CORE
Metadata, citation and similar papers at core.ac.uk
Provided by NASA Technical Reports Server

N82-13709

MANUAL CONTROL ANALYSIS OF DRUG EFFECTS ON DRIVING PERFORMANCE*

By Alison Smiley, Kenneth Ziedman and Herbert Moskowitz

Southern California Research Institute

SUMMARY

Effects of secobarbital, diazepam, alcohol and marihauna on car-driver transfer functions obtained using a driving simulator were studied. The first three substances, all CNS depressants, reduced gain, crossover frequency and coherence which resulted in poorer tracking performance. Marihuana also impaired tracking performance but the only effect on the transfer function parameters was to reduce coherence.

INTRODUCTION

Manual control analysis of tracking performance has been most frequently used to study changes in task variables, such as controlled element dynamics, rather than operator variables such as fatigue, or drug effects. This paper addresses the issue of drug effects on the tracking behavior of human operators, a topic of great interest because of its importance to traffic safety. The drugs studied were secobarbital, a sedative hypnotic, diazepam, a widely prescribed sedative minor tranquilizer, and marihuana, a common recreational drug. The diazepam and marihuana were combined with alcohol.

The transfer function approach for examining drug effects was chosen for two reasons. First, it allows some differention between drugs in terms of which aspects of perceptual-motor behavior are being affected. Second, it provides a unified framework in which to interpret results, unlike the interpretation of an assortment of tracking parameters.

There have been few published studies of drug effects on transfer function parameters. Allen et al (reference 1) using both an instrumented car and a driving simulator found the effect of alcohol was to reduce the driver's gain and decrease the coherence (i.e., the driver became a less responsive and less linear tracker). Reid (reference 2) calculated describing functions for subjects performing a compensatory tracking task under the influence of alcohol alone and in combination with marijuana. Similar effects of reduced gain and reduced linearity of response were found as well as an increase in subject internal processing time. All these changes in control

* This work supported by The National Institute on Drug Abuse and The National Highway Traffic Safety Administration under NIDA Contract No. 271-76-3316

502 INTENTIONALLY BLANK

contributed to degraded tracking performance.

Tracking task measures related to transfer function parameters have been used to distinguish between the effects of different drugs. Smiley et al. (reference 3) compared the effects of alcohol alone and in combination with diazepam, diphenhydramine (an antihistamine) and marihuana on driving in an instrumented car. The power spectra of steering wheel angle, a measure of the amplitude of steering movement over a range of frequencies, showed: (1) that subjects made larger steering movements under the alcohol + diphenhydramine, alcohol + marihuana and alcohol alone treatments when compared to placebo, and smaller movements under the alcohol + diazepam treatment and (2) that subjects' steering movements were slower under all drug treatments, and slowest for the alcohol + diazepam condition, when compared with placebo.

PROCEDURES

Drug Treatments: The results reported in this paper are derived from three separate experiments on the effects of drugs on human performance. The first experiment examined secobarbital alone at three dose levels: 0, 1.1 and 2.2 mg/kg bodyweight using 15 subjects. The second and third experiments were drug-alcohol interaction studies with the drug and the alcohol each tested at three levels. A separate group of 15 subjects was tested at each alcohol level, making a total of 45 subjects tested in each of the two studies. Each subject received all three drug doses. Dose levels used in the second experiment were: diazepam: 0, 0.11, 0.22 mg/kg bodyweight and alcohol: 0, 0.51, and 1.02 gms/kg bodyweight. For the third experiment dose levels were: marihuana: 0, 100, 200 mcg THC/kg bodyweight and alcohol: 0, 0.425 and 0.68 gms/kg bodyweight. The alcohol was administered in a vodka-orange juice mixture, the diazepam and secobarbital by capsules, and the marihuana by smoking.

The dose levels of secobarbital and diazepam were those generally used in therapeutic situtations. The highest dose level of alcohol produced a blood alchol concentration (BAC) of 0.11%, just over the 0.10% BAC legal presumptive limit for impariment in California. A questionnaire, given to the subjects who received marihuana, showed that the 100 and 200 mcg THC/mg bodyweight doses produced the same "high" as the subjects experienced in their social use of marihuana between "less than half the time" and occasionally".

Subjects: Participants met the following criteria: male, 21-45 years old, 61.5-91 kg bodyweight, 20/30 minimum vision in each eye, moderate to light heavy alcohol use as defined by the Cahalan et al (reference 4) scale, and having at least three years driving experience. Subjects were screened using a medical examination and a standardized personality test for possible physical or emotional counter indications.

Testing Schedule: Subjects attended three training days within a

three-week period. On each training day subjects completed two forty-five minute simulator runs. After training, subjects attended three treatment sessions separated by two week intervals. At each treatment session, a subject was given an eight-minute "warm-up" run in the simulator, after which dosing began. Sixty-five minutes after the start of dosing the subject began a 45-minute simulator run. The testing time was chosen so that the drug and alcohol blood levels would peak during the run. Measurements of blood alcohol concentration were taken before dosing to insure an initial 0% BAC, just before and just after testing, and every hour until the BAC was below 0.03%. Pulse rates and blood samples to determine drug levels were also taken during these experiments but the results will be reported elsewhere.

Apparatus: The driving simulator used in this study was developed to test performance of control and decision skills shown to be both critical to the driving task, and sensitive to drug effects. The simulator design was based on a general purpose digital computer (PDP 11/60) and associated graphics system (Megatek 7000) which provided:

* implementation of realistic vehicle dynamics
* generation of a roadway (straight, curved, etc.) and roadway elements (signs, obstacles, other vehicles, etc.) and
* data recording and analyses.

Detailed descriptions of the simulator are given in Michaelson et al. (reference 5) and Allen et al (reference 6). A number of tasks were performed during the run including curve negotiation, passing maneuvres and emergency stops. The results reported in this paper were derived from one task, the wind-gust control task, which was presented three times and lasted approximately 2 minutes each time. In this task the driver was required to keep the simulator centered in the lane at a constant speed of 80 k.p.h. while being buffeted by simulated wind gusts. A heading angle disturbance signal consisting of a sum of seven sine waves was used to create the wind gust effect and allowed the derivation of car-driver transfer functions.

THEORETICAL ANALYