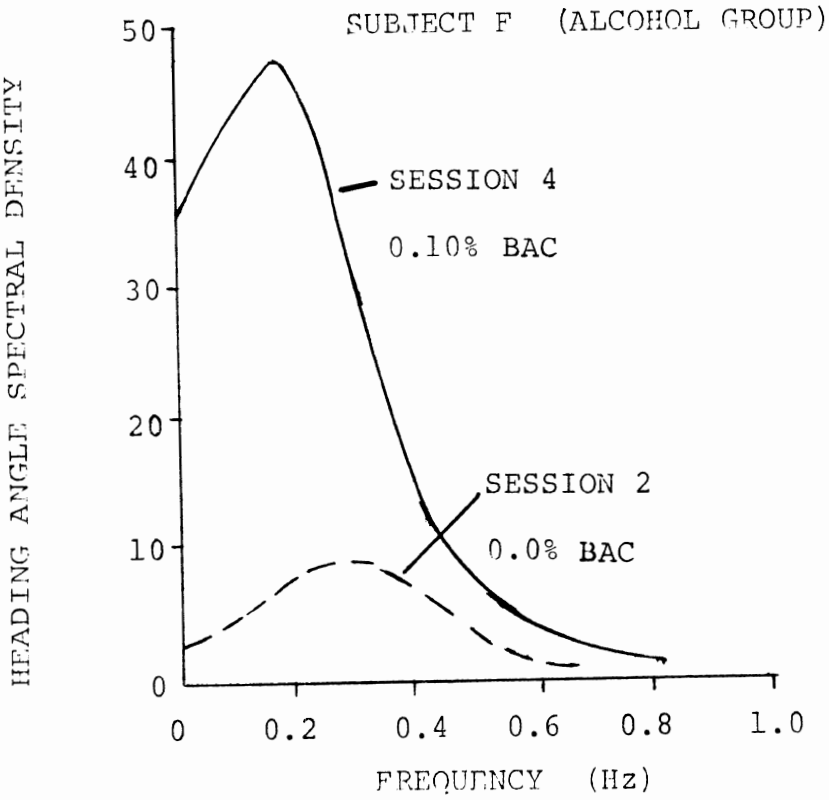


Figure 30. Heading angle power spectra of a placebo and alcohol group subject in sessions 2 and 4.

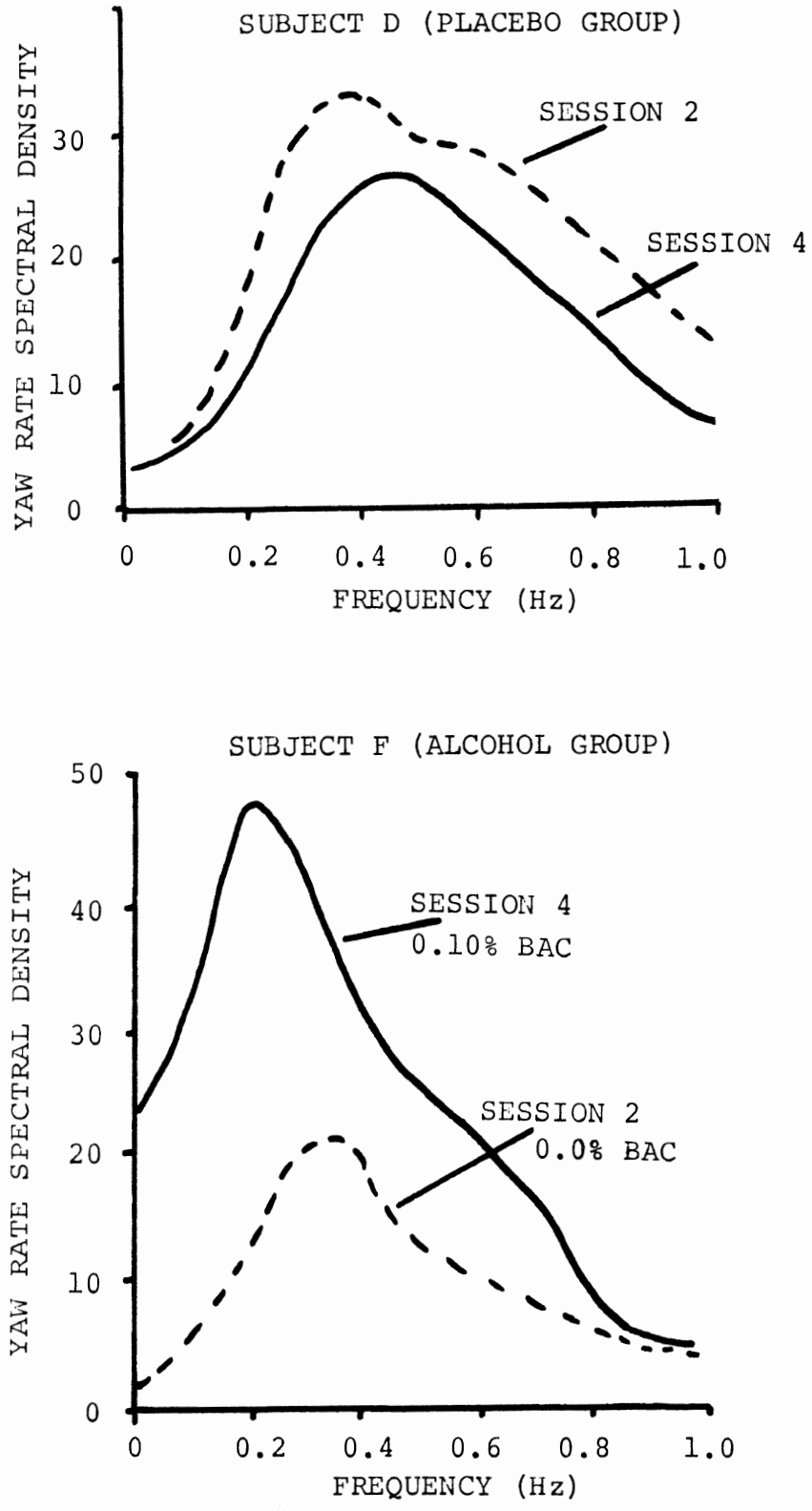


Figure 31. Yaw rate power spectra of a placebo and alcohol group subject in sessions 2 and 4.

yaw rate power spectra, respectively. In general, the dominant frequency and bandwidth of the subject in the placebo group is not changed between sessions, but there is a reduction in the RMS values, indicating a reduction in steering wheel displacement, lateral position error, heading angle and yaw rate deviations, showing that performance in vehicle control improved as a function of practice between sessions 2 and 4. The alcohol group subject performed similarly to the placebo subject in the practice session 2, but showed a reduction in the dominant frequency and bandwidth of all signals under alcohol. This was accompanied by an increase in the RMS in all signals, showing that although the subject increased the amplitude of steering corrections, there was a decrement in vehicle control performance.

These examples are for two specific subjects, one belonging to the control group and the other to the alcohol group. It is to be expected, of course, that there are individual differences in the responses of subjects under alcohol.

Analyses of this type were made for the data of the other subjects.

FREQUENCY BANDWIDTH. The frequency bandwidth was computed as the bandwidth of a hypothetical rectangular filter which would pass a signal with the same mean square value as the actual filter, when the input is white noise.

The means of the frequency bandwidths of the signals for 8 placebo and alcohol group subjects are shown in Figure 32, over the five test sessions. Analyses of variance of the values of the frequency bandwidths showed that there were significant Treatment Group x Session interactions for steering wheel displacement, heading angle and yaw rate. Individual comparisons of means, by Tukey (b) tests, between treatment groups, within sessions, showed:

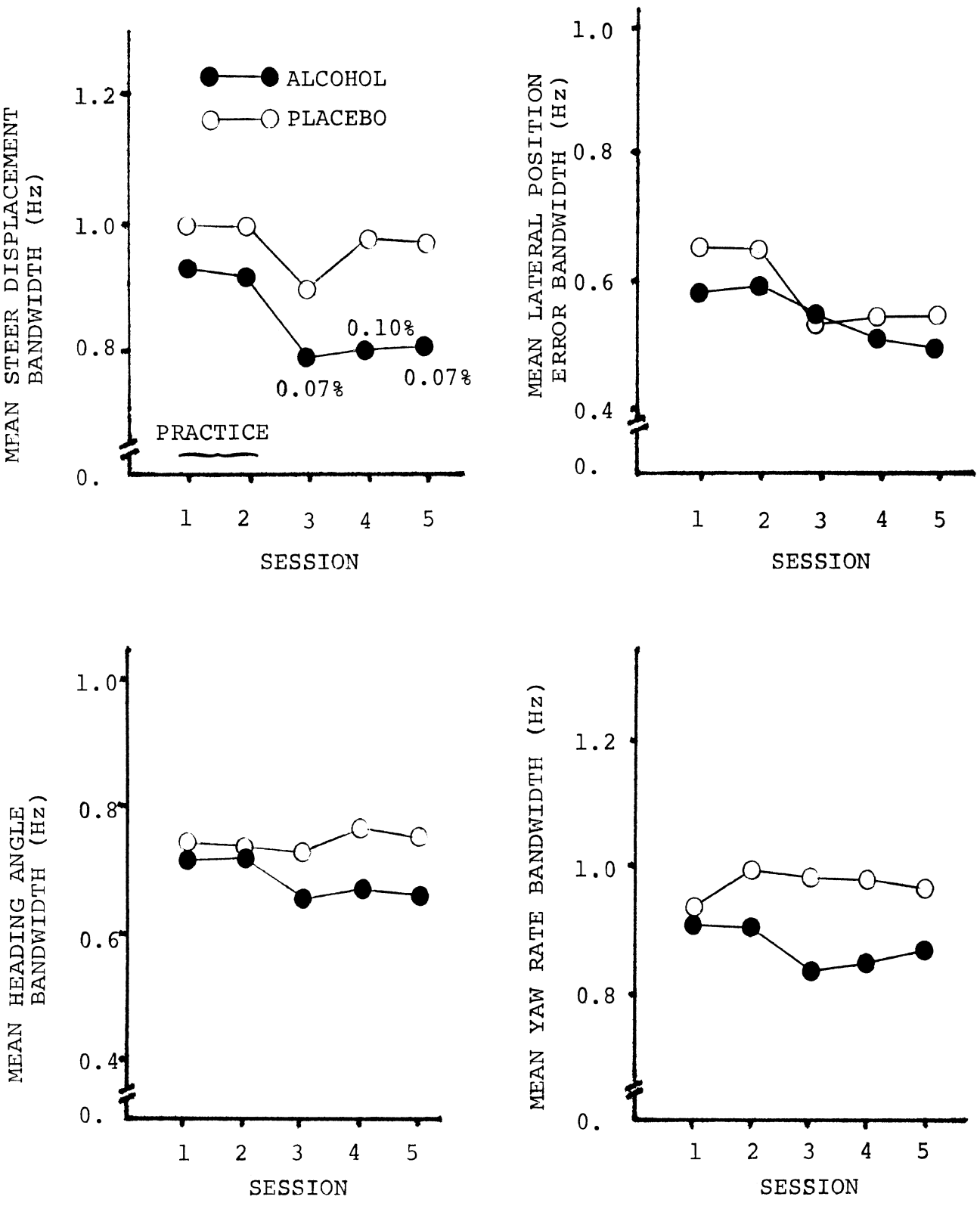


Figure 32. Mean frequency bandwidths of performance measures in each session for placebo and alcohol group subjects.

(1) Mean steering wheel displacement frequency bandwidth was reduced at 0.10% BAC and at 0.07% BAC in the elimination phase.

(2) The mean heading angle frequency bandwidth was reduced at all alcohol dose levels.

(3) The mean yaw frequency bandwidth was reduced at all alcohol dose levels.

The means of the RMS values of the performance measures are shown in Figure 33. Analyses of variance of the RMS values were made. Individual comparisons among means of these signals showed that:

(1) Mean lateral position error RMS was increased at 0.10% BAC and at 0.07% BAC during alcohol elimination.

(2) Mean heading angle RMS was increased at 0.10% BAC and at 0.07% during alcohol elimination.

SUMMARY OF RESULTS OF DRIVING SIMULATOR STUDY OF STEERING PERFORMANCE

1. CONTINUOUS DISTURBANCE ANALYSES

(a) High level disturbance: mean and variance of lateral position error significantly greater at 0.10% BAC than 0.0% BAC.

(b) Low level disturbance: variance of lateral position error significantly greater at 0.10% BAC and 0.07% BAC in the elimination phase, than 0.0% BAC.

(c) Heading angle means and variances were not significantly affected by the alcohol conditions, in high or low level disturbances.

(d) Yaw rate means and variances were not significantly affected by the alcohol condition, in high or low level disturbances.

(e) Steering-wheel displacement mean was significantly greater at 0.07% BAC in the alcohol elimination phase than

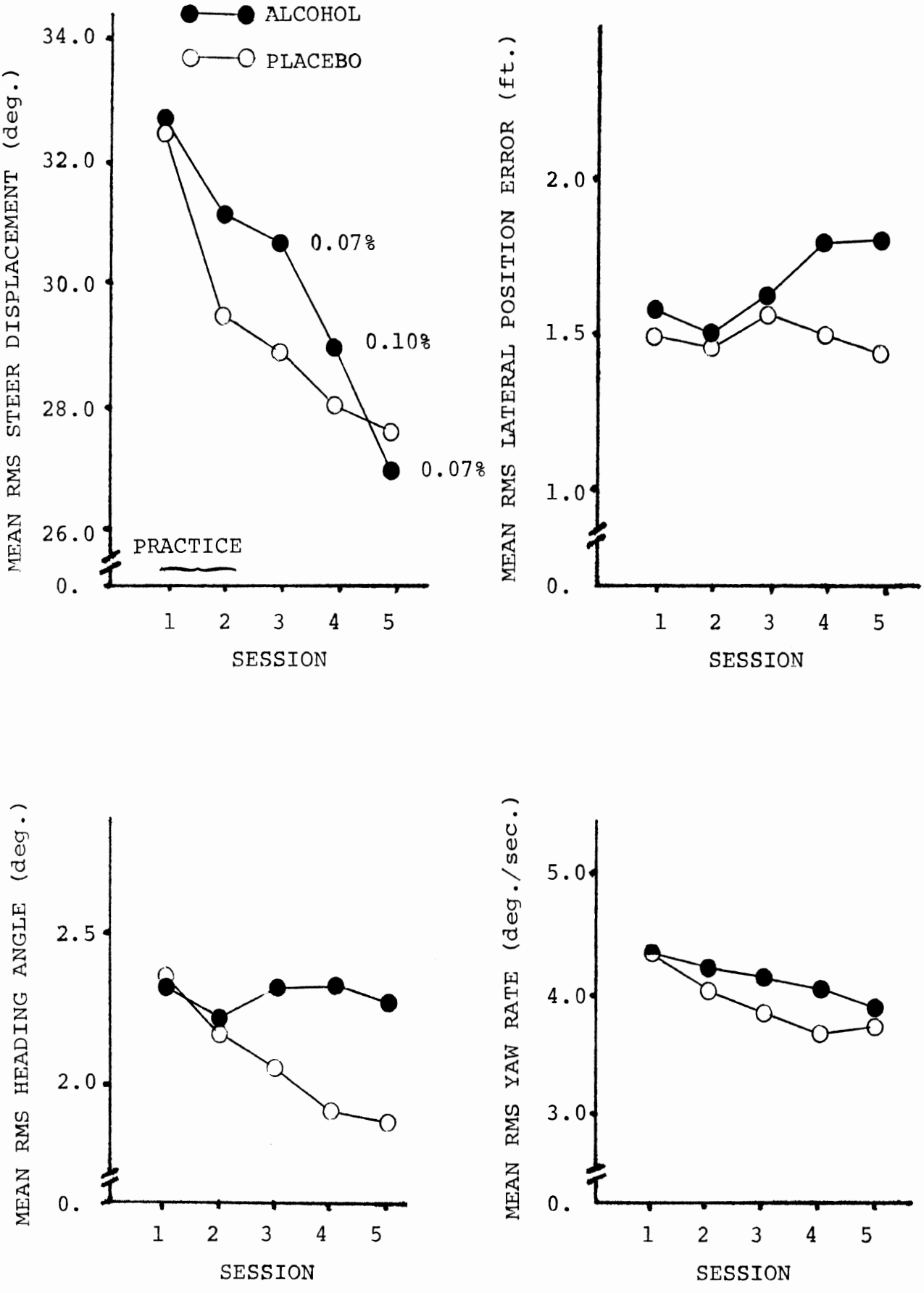


Figure 33. Mean RMS of performance measures in each session for placebo and alcohol group subjects.

at 0.0% BAC, in the low level disturbance condition. There were no other significant alcohol effects on means or variances of steering displacement in the high and low disturbance conditions.

(f) Steering-wheel displacement rate means and variances were not significantly affected by the alcohol treatments in either high or low disturbance conditions.

2. STEP INPUT DISTURBANCE ANALYSES

(a) Mean decision time to detect the direction of a step input disturbance was significantly greater at 0.07% BAC in the alcohol uptake and elimination phases than at 0.0% BAC.

(b) Mean total time (decision and steering response time) to step disturbances was significantly greater at 0.07% uptake, 0.10% and 0.07% elimination, than at 0.0% BAC.

(c) Lateral position mean error during 10 seconds after a step disturbance was significantly greater at 0.10% BAC and 0.07% BAC in elimination than at 0.0% BAC.

(d) Lateral position mean variance during 10 seconds after a step disturbance was significantly greater during the first two seconds at BAC's of 0.07% uptake, 0.10% and 0.07% elimination, and during 2-4 seconds at a BAC of 0.07% elimination, than at 0.0% BAC.

(e) Heading angle mean error was significantly greater following onset of a step disturbance during the first two seconds at BAC's of 0.07% uptake, 0.10% and 0.07% elimination, during 2-4 seconds at BAC's of 0.10% and 0.07% elimination, and during 4-6 seconds at BAC of 0.07% elimination, than at 0.0% BAC.

(f) Heading angle variance was significantly greater following onset of a step disturbance during the first two seconds at 0.07% uptake, 0.10% and 0.07% elimination; and

during 2-4 seconds at BAC of 0.07% elimination, than at 0.0% BAC.

(g) The yaw rate means or variances were unaffected by the alcohol treatment during settling time following step disturbances.

(h) The steering-wheel displacement means or variances were unaffected by the alcohol treatments during settling time following step disturbances.

(i) There were minor effects on steering-wheel displacement rate means and variances attributable to the alcohol treatments, with lower values of means and variances of rates during the first two seconds after the onset of a step disturbance found in some conditions where alcohol had been administered.

3. SPECTRAL ANALYSES

(a) Mean frequency bandwidths, in responding to the continuous, high-level disturbance were reduced for:

(1) steering-wheel displacement at 0.10% BAC and 0.07% BAC elimination,
(2) heading angle at all alcohol doses, and
(3) yaw rate at all alcohol doses.

(b) Mean RMS values, in responding to the continuous, high-level disturbance were increased for:

(1) lateral position error at 0.10% BAC and 0.07% BAC elimination, and
(2) heading angle at 0.10% BAC and 0.07% BAC elimination.

DRIVING SIMULATOR STUDY OF CAR-FOLLOWING PERFORMANCE

OBJECTIVES

The objectives of this study were to obtain some initial information on the effects of moderate doses of alcohol on car-following behavior in a driving simulator. While car-following is a task which is carried out frequently by drivers due to the density of traffic found in most parts of the country, there appear to have been no studies reported on the effects of alcohol on this demanding, though common task.

METHOD

SUBJECTS

Six drivers were used in this test, 2 females and 4 males. They were aged 21-30 years.

APPARATUS

The HSRI car-following simulator was used in these tests. The simulation is in 1/12 scale. The driver sits at one end of a moving belt which is delineated to simulate a two-lane, straight road and obtains a view of 600 feet of roadway in front of him. The subject is positioned in an automobile seat and has conventional accelerator and brake controls, and holds a box containing push-button switches. A speedometer is visible to him, as he looks through the windshield, positioned slightly to the right of the view directly ahead. In addition, there are two lamps mounted at an angle of 25° to the right and left of the straight ahead position, on either side of the belt. These lamps provide the side-task, in which one or the other of the lamps is lighted for a period of 4 seconds, in a

random order. The subject responds to the side-task signals by depressing the left or right push-button switch with the thumb of the left or right hand, as he holds the switch box. When the subject depresses the accelerator, the roadway belt begins to move towards him, thereby simulating movement of his vehicle over the road. He controls the speed of his vehicle by actuation of the accelerator to increase speed, or to coast down, or by application of the brake to achieve greater decelerations. The response of the roadway belt to accelerator and brake inputs properly simulates the dynamic characteristics of an automobile.

Riding on the roadway belt is another vehicle, whose speed is controlled by a separate servo system. This vehicle has the capability of showing rear lamps lighted, such as tail lamps in night driving, as well as showing stop signals when the lead vehicle begins braking. The subject rests his left foot on a switch and responds to the occurrence of stop signals by depressing the switch as soon as possible, so that response times to stop signals can be measured. The speed of the lead car and the occurrence of stop signals is derived from a magnetic tape, which was produced by recording the speed-time history of an actual vehicle driven on the road. Six such speed-time history profiles were generated for use in this test in the simulator.

The view obtained by the subject of the roadway and the lead vehicle is shown in Figure 34. The operation of the simulator is described in further detail in a separate report (Campbell and Mortimer, 1972), which also shows the results of previous validation studies which show close correspondence in car-following tests made in the simulator and on the road.

EXPERIMENTAL DESIGN

Each subject acted as his own control in a complete factorial experiment.

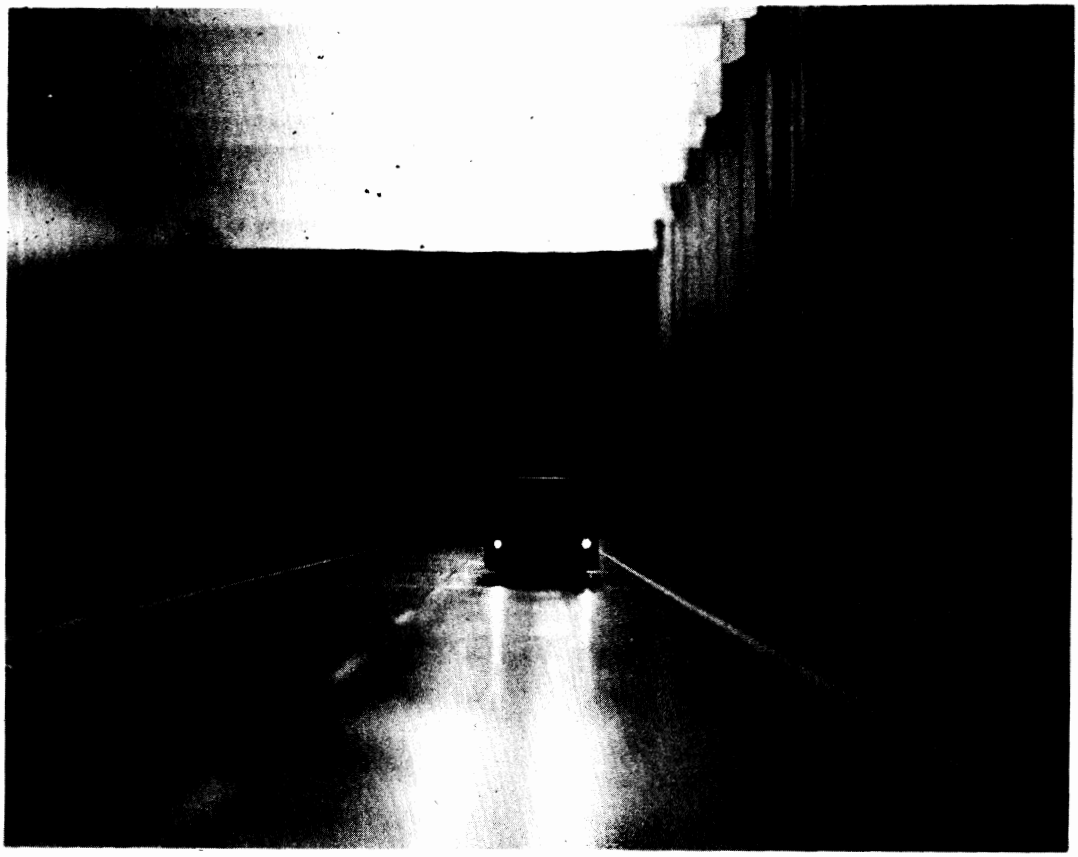


Figure 34. Driver's view in the car-following simulator.

The independent variables were:

1) Side-task, with and without the side-task.

2) Alcohol treatment, 0.0%, 0.05%, 0.10% blood alcohol concentrations (BAC).

There were therefore 6 combinations of treatment conditions in the factorial design. Each subject served on 4 days, with one day intervening between each session. The first day was devoted to practice in the car-following simulator, with-and without-the side-task being used. About 30 minutes was spent in car-following without the side-task and the same time with the side-task to which the subject had to respond, as well as carrying out the car-following task and the detection of stop signals. Data were collected on days 2-4. On each of these days the subject made 2 test runs, each lasting about 10 minutes. There were 6 combinations of ordering of the test conditions, and each subject received one of these orders. The constraint on this ordering scheme was that on each day the subject performed at one of the alcohol dose treatment levels, but carried out the task on one trial with the side-task and on the other trial without the side-task. Each subject carried out the task with the lead car input being each of one of six lead car speed-time history tapes.

PROCEDURE

The subjects were initially given some practice on the first day in the car-following task. On each succeeding day the subjects received a beverage containing a carbonated low-calorie soft drink and 200° alcohol as already described for the previous experiment. Subjects receiving a placebo dose had a drink which contained a small amount of alcohol floated on top to simulate the alcohol flavor. Subjects were allowed 15 minutes in which to consume the drink, after which another 45 minutes elapsed before testing began.

On each trial the lead car was initially positioned at a simulated distance of 150 feet ahead of the subject's vehicle. The subjects were instructed to try to maintain a constant headway of this distance throughout the test. However, they were not given any further feedback concerning the actual headway which they maintained at any time. They were also told that the hierarchy of importance they should attach to the three tasks which they had to carry out was: 1) responding to the side-task signals, 2) maintaining a constant headway of 150 feet, and 3) responding to stop signals by depressing the foot switch as soon as possible.

Each simulation was carried out with the overhead lights in the simulator extinguished, to simulate a night driving condition. The roadway belt was illuminated in front of the subject's vehicle to simulate the effect of headlamps providing illumination of the road.

The dependent variables used in the test consisted of the following:

1) Response time to side-task signals.

2) Analog data samples, taken 30 times/second of the instantaneous headway, following (subjects') car velocity, relative velocity, following-car acceleration and relative acceleration.

3) Response time in milliseconds, to stop signals given on the lead vehicle.

Each of these signals was acquired by a PDP 11/45 digital computer and stored on magnetic tape for subsequent statistical analyses.

RESULTS

RESPONSE TIME TO SIGNALS OF THE SIDE-TASK

The times required to respond to each onset of a signal given by the side-task lamps formed the data submitted to an

analysis of variance, to evaluate the effect of the 3 levels of the alcohol treatment. The mean response times are shown in Table 4 for each level of the alcohol treatment. There were no significant differences between these means.

CAR-FOLLOWING TASK

The variables that were used to measure car-following performance consisted of means and standard deviations during the various trials, of the velocity and acceleration of the lead- and following-vehicles, and the instantaneous difference between these values (i.e., relative velocity). Each variable was subjected to an analysis of variance with factors of side-task presence (with and without the side-task), treatment conditions (placebo, 0.05% BAC, and 0.10% BAC), and subjects. Spectral analyses of these data were also carried out.

Table 4 shows the significant effects found. Mean standard deviations of the acceleration of the following car and the relative acceleration were significantly greater when the side-task was not used. In addition, the mean standard deviation of relative acceleration was significantly greater when the BAC of subjects was at 0.10% than at 0.05% or without alcohol.

It would have been expected that the following car acceleration standard deviation would be less without the side-task than with the side-task, because the driver's sensitivity to changes in lead vehicle speed would be expected to be greater when the side-task is not present. That the standard deviation of relative acceleration was greater at 0.10% BAC is rational, and indicates that the drivers were compensating for the lag, caused by alcohol, in the perception of increasing or decreasing speed of the lead vehicle. This resulted in increased use of acceleration or deceleration of the vehicle they were controlling, in order to maintain a constant headway distance.

Table 4. Summary of Means of Significant[1] Effects Found in the Car-Following Simulator Tests.

SIDE-TASK	BAC 0.0%	0.05%	0.10%
Geometric Mean Response Time to Signals of Side-Task(sec)(not sig.)	.75	.75	.78

CAR-FOLLOWING	SIDE-TASK WITH	WITHOUT
Mean Standard Deviation of Following Car Acceleration (ft/sec)	2.61	2.79
Mean Standard Deviation of Relative Acceleration (ft/sec)	2.99	3.15

	BAC 0.0%	0.05%	0.10%
Mean Standard Deviation of Relative Acceleration (ft/sec)	2.79	2.92	3.38*
Mean Relative Velocity Bandwidth (Hz)	.097	.119	.115

RESPONSE TO STOP SIGNALS			
Mean Response Time (sec)	.77	.71	.85

* Means underlined differ significantly from those not underlined but not from those underscored with a dashed line.

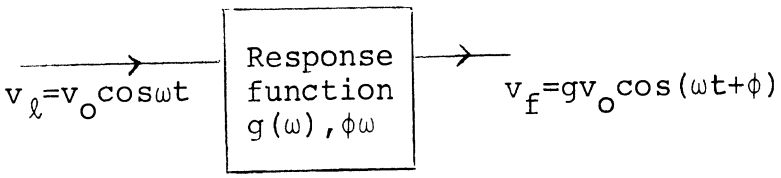
[1] ($p < 0.05$)

The power spectra of relative velocity showed that the mean bandwidth for the subjects carrying out the car-following task without alcohol (0.0%) was significantly less than at BAC's of 0.05% and 0.10%. The increased relative velocity bandwidth in the presence of alcohol can be attributed to the following car driver occassionally applying step inputs of acceleration or deceleration to compensate for an interval of inattentiveness (open-loop driving) or reductions in sensitivity to headway and relative velocity cues. The sudden step inputs contain the higher frequency components of relative velocity.

PEAK HEADWAY ERROR RESPONSE FUNCTION. A measure was derived of peak headway error incurred by the driver of the following vehicle in responding to sinusoidal changes in lead car velocity at discrete frequencies within the range of frequencies encountered in this study.

The Headway error at time t, ΔH_t, in terms of the lead and following car velocity profiles, is given by

$$1)\quad \Delta H_t = \int_0^t v_\ell(\tau)d\tau - \int_0^t v_f(\tau)d\tau$$



If the input, lead car velocity is a co-sinusoid of frequency ω,

$$2)\quad v_\ell = v_o \cos\omega t,$$

and the system frequency amplitude and phase response functions

are $g(\omega)$ and $\phi(\omega)$, respectively, then the output, following car velocity, v_f, is:

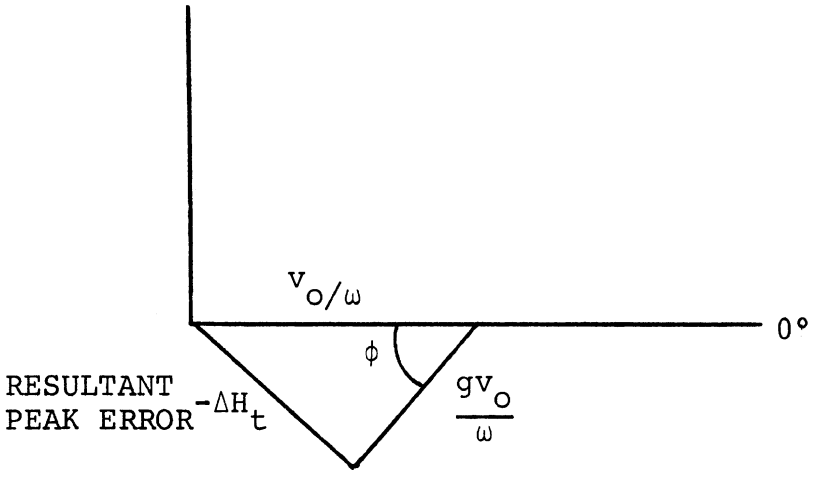
3) $v_f = g v_o \cos(\omega t + \phi)$.

Substituting expression 2) and 3) for lead- and following-car velocities into equation 1) results in:

$$\Delta H_t = v_o \int \cos\omega\tau d\tau - g v_o \int \cos(\omega\tau + \phi) d\tau$$

$$\Delta H_t = v_o \frac{\sin \omega\tau}{\omega} - \frac{g v_o}{\omega} \sin(\omega t + \phi)$$

Since both sinusoids in expression 4) are varying at the same frequency, ω , the resultant response can be expressed as a simple sinusoid at frequency ω whose amplitude and phase can be determined from the individual amplitudes and phases from a phasor diagram, as shown below.



The peak amplitude of the resultant sinusoid is given by:

$$|\Delta H_t| = v_o \sqrt{1 + g^2 - 2g \cos\phi}$$

where g is the amplitude response, and
ϕ is the phase response

The normalized peak amplitude obtained in this way describes the maximum headway error in feet occurring within one cycle of the lead car velocity oscillation of unit amplitude (1 ft/sec) at the given frequency.

Figures 35-40 show the relationship between peak headway error per unit of lead car velocity as a function of lead car velocity frequency, for each subject in the 0% and 0.10% BAC conditions, with the side-task.

Since these curves are for individual subjects it would be expected that they exhibit variability. However, it is reasonably apparent that there are no differences due to alcohol at lead car velocity frequencies of less than about 0.06 Hz. At higher frequencies a divergence in the curves can be noted, indicating greater error in the headway when car-following with 0.10% BAC than without alcohol.

This behavior may be attributable to the drivers' response to low frequencies of lead car velocity being inappropriate when he is operating without alcohol. If it is assumed, that without alcohol, the driver is more sensitive to changes in lead vehicle behavior, then these data suggest that his responses increase the resultant error at low frequencies, whereas under alcohol the driver tends not to respond, which is a more appropriate form of behavior to low frequency inputs.

On the other hand, at the higher lead car velocity frequencies, the driver under alcohol continues to lag in his responses due to reduced ability to perceive changes in lead car velocities or in the headway between the vehicles, and because his response behavior may not be as accurate as without alcohol, once the error has been perceived. The driver who is operating without alcohol responds earlier because of his ability to detect smaller changes in relative velocity

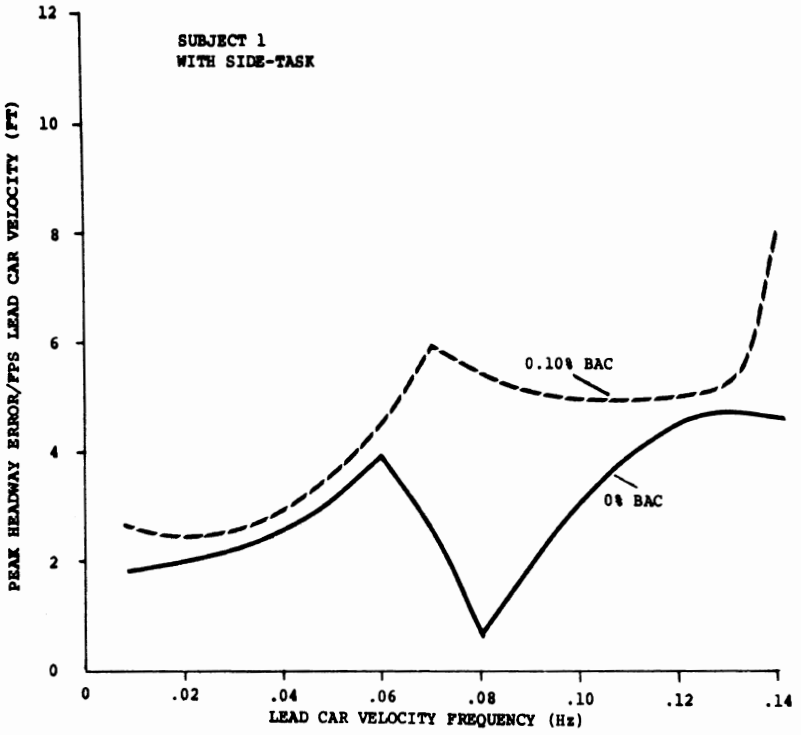


Figure 35. Estimated peak headway error at 0.0% and 0.10% BAC for subject 1.

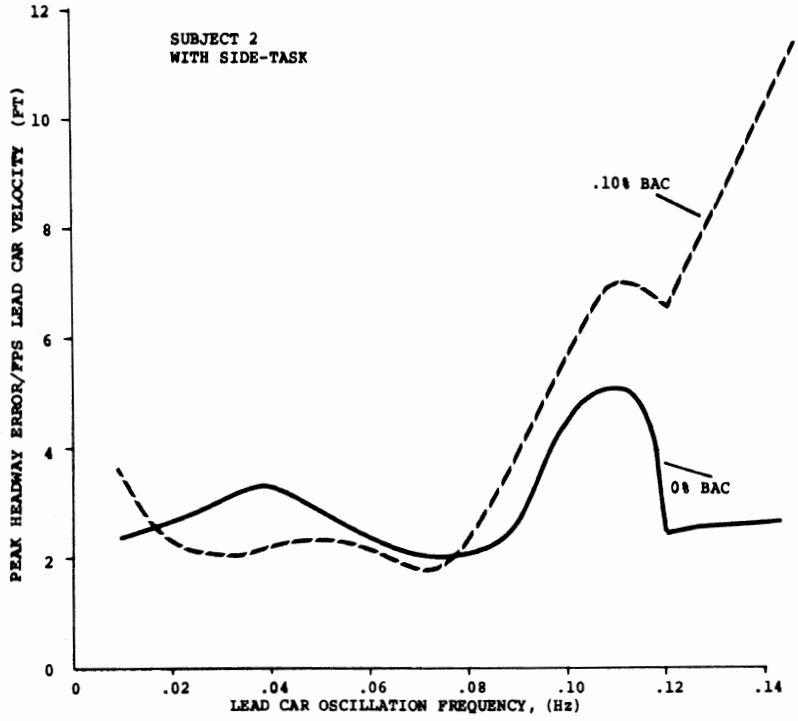


Figure 36. Estimated peak headway error at 0.0% and 0.10% BAC for subject 2.

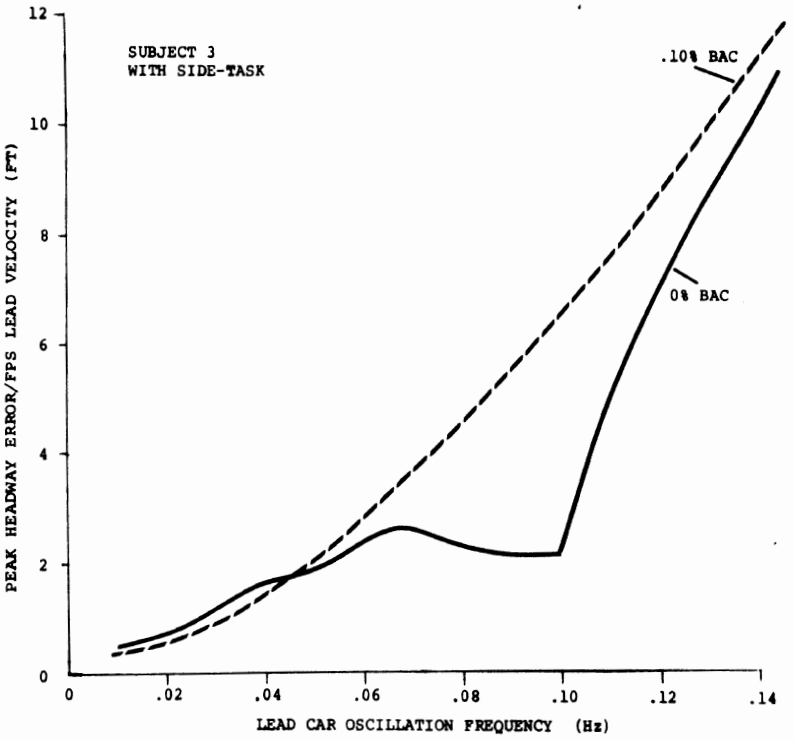


Figure 37. Estimated peak headway error at 0.0% and 0.10% BAC for subject 3.

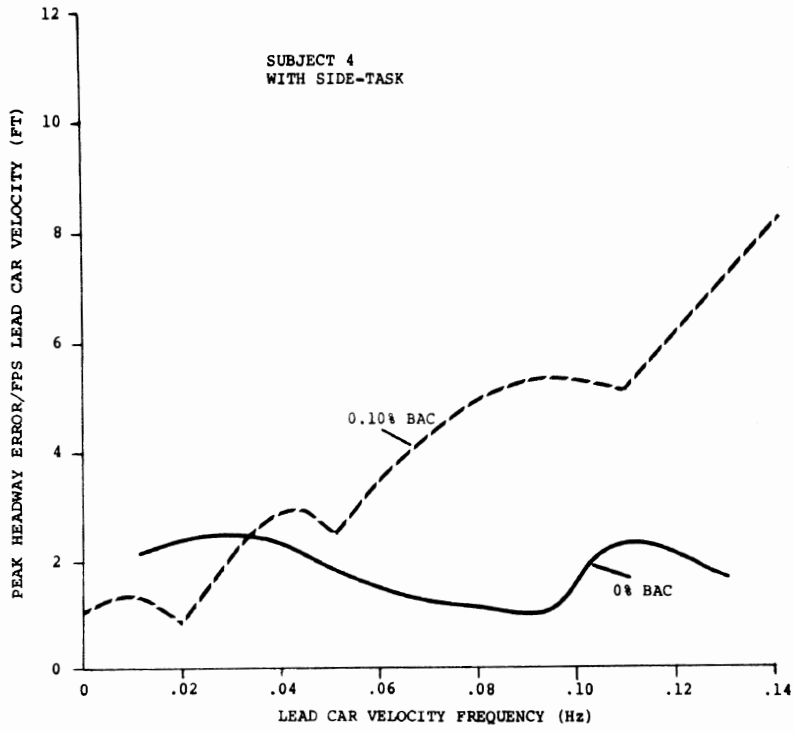


Figure 38. Estimated peak headway error at 0.0% and 0.10% BAC for subject 4.

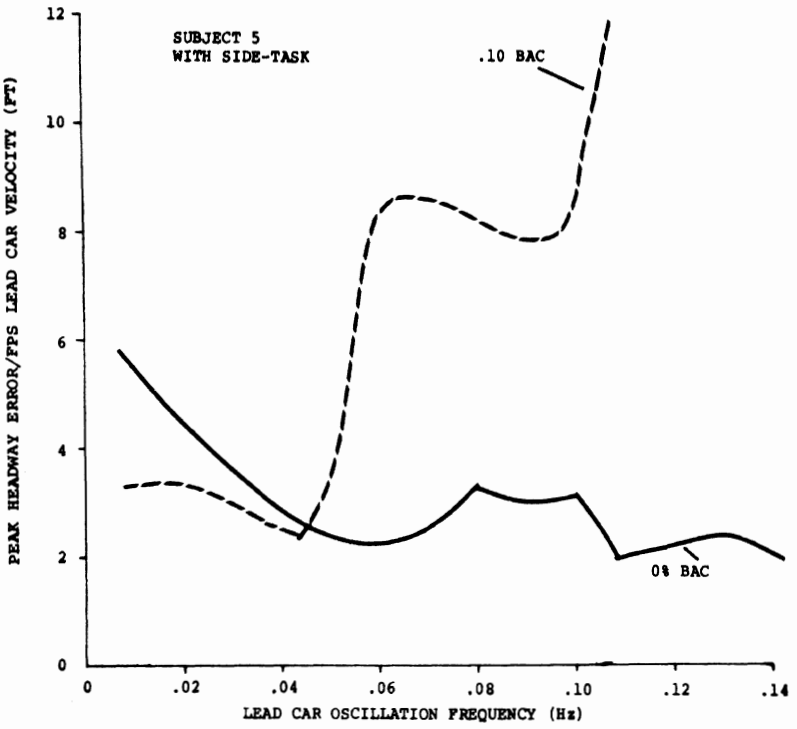


Figure 39. Estimated peak headway error at 0.0% and 0.10% BAC for subject 5.

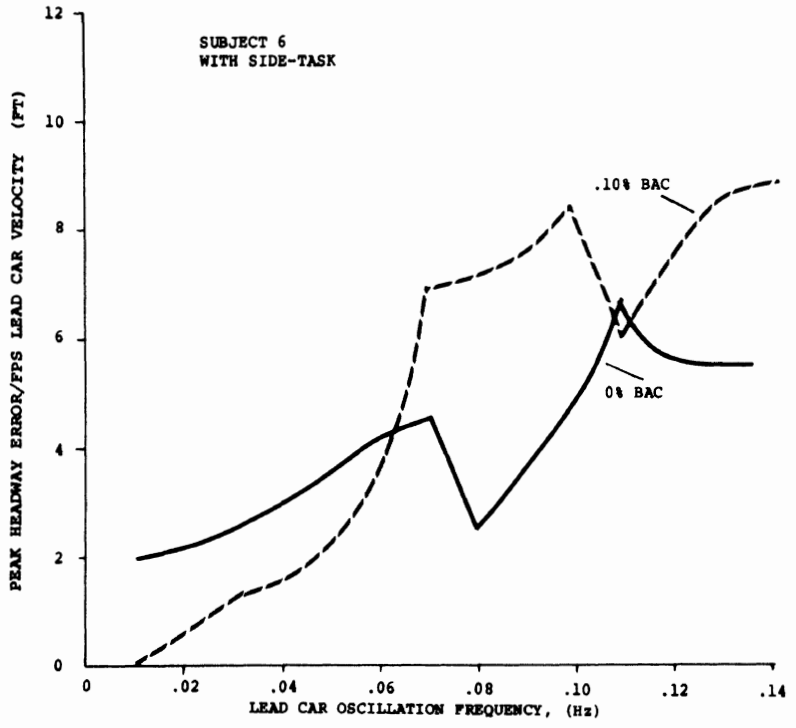


Figure 40. Estimated peak headway error at 0.0% and 0.10% BAC for subject 6.

and headway and because the control modulation which he inserts is more appropriately matched to the extent of the error perceived.

Thus, the analysis indicated that alcohol did not degrade performance when drivers were responding to low frequency lead vehicle velocity inputs, but that the impairment of alcohol was noted at the higher frequencies, above about 0.06% Hz.

RESPONSE TIME TO STOP SIGNALS

The responses of the subjects to stop signals given by the lead vehicle were recorded and subjected to an analysis of variance with fixed factors of alcohol treatments and the side-task. A significant alcohol treatment main effect was obtained.

The mean response times to stop signals at each level of the alcohol dose condition, is shown in Table 4. Individual comparisons between these means indicated that the mean response time at 0.10% BAC was significantly greater than that at 0.05% ($p < .05\%$), but not from that at 0.0% BAC.

The main effect of the side-task was not significant, although mean response times to stop signals were greater with the side-task (0.82 sec) than without the side-task (0.73 sec).

SUMMARY OF RESULTS OF DRIVING SIMULATOR CAR-FOLLOWING TEST

1. Response Time to Signals of the Side-Task.
   No significant differences were found due to alcohol.

2. Car-Following.
   (a) Mean standard deviation of following-car acceleration was significantly greater with-than without- the side-task.
   (b) Mean standard deviation of relative acceleration was significantly greater with the side-task than without; and at 0.10% BAC than at 0.0% or 0.05%.
   (c) Mean relative velocity bandwidths were significantly greater at 0.10% and 0.05% than 0.0% BAC.
   (d) Peak Headway Error per unit of lead-car velocity change was greater at 0.10% than 0.0% BAC at lead-car velocity frequencies above 0.06 Hz, with no effects of alcohol at lower frequencies. (The effect of 0.05% BAC was not evaluated on this criterion).

3. Response Time to Stop Signals.
   Mean RT's to stop signals were significantly greater at 0.10% than 0.05% BAC, but not at 0.0% BAC.

CAR DRIVING STUDY

OBJECTIVES

The purpose of this study was to investigate the effect of moderate doses of alcohol on a number of driving-related skills, consisting of lateral (steering) and longitudinal (speed) control, car-following and passing decisions.

METHOD

SUBJECTS

A total of 40 drivers participated in the study. Eleven subjects were randomly assigned to the placebo and alcohol groups for testing in daytime, while nine subjects were assigned to each group for the night tests. The median age of the subjects was 30 years, and the range 19 to 56 years. There were 17 females and 23 males.

TABLE 5. DISTRIBUTIONS OF AGE, SEX, DRIVING EXPERIENCE, AND MORTIMER-FILKINS TEST SCORES BY SUBJECT GROUP IN THE CAR DRIVING TEST.

GROUP	AGE (YEARS)		NUMBER OF EACH SEX		DRIVING EXPERIENCE (YEARS)		MORTIMER-FILKINS SCORE[1]	
	$\bar{X}$	S.D.	M	F	$\bar{X}$	S.D.	$\bar{X}$	S.D.
PLACEBO	29.4	10.0	11	9	12.9	9.6	45.7	27.9
ALCOHOL	30.6	8.6	12	8	14.5	9.9	38.3	24.6

Table 5 shows the age, sex, driving experience, and Mortimer-Filkins test scores of the subjects. Four (20%) of the

[1]Scores of 85+ are considered indicative of problem drinking; scores of 60-84 indicative of presumptive problem drinking; scores of less than 60 indicate no overt drinking problems.

subjects scored sufficiently high to be diagnosed as problem drinkers, which is more than would be expected by a random sampling of drivers.

TEST VEHICLE

A station wagon (Figure 41) equipped with dual steering, brake and throttle, was used as the test vehicle. It was equipped with a cruise control system which could be set and deactivated from an experimenter's station in the rear seat. Speed was measured with a fifth wheel for display on a meter and recording on a strip-chart recorder. The vehicle also carried a TV camera and video recorder. The camera was normally mounted on a tripod inside the car and aimed through the front or rear window of the test vehicle. In the lateral control test it was mounted on the roof, pointing downward to scan the pavement. Speed and acceleration information were recorded on a strip chart recorder.

ROADS

Tests were conducted on two roads which were parallel to one another and readily accessible one from the other. One road was a limited-access freeway, which was straight and flat over most of the seven mile test section. The other road was a two-lane highway, which had one slightly curved section. The speed limit on the two-lane road was 45 mph over most of its length, and 70 mph on the freeway.

INDEPENDENT VARIABLES

Two independent variables were investigated: (a) blood alcohol concentration (0%, and 0.085%) and, (b) ambient lighting conditions (day, night).

THE TESTS AND DEPENDENT VARIABLES

Seven different tests were conducted with each subject, and are described here.

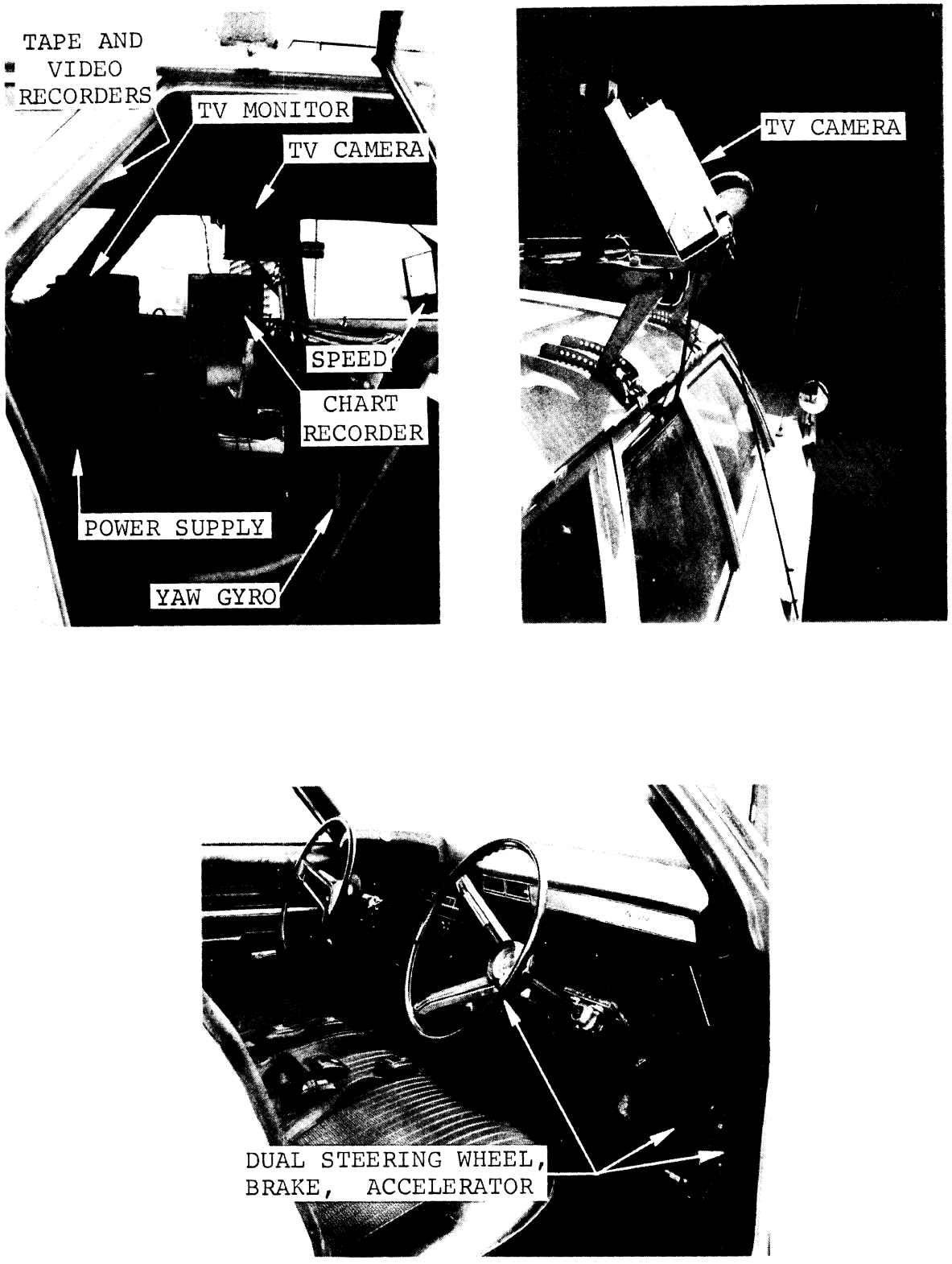


Figure 41. The test car.

A. TV camera, monitor and recording equipment in rear compartment;
B. roof-mounted TV camera to measure lateral position;
C. dual controls, in test car.

1. Passing Gap Time Judgments. This test was conducted on both the two-lane road and freeway. Subjects were asked to follow a lead car operated by an experimenter at a distance they would elect if they were preparing to pass it. The lead car was driven at a constant 40 mph on the two-lane road and at 50 mph on the freeway. The subjects observed oncoming traffic on the two-lane road, and overtaking vehicles on the freeway, in the rearview mirrors, and indicated their judgment of the last moment they felt they could safely pull out and begin a passing maneuver. They did not actually perform such a maneuver, however. Time was measured with a stopwatch from the subject's verbal response until the gap closed. In the case of overtaking traffic the gap was considered closed when the front bumper of the overtaking vehicle came even with the rear bumper of the subject's vehicle. In the case of oncoming traffic the gap was considered closed when the front bumper of the oncoming car was adjacent to the front bumper of the lead car. Each subject made about 30 such judgments.

2. Car Following with Speed of Lead Car Constant. These data were taken without the subject's knowledge at the same time as the gap time judgments. The image of the lead car was continuously recorded using the video equipment. The image size was later measured on a video screen and converted to headway distance between the cars with measures made at two-second intervals. These data were taken for about seven miles on each of the two-lane and freeway routes used in the tests, and indicated the variability in the distance which the subjects maintained between the lead vehicle and their own.

3. Car Following with Speed of Lead Car Varying. In this test the experimenter operating the lead car followed a specified

speed profile in a range from 50-65 mph, on the freeway. Accelerations were moderate (approximately 5 ft/sec^2) and decelerations were made without use of the brakes. Steady-state conditions were held for a minimum of 15 secs, or longer, if required for the subject to stabilize his position. Data were taken using the TV equipment as in Test-2. The audio channel of the TV system was used to indicate the time of onset of various maneuvers by the lead car.

4. Speed Judgments. In this test the subjects were required to judge the speed, in miles per hour, of cars which were overtaking them on a freeway. Using a cruise control, the subject drove at 50 mph. The experimenter directed the subjects to look at overtaking vehicles in the rearview mirrors, and when they were about 100 feet behind asked the subjects to judge the speed of the overtaking vehicles. A minimum of 20 such judgments were made by each subject. Actual velocities were determined by taking video recordings of the passing vehicles over known time intervals.

5. Lateral Path Error. This test measured the ability of subjects to drive a line parallel to the edge of the roadway. The data were taken surreptitiously. The subjects were led to believe that their ability to hold a specified speed was being measured. They were simply told to drive in the right hand lane and to maintain a constant speed of 55 mph as well as possible. The video recording system was used, with the video camera fixed to a roof bracket on the car (Figure 41). This afforded a lateral view of about six feet out from the side of the car. The distance from the tire track to the lane edge line was later measured to compute path error variance.

6. Speed Production. This test measured the ability of the subjects to drive at various speeds without being able to

see the speedometer. The test began from a standing start with the speedometer covered. The subject was requested to attain some designated speed (between 50 and 65 mph, in 5 mph increments) and verbally indicate when the command speed had been reached. The actual speed was read from the fifth wheel output at that time, and another command speed given to the subject. Each of the four possible speeds were replicated seven times in a random order.

7. Speed Maintenance. This test measured the ability of the subjects to hold a designated command speed for a distance of several miles. The subject accelerated the car up to 50 mph and maintained that speed for several seconds. The speedometer was then covered and the subject's task was to try to maintain 50 mph for the next seven miles. Actual speeds were recorded from the output of the fifth wheel at 15 sec intervals during this test.

PROCEDURE

The subjects were collected at their residences and delivered to the laboratory about one hour before the test was due to start. They were immediately given a drink designed to bring them to the target BAC (0.085%). The drink consisted of equal parts of 200 proof alcohol, ginger ale or a non-carbonated orange drink. Control subjects received the ginger ale or the orange drink with about a teaspoonful of alcohol. In addition, the rim of the glass was moistened with alcohol to provide appropriate taste and odor. The amount of alcohol was determined by body weight and judged body build. While the subjects consumed the drink the general instructions were read to them. When the drink had been finished, the subject, experimenter, and driver of the lead car employed in the first few tasks left for the test site. The subject drove

the experimental vehicle and was told to follow the other test vehicle. After about one mile the two cars merged onto a freeway. The lead car drove at 50 mph and the subject was instructed to follow it at a reasonable distance and, when practical, to pass the lead car to "get a feel for the acceleration performance characteristics of the test car." When he had done so and pulled back into the right lane he slowed to 50 mph and the lead car passed to set up another passing opportunity. After the second practice pass the lead car once again passed and then led the way to the test site.

The test site centered on a service station where permission had been secured to park a car and use 110 vac power to run the Breathalyzer in that car. Immediately on arrival at this site the subject was given a breath test. Additional breath tests were given at 45 minute intervals thereafter. Whenever the subject's BAC fell below 0.07% a booster dose was administered from a supply carried for that purpose. Control subjects were given booster doses also at about 90 minute intervals.

As soon as the breath test had been given the instructions for the first test were read and the test begun. Two experimenters rode with the subject at all times. One rode in the front seat on the passenger side. His primary function was safety, to be sure that the subjects maintained adequate control of the car at all times. He was prepared to take control of the car from the subject if needed. In addition, he monitored the subject's performance and assisted in coaching and correcting where necessary. The other experimenter sat in the right rear seat, administering the instructions and recording data.

Testing continued until all measures previously described were completed. This took up to four hours. The subject was then returned to the laboratory. After about one hour the

subject was paid and driven to his residence.

RESULTS

Significant differences were found in the variance in judging passing gap times on the secondary road (Task 1), in car-following performance with the lead car's speed constant (Task 2), and varying (Task 3), and in speed maintenance capability (Task 7). These findings are summarized in Table 6.

TASK 1. PASSING GAP TIMES

The analysis of variance (ANOVA) of the variances in judging passing gap times to oncoming vehicles on the secondary road showed that the variance in the day group was smaller than in the night group (7.7 vs 18.1 seconds). The differences associated with alcohol were not significant, although the mean variance of the alcohol group (14.6 sec) was greater than the placebo group (11.3 sec).

TASK 2. CAR-FOLLOWING WITH SPEED OF LEAD CAR CONSTANT

The analysis of variance of the mean headways measured on the secondary road showed that differences associated with levels of alcohol and the interaction of alcohol with the ambient lighting condition (day, night) were significant. Newman-Keuls tests showed that there were no differences due to alcohol at night, but in daytime the alcohol group maintained a greater mean headway than the placebo group (133 vs 92 feet, respectively). The mean variances in headway were significantly ($p < .01$) greater for the alcohol subjects on both the secondary road and the freeway (Table 6).

TASK 3. CAR-FOLLOWING WITH SPEED OF LEAD CAR VARYING

The analysis of means on this task for the seventeen steady-state or transitional conditions revealed many significant

TABLE 6. SUMMARY OF MEANS OF SIGNIFICANT ($p < .05$) EFFECTS FOUND IN THE DRIVING TESTS.

Passing Gap Judgment		
Variance in time (sec), on secondary road (oncoming vehicles)	DAY 7.7	NIGHT 18.1
Car-Following with Lead Car's Speed Constant	PLACEBO GROUP	ALCOHOL GROUP
Mean Headway (feet), on secondary road in the day	92	133
Variance in Headway (feet),		
on secondary road	556	995
on freeway	1112	1606
Car-Following with Lead Car's Speed Varying		
Mean Headway (feet), in six conditions	DAY 221	NIGHT 166
Variance in Headway (feet),		
in two conditions	429	129
	PLACEBO GROUP	ALCOHOL GROUP
in one condition	40	244
Speed Maintenance		
Variance in speed (mph)	5	8

effects associated with the ambient lighting condition, with greater headways maintained during the day sessions. In only one set of conditions was there a significantly greater variance in headway attributable to alcohol.

TASK 7. SPEED MAINTAENANCE

The analysis of variance of speed variance showed that differences associated with alcohol were significant ($p < .05$). The mean variance for the alcohol group was 8 mph versus 5 mph for the placebo group.

SUMMARY OF RESULTS OF CAR DRIVING STUDY

1. Passing Gap Time Judgments.
   There was a significantly greater mean variance in passing gap times to oncoming vehicles accepted at night than in the day, on the secondary road. There was no alcohol effect.

2. Car-Following with Speed of Lead Car Constant.
   On the two-lane road in daytime, drivers at 0.085% BAC maintained significantly greater mean headway than at 0.0% BAC. The variance in headways maintained on both roads was greater at 0.085% BAC than 0.0% BAC.

3. Car-Following with Speed of Lead Car Varying.
   Greater headways were maintained in the daytime, but there were no significant effects due to the alcohol treatment. In two conditions of lead car maneuvers variance in headway was significantly greater in the day than at night. And in one condition the variance in headway was significantly greater at 0.085% than 0.0% BAC.

4. Speed Judgments of Overtaking Vehicles.
   No significant effects were found.

5. Lateral Path Error.
   No significant effects were found.

6. Speed Production.
   No significant effects were found.

7. Speed Maintenance.
   The variance in the ability to hold a constant speed of drivers at 0.085% BAC was significantly greater than those at 0.0% BAC.

DISCUSSION

The results of the studies which have been carried out in this program of research have indicated that there are a number of skills which are impaired by alcohol, and that many of these are related to driving performance and, presumably thereby, to traffic safety.

SENSORY, PERCEPTUAL-MOTOR AND INFORMATION-PROCESSING SKILLS

The indication that greater illumination was needed to identify the orientation of Landolt Rings under alcohol than without alcohol, has some importance for night driving. While there have been some reports of impairments in visual acuity due to alcohol (e.g., Mortimer, 1963), the measurements were usually taken under relatively high levels of illumination, or visual adaptation.

It was also found that the color discrimination thresholds of red stimuli in the right and left lateral plane were decreased for the subjects at 0.10% BAC, compared to those without alcohol. This effect was not found for the other colors used in this experiment. Peters (1942) found a similar color field contraction in one subject who had consumed 84 ounces of beer over a three hour period. However, Peters' subject also demonstrated contractions of color fields for blue and green stimuli, a result not replicated here. Further testing should be carried out to establish these findings. Certainly, there are serious safety implications on the effect of this reduction in the lateral visual field of red stimuli. For example, many of the most important traffic signs and signals use red backgrounds or red lamps. Also, tail and stop lamps of vehicles are red. It is possible that a reduction in visual field, due to alcohol, of red stimuli reduces the likelihood that such signs and signals will be noticed or the time available for

the driver, after detecting them, to take appropriate action.

The complex reaction time test showed that there was an increase in the time required to process information due to alcohol at 0.10% BAC. Similarly, a detrimental effect of alcohol on short-term memory and simple motor skill was found in the digit-memory task, in which more errors were made at 0.10% BAC than without alcohol. Thus, alcohol appears to have an effect upon information storage and recall and on the decision time required to select a correct response in relatively simple tasks.

That alcohol has an effect upon simple perceptual-motor tasks has been found in a number of previous studies (e.g., Drew et al., 1958; Sturgis and Mortimer, 1973), and was shown here by the significant increase in tracking error time in the stylus tracking task at 0.10% BAC compared to performance without alcohol.

STEERING SKILLS

While the foregoing tasks have relevance for aspects of safe driving behavior, their specific effects on the driving task cannot be directly determined. However, the driving simulator studies of lateral control performance did show some quite specific effects of alcohol on this major aspect of the vehicle control task. Ample evidence is provided in these studies that steering performance is considerably degraded by moderate doses of alcohol, and also that there appear to be differences in the effects of alcohol during the uptake and elimination phases.

When controlling against a simulated continuous disturbance, such as might be posed by wind gusts of varying amplitudes and frequencies, generally similar findings were obtained for the high and the low level disturbances. These results indicated

that the mean lateral position error in tracking the roadway lane was increased at 0.10% BAC and 0.07% BAC in the elimination phase, compared to performance without alcohol. Similarly, there was an increase in the variance of tracking about the lane due to these same alcohol conditions. In another recent study using a closed-loop driving simulator, increasing BAC levels of up to 0.12% produced tracking position error that were correlated (r=0.57) with BAC (Sugarman et al., 1973). While there was no significant effect attributable to alcohol on the means and variances of the heading angle and its derivative, yaw rate, spectral analyses showed that there were increases in the RMS of lateral position error and heading angle at 0.10% BAC and 0.07% BAC in the elimination phase.

Therefore, there was an absolute increase in the mean deviation from the center of the lane attributable to these two alcohol conditions, as well as increases in the variation of both the lateral position and heading angles.

Further, the spectral analyses also showed that the bandwidths of heading angle and yaw rate were reduced in all the alcohol treatments, compared to placebo conditions. These results indicate that the sensitivity of drivers to heading angle and yaw rate stimuli was reduced by the alcohol conditions. The previously cited data showed that this resulted in an increase in lateral position and heading angle errors, which would result in an offset of the vehicle about the center of the lane and an increase in the variation about the center of the lane, such that the vehicle would appear to wander about the roadlane more when the driver had consumed alcohol than without alcohol.

The findings also showed that the mean steering wheel displacement was significantly greater at 0.07% BAC in the elimination phase than without alcohol (in the low level disturbance

condition only), showing that drivers tended to apply greater amplitudes of inappropriate steering wheel motions than those drivers without alcohol. Thus, the greater errors associated with tracking of the vehicle were not due to a reduction in the extent of steering wheel movement used by the drivers under alcohol. However, the spectral analyses also showed that the bandwidth of steering wheel displacement was reduced at 0.10% BAC and 0.07% BAC in the elimination phase compared to the performance without alcohol. A similar result was obtained by Reed et. al (1973). This means that drivers were using more coarse, i.e., low frequency, steering wheel movements under alcohol. Without alcohol they were more responsive in the manner in which they utilized the steering wheel as a means of controlling the vehicle.

Fundamentally, these findings indicate a reduction in sensitivity of drivers to those cues which are subtle but important for vehicle lateral control, namely heading angle and yaw rate. The drivers relied more on lateral position cues when operating under alcohol than without alcohol. In addition, their responsivity with the steering wheel was reduced, with emphasis being placed on lower frequency responses.

When the drivers were exposed to step input disturbances, simulating the sudden onset of a wind gust which remained present at the same force for a sufficient time for the driver to stabilize his performance; or, the opposite case where the gust is suddenly removed, it was found that about 6-8 seconds was required for drivers to regain the same level of lateral control performance as they had attained prior to the step disturbance being applied. The analysis showed that there were significant effects on steering performance attributable to alcohol. The analyses were made during the first 10 seconds

following the application or removal of the simulated wind gust, with this period of 10 seconds being evaluated during five intervals of 2 seconds each.

As found for the continuous disturbance analyses, the lateral position mean error was significantly greater at 0.10% BAC and 0.07% BAC elimination than without alcohol during all of the 10 seconds which were evaluated. The mean variance in lateral position was significantly greater at all alcohol doses during the first 2 seconds, and during 2-4 seconds after the step disturbance at 0.07% BAC in the elimination phase. Generally, similar findings were obtained for the mean heading angle and heading angle variance. Yaw rate means and variances were unaffected by the alcohol doses.

Therefore, the effect of the alcohol doses was to produce an increase in lateral positon mean error, as was also found in the analysis of the continuous disturbance tests. In addition, the lateral position mean variance was affected by all alcohol doses during the first 2 seconds after the application of the step disturbance, and the same was found for the heading angle mean and mean variance. Further effects were found up to the third interval following the step disturbance, i.e., 4-6 seconds, primarily indicating that the lateral position mean variance and the heading angle mean and mean variance were affected at 0.07% BAC during the elimination phase.

It will have been noted that, in the analysis of the continuous disturbance tests, the effect of 0.07% BAC in the elimination phase was greater than at the same BAC during the uptake phase. Data from the step disturbance tests confirm that the effect of alcohol on steering control skills appears to be greater during the alcohol elimination phase than at an equivalent

BAC during uptake. This effect was also shown by the experiment of Sugarman et al. (1973).

The analysis revealed only minor effects of alcohol upon the manner in which the steering wheel was moved in response to the step disturbances across the intervals following the disturbance, either in terms of displacement or rate. Where any significant effects were found, they indicated that there was some reduction in the rate of steering wheel movement during the first 2 seconds after the application of a step disturbance in some of the alcohol conditions. Since these effects were found in higher-order interactions they are quite specific to particular test conditions and are not necessarily stable findings.

It should be noted that the analysis of the continuous disturbance tests found only minor effects of alcohol on steering wheel displacement or rate of displacement.

Some insight into the underlying reasons for the increased errors in the lateral positon and heading angle found in the step disturbance tests was obtained by evaluation of the time required by the driver to detect and to determine the direction of the step input in order to apply a counteracting steering wheel movement. The analysis showed that the mean detection time to apply a steering correction was significantly greater at 0.07% BAC in both the uptake and elimination phases. While the effect of 0.10% BAC was not statistically ($p<.05$) significant, Figure 20 clearly shows that there was a substantial difference which could have been expected to be significant, had more data been collected. Therefore, the ability to detect and determine the direction of a step input was impaired by these alcohol dose levels. In addition, there was also a significant effect, at all alcohol dose levels, on the total

time required to reach a decision concerning the direction of movement of the steering wheel to counteract the disturbance and to accomplish the initial steering wheel movement. While much of the effect of the alcohol on the total time to respond was due to the detection time being increased (Figure 20), there was also an increase in the mean movement time in all of the alcohol conditions. This is shown in Table 7, which indicates the mean detection times in the three alcohol treatment conditions for both the placebo and the alcohol group subjects; and also shows the mean total time for both groups in

TABLE 7. INCREMENT IN MEAN STEERING WHEEL MOVEMENT TIME IN EACH ALCOHOL DOSE IN INITIAL RESPONSE TO STEP DISTURBANCES, IN SECONDS.

Mean Time	Group	BAC		
		0.7% (Uptake)	0.10%	0.07% (Elimination)
Total	Placebo	0.645	0.645	0.642
Detection	Placebo	0.342	0.367	0.361
Movement	Placebo	0.245	0.225	0.211
Total	Alcohol	0.720	0.740	0.777
Detection	Alcohol	0.400	0.420	0.431
Movement	Alcohol	0.320	0.320	0.346
Increment in movement time due to alcohol		0.075	0.095	0.135

the same treatment conditions. The movement time is computed by subtracting the mean detection time from the mean total time within a treatment level, and subject grouping, and these are shown as mean movement times for the placebo and alcohol groups. It will be noted that the mean movement time for the placebo subjects was between .211 seconds and .245 seconds, while that for the alcohol groups was between .320 seconds and .346 seconds. The differences between corresponding values of the mean movement times of the placebo and alcohol groups indicates the increment in movement time attributable to alcohol. This is shown to be .075, .095 and 0.135 seconds due to BAC levels of 0.07% in uptake, 0.10%, and 0.07% in elimination, respectively.

Therefore, the initial, large amplitude, steering wheel movement that the drivers made in response to the step disturbances were made at a lower rate than those by subjects carrying out this task without alcohol. This result is partly corroborated by the analyses made directly on the steering wheel rate means and variances in the five two-second intervals after the step disturbance. As mentioned previously, some combinations of treatments produced lower steering wheel mean rates in the alcohol conditions than without alcohol. However, the initial steering wheel movement time is a relatively small part, i.e., about 0.3 seconds (Table 7), of a two-second interval, such that a measure which integrates steering wheel rates over a time as long as 2 seconds would be insensitive to the initial steering wheel movement.

Therefore, further evidence is derived that both error detection time, which involves the perception of an error in tracking and its direction, and the time required to move the steering wheel a distance equivalent to that imposed by the

simulated wind gust, were significantly increased. Therefore, both the perceptual and motor response behavior of the drivers was impaired by the alcohol dose levels that were used. The effects of these perceptual and motor defieciencies, due to alcohol, were shown in increases in lateral position and heading angle errors.

It will be noted that yaw rate means and variances were not affected by the alcohol treatments in these analyses of the settling times. This is to be expected, since the largest contribution to the yaw rate values would be that attributable directly to the step disturbance itself, with differences in a two-second interval between the alcohol treatment groups being quite negligible, by comparison.

CAR-FOLLOWING SKILLS

There has been no previous study reported concerned with the effects of alcohol on a car-following task. The test conducted in this study used a driving simulator. However, previous comparisons (Campbell & Mortimer, 1972) between results obtained in the simulator and in automobile driving tests have found a good degree of correspondence.

The response times to the side-task were unaffected by alcohol, showing that subjects maintained vigilance on this task, as they had been instructed to do. On the other hand, there was an increase in response times to stop signals of the lead vehicle at 0.10% BAC compared to 0.05% BAC, but not compared with the mean response times of subjects without alcohol. Therefore, the action of alcohol in affecting response times to stop signals of the lead vehicle is somewhat inconclusive. No effect of alcohol was noted in a previous study (Post, 1972) in which response times were obtained to stop and turn signals presented

by a lead vehicle, when subjects were at 0.06% BAC or without alcohol.

There were some indications that alcohol impaired car-following performance. For example, there was an increase in the mean standard deviation of relative acceleration between the lead vehicle and the following vehicle at 0.10% BAC compared to 0.05% BAC or without alcohol.

In addition, a computed value, peak headway error, was greater for subjects at 0.10% BAC than without alcohol at lead vehicle velocity frequencies above 0.06 Hz. This finding suggests that, at the higher frequencies of changes in lead-vehicle velocity, subjects under alcohol are less sensitive to detection of velocity changes of the vehicle they are following, resulting in greater headway errors being produced. It was suggested that the reason for no difference being found at frequencies below about 0.06 Hz, with or without alcohol, was that the drivers under alcohol were also less sensitive to detection of the lead-vehicle velocity changes, but also less responsive. It is assumed that this reduction in sensitivity to detection of low frequency lead-car velocity changes and reduction in responsiveness of the drivers under alcohol, was generally beneficial to performance by reducing the noise in the following-driver's output.

That the mean relative velocity bandwidths were greater at both alcohol doses than without alcohol is interpreted to mean that the drivers under alcohol were less sensitive to changes in relative velocity and produced high frequency following-car velocity responses in an open-loop manner to reduce large discrepancies in the headway, when these were noticed.

The study of car-following performance, therefore, suggests that drivers were less sensitive to higher frequency components of lead-vehicle velocity excursions above about 0.06 Hz. Below

this frequency there were no detrimental effects noted due to alcohol. The reduction in sensitivity to higher frequency changes in lead-vehicle velocity produced greater relative velocity frequencies under alcohol, which may have also been obtained due to open-loop responses to noted errors in relative velocity or headway. This type of response may have been partly responsible also for the increase in the mean standard deviation of relative acceleration obtained at the 0.10% BAC than the other alcohol treatment conditions.

Certainly, these findings on the effect of alcohol on car-follwing performance are complex and are preliminary in nature. They are, however, to some extent in correspondence with the findings of the studies carried out on vehicle lateral control, which also indicated a reduction in sensitivity of drivers to higher frequency components of yaw rate and heading angle cues for steering control.

CAR-DRIVING SKILLS

Measurements were also taken in a car-driving study, carried out on two-lane and limited-access roads, on a number of aspects of the driving task. The only measure related to steering performance was the path error, in which no significant effects were found due to alcohol. This was probably due to the limited amount of such data that were gathered in this test. The standard deviation of path error was about 10 inches, in the day or night driving conditions. This is greater than found in the continuous disturbance tests in the simulator, and also than reputed by Soliday (1974) for ten subjects driving on a limited-access road. He reported lateral position standard deviations of about 5.0 inches, but did not evaluate the effects of alcohol.

Measures related to car-following performance included the ability to maintain a fixed speed and car-following when the

speed of the lead car was either constant or varying. It was found that there was an increase in variance in the ability to hold a constant speed due to alcohol. In addition, when car-following with the speed of the lead car held constant, the variance in headways was greater due to alcohol. This effect was less pronounced when the lead car was varying speed.

These data suggest that drivers who have consumed alcohol to attain levels of about 0.085% BAC are likely to be more variable in the speed they maintain as well as in the headways that they maintain with respect to a vehicle ahead of them. These findings would manifest themselves in the traffic stream by an introduction of variation in speed attributable to a driver under alcohol which will have an affect upon the overall smoothness of the flow of traffic, and increase the propensity for rear-end collisions (Solomon, 1964).

The driving simulator studies of car-following were analogous to those carried out on the road in the condition where the speed of the lead car was varying. The simulator study indicated that greater errors in the headway would accrue due to higher frequency changes in lead-car velocity, which would have the net effect of increasing the variance in headway, as found in at least one condition in the field test.

CONCLUSIONS

Because of the difficulty in instrumenting an actual vehicle to measure the specific components of the cue structure which may be utilized by a driver for steering control, as well as the difficulty in carrying out studies concerned with the effects of alcohol on a road network, the emphasis on the steering tests was placed on driving simulator measurements. These have clearly shown that there are reductions in the ability of drivers at moderate levels of alcohol to have adequate lateral control of the vehicle. In a previous discussion of some of these results (Mortimer & Sturgis, 1974) it was indicated that alcohol has the effect of reducing the ability of drivers to attend to yaw rate and heading angle cues, and produces an emphasis upon lateral position cues for steering the vehicle. This is accompanied by coarser manipulation of the steering wheel, characterized by a reduction in high frequency steering wheel movements, usually of small amplitude. This general behavior is analogous to that of a beginning driver, who uses large steering wheel excursions, at low frequencies, and who is mainly concerned with reducing the lateral position error of the vehicle in the lane.

This analysis of the effect of alcohol on changes in steering behavior is also confirmed by the eye-marker study (Mortimer & Jorgeson, 1972) which was also carried out as part of this program. That study found that drivers tended to reduce the lateral excursions of eye fixations, increase the dwell time of eye fixations, and bring their eye fixations closer to the vehicle. Some of these same effects were also found in a similar study by Belt (1969). It follows that, if drivers increased the dwell time of eye fixations, they would have less

time available for scanning the environment, which was also shown by these studies. That eye fixations were brought in closer to the vehicle also emphasizes a change from the utilization of yaw rate and heading angle cues to lateral position cues. Other studies (e.g., Mortimer, 1967) have shown that a reliance upon the lateral position cues alone for vehicle driving is inadequate and leads to instability of control.

It is believed that the studies that have been completed in this program provide considerable insight into problems associated with the lateral vehicle control task which can be affected by moderate doses of alcohol. Since about 4% of randomly sampled drivers (Carlson et al., 1973), whose BAC levels were measured at roadblocks, exceeded 0.10% - the maximum level used in these tests - it can be inferred that a substantial proportion of drivers on the roads are significantly impaired in the basic steering control task. The findings of this study help to explain the more likely involvement of drinking drivers in single-vehicle, run-off-the-road crashes (Voas, 1973).

The study also has shown that simple information-processing tasks are impaired at these levels of alcohol, as also reported by other investigators (Moskowitz & DePry, 1968; Moskowitz & Burns, 1971; Moskowitz & Sharma, 1974). This means that a driver, who has been using alcohol and is confronted with a complex traffic environment, may fail to adequately select the most effective course of action.

In addition, the study indicated that alcohol affects visual acuity at mesopic levels of adaptation, which has an influence upon safety in night driving. A reduction in the lateral horizontal fields of red stimuli under alcohol was also found, with implications for its effects upon the

visibility of important traffic signs and controls and vehicle rear signals, which are normally coded by that color.

The information on car-following, obtained in this study, is preliminary. However, it does suggest that there are impairments due to the moderate alcohol levels that were used. These findings, coupled with those obtained in the driving study, suggest that drivers under alcohol have greater variability in speed-holding and car-following tasks which reduces smoothness of the flow of traffic, and increases the likelihood of rear-end collisions. More extensive studies should be conducted upon the effects of alcohol on car-following tasks so that the more specific effects of the drug can be determined.

Finally, the BAC level during alcohol absorption (uptake) had less effect on performance than the same level during elimination, suggesting that the detrimental effects of alcohol are increased by temporal factors, such as fatigue.

APPENDIX

ALCOHOL DOSE ADMINISTRATION

Body build has been found to be an important parameter in determining alcohol doses, as subjects of the same total body weight but with different amounts of body fat will typically reach different peak BAC's. Sturgis (1972) administered alcohol to 16 subjects in a study concerning the effects of alcohol on psycho-motor skills and found great variation in peak BAC's when a strict body weight formula was used. Peak BAC was ostensibly positively correlated with amount of body fat. With a target peak BAC of 0.10% (g/100 ml), actual values of 0.075 to 0.13 were attained. Wallgren and Barry (1970) report that alcohol is only slightly soluble in tissue lipids. At body temperature, lipids absorb only about 4% of the quantity of alcohol dissolved in a corresponding volume of tissue water. Total body weight is thus not always an accurate estimator of soluble body mass. Widmark (1932) described the factor r to represent "reduced body mass" which signifies "the fraction of the body volume in which alcohol would be present if it were distributed at a uniform concentration equal to that observed in the blood." Widmark empirically determined r for 20 male subjects and found a mean of 0.68 and standard deviation of 0.085. Clearly, r must be taken into account for accurate calculation of doses.

Snapper (1972) employed a dosage formula which required visual estimates of subjects' body fat, and had considerable success in reducing the variance in resultant peak BAC's. An adaptation of this formula is shown in Figure A.1. The

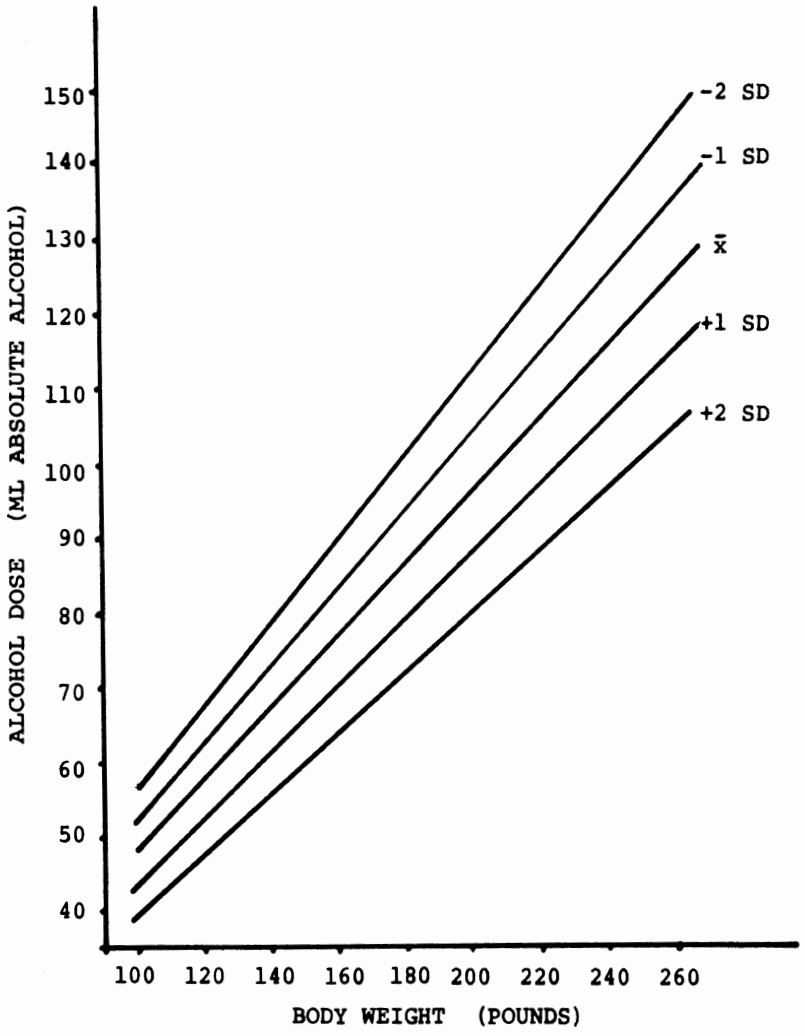


Figure A.1. Alcohol doses required for peak BAC of 0.10% (100 mg/100 ml) by total body weight and experimenter's estimate of body fat in standard deviation units.

formula incorporated in Figure A.1. is based on empirical findings that a dose of 0.455 ml of absolute alcohol per pound of body weight (1 ml/kg or 0.78 g/kg) results in an average peak BAC of 0.10%. Additionally, it enables correction for different amounts of body fat by estimates in standard deviation units of the divergence of the subjects body build from "average." One standard deviation unit is equal to approximately 4.4% of the "average" dose. Thus, a subject weighing 160 lbs could receive a dose of from 66 to 79 ml (± 2 SDs) of absolute alcohol depending upon his estimated body build.

In this study, a similar formula was used, but the average first alcohol dose was 0.32 ml of absolute alcohol per pound of body weight (0.54 g/kg), mixed 1:6 with a low-calorie carbonated soft drink. The second dose contained a mean of 0.23 ml absolute alcohol per pound (0.39 g/kg) mixed in the same ratio.

REFERENCES

Belt, B.L. Driver Eye Movements as a Function of Low Alcohol Concentrations. Driving Research Laboratory, Ohio State University, 1969.

Bjerver, K. and Goldberg, L. Effect of Alcohol Ingestion on Driving Ability: Results of Practical Road Tests and Laboratory Experiments. Quarterly Journal of Studies on Alcohol, 2, 1-30, 1950.

Burg, A. Relation Between Vision Quality and Driving Record. Proceedings, Symposium on Visibility in the Driving Task. Highway Research Board, May 13-15, 1968.

Campbell, J.D. and Mortimer, R.G. The HSRI Part-Task Driving Simulator for Research in Vehicle Rear Lighting and Related Studies. Highway Safety Research Institute, University of Michigan, Report No. UM-HSRI-HF-72-12, 1972.

Carlson, W.L., Chapman, M.M., Clark, C.D., Filkins, L.D., and Wolfe, A.C. Washtenaw County BAC Roadside Survey. Highway Safety Research Institute, University of Michigan, 1971.

Carpenter, J.A. Contributions from Psychology to the Study of Drinking and Driving. Quarterly Journal of Studies on Alcohol, No. 4, 234-251, 1968.

Cohen, J., Dearnly, E.J. and Hanse, C.E.M. The Risk Taken in Driving Under the Influence of Alcohol. British Medical Journal, 1438-1442, 1958.

Coldwell, B.B., Penner, D.W., Smith, H.W., Lucas, G.H., Rogers, R.F. and Darroch, F. Effect of Ingestion of Distilled Spirits on Automobile Driving Skill. Quarterly Journal of Studies on Alcohol, 19, 590-616, 1958.

Drew, G.C., Colquhoun, W.P. and Long, H.A. Effect of Small Doses of Alcohol on a Skill Resembling Driving. British Medical Journal, 2, 993-999, 1958.

Filkins, L.D., Clark, Cheryl D., Rosenblatt, C.A., Carlson, W.L., Kerlan, Margaret W., Manson, Hinda. Alcoholism Abuse and Traffic Safety: The Study of Fatalities, DWI Offenders, Alcoholics, and Court-Related Treatment Approaches. Final Report, Contract FH-11-6555 and FH-11-7129, U.S. Department of Transportation, NHTSA, Highway Safety Research Institute, University of Michigan, 1970.

Forney, B.B. and Hughes, F.W. Delayed Auditory Feedback and Ethanol: Effect on Verbal and Arithmetic Performance. Journal of Psychology, 52, 185-192, 1961.

Forney, B.B., Hughes, F.W. and Greatbatch, W.H. Measurement of Attentive Motor Performance After Alcohol. Perceptual and Motor Skills, 19, No. 1, 151-154, 1964.

Goldstein, L.G. Research on Human Variables in Safe Motor Vehicle Operation: A Correlational Summary of Predictive Variables and Criterion Measures. George Washington University, Washington, D.C., 1961.

Griep, D.J. Alcohol and Road Safety. Institute for Road Safety Research (SWOV), 1968.

HSRI. Alcohol Safety. Final Report, Contract FH-11-6555, U.S. Department of Transportation, Highway Safety Research Institute, University of Michigan, 1969.

Huelke, D.F., and Davis, R.A. A Study of Pedestrian Fatalities in Wayne County Michigan. Highway Safety Research Institute, University of Michigan, 1969.

Jones, T.O. Vehicle Countermeasures for Intoxicated Drivers. Society of Automotive Engineers, Report No. 720136, 1972.

Kalin, R. Effects of Alcohol on Memory. Journal of Abnormal and Social Psychology, 69, No. 6, 635-641, 1964.

Kerlan, M.W., Mortimer, R.G., Mudge, B., Filkins, L.D. Court Procedures for Identifying Problem Drinkers, Volume 1: Manual. Contract FH-11-7615, NHTSA, U.S. Department of Transportation, Report No. DOT-HS-800632, Highway Safety Research Institute, University of Michigan, 1971.

Kristofferson, M.W. Effects of Alcohol on Perceptual Field Dependence. Journal of Abnormal Psychology, 73, 387-391, 1968.

Light, W.O. and Keiper, C.G. Effects of Moderate Blood-Alcohol Levels on Automobile Passing Behavior. Proceedings, 13th Annual Conference of the American Association for Automotive Medicine, 239-267, 1969.

McCarroll, J.R. and Haddon, W. A Controlled Study of Fatal Automobile Accidents in New York City. Journal of Chronical Diseases, 15, 811-826, 1962.

Mortimer, R.G. Effect of Low Blood-Alcohol Concentrations in Simulated Day and Night Driving. Perceptual and Motor Skills, 17, 399-408, 1963.

Mortimer. R.G. Driving with a CRT Display. Perceptual and Motor Skills, 25, 899-900, 1967.

Mortimer, R.G., Filkins, L.D., Lower, J.S. Development of Court Procedures for Identifying Problem Drinkers: Final Report. Contract FH-11-7615, NHTSA, U.S. Department of Transportation, Report No. DOT-HS-800631, Highway Safety Research Institute, University of Michigan, 1971.

Mortimer, R.G. and Jorgeson, C.M. Eye Fixations of Drivers as Affected by Highway and Traffic Characteristics and Moderate Doses of Alcohol. Proceedings, Annual Meeting, Human Factors Society, Los Angeles, October 1972.

Mortimer, R.G. and Sturgis, S.P. Effects of Low and Moderate Levels of Alcohol on Steering Performance. Proceedings, 6th International Conference on Alcohol, Drugs and Traffic Safety, Toronto, September 8-13, 1974.

Moskowitz, H. and DePry, D. The Effect of Alcohol on Auditory Vigilance and Divided Attention Tasks, Quarterly Journal of Studies on Alcohol, 29, 54-63, 1968.

Moskowitz, H. and Sharma, S. Effects of Alcohol on Peripheral Vision as a Function of Attention, Human Factors, 16, No. 2, 174-180, 1974.

Newsweek. France: Bitter Harvest. 30, December 28, 1970.

Oltman, P.K. A Portable Rod-and-Frame Apparatus. Perceptual and Motor Skills, 26, 503-506, 1968.

Perrine, M.W. and Huntley, M.S. Influences of Alcohol Upon Driving Behavior in an Instrumented Car. Contract No. FH-11-7469, U.S. Department of Transportation, University of Vermont, Report No. DOT-HS-800625, 1971.

Peters, H.B. Changes in Color Fields Occasioned by Experimentally Induced Intoxication. Journal of Applied Psychology, 26, 692-701, 1942.

Post, D.V. The Effect of Alcohol Upon Responses Given to Automobile Rear Lighting Systems, MS Thesis, Eastern Michigan University, October 1972.

Rabin, A. and Blair, H. The Effects of Alcohol on Handwriting. Journal of Clinical Psychology, 9, No. 3, 284-287, 1953.

Reed, L.D., Ibrahim, M.K.F., Miller, R.D. and Hansteen, R.W. The Influence of Alcohol and Marijuana on a Manual Tracking Task. Society of Automotive Engineers, Report No. 730092, 1973.

Road Research Laboratory. Research on Road Safety. HM Stationery Office, London, 1963.

Schmidt, W.S. and Smart, R.G. Alcoholics, Drinking and Traffic Accidents. Quarterly Journal of Studies on Alcohol, 20, 631-644, 1959.

Snapper, K. and Edwards, W. Effects of Alcohol on Psycholmotor Skill and Decision-Making. Grant No. MH22063-01, NIAAA, Highway Safety Research Institute, University of Michigan, 1972.

Soliday, S.M. Some Characteristics of the Track of an Automobile Driven at Two Different Speeds. Perceptual and Motor Skills, 39, 495-498, 1974.

Solomon, D. Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle. Bureau of Public Roads, 1964.

Sturgis, S.P. and Mortimer, R.G. Effects of Practice and Alcohol on Selected Skills: Implications for an Automobile Alcohol Ignition Interlock. Perceptual and Motor Skills, 37, 267-274, 1973.

Sugarman, R.C., Cozad, C.P. and Zavala, A. Alcohol-Induced Degradation of Performance on Simulated Driving Tasks. Society of Automotive Engineers, Report No. 730099, January 1973.

Voas, R.B. Factors Related to Alcohol Involvement in Crashes. Proceedings, First International Conference on Driver Behavior, Zurich, October, 1973.

Waller, J.A. Accident Patterns Associated with Drinking and Violations Among Drivers with Alcoholism, Other Medical Conditions, and No Medical Conditions. In: Report of the Secretary's Advisory Committee on Traffic Safety, D.H.E.W., Washington, D.C. 1968.

Wallgren, H. and Barry, H. Actions of Alcohol, Volume I: Biochemical, Physiological and Psychological Aspects. Elsevier Publishing Co., New York, 1970.

Widmark, E.M.P. Die Theoretischen Grundlagen und die Praktische Verwendbarkeit der Gerichtlich-Medizinischen Alkoholbestimmung. Fortschritte der Naturwissenschaftlichen Forschung, Heft 11, E. Abderhalden, Ed., Urbon und Schwarzenberg, Berlin-Wien, 1932.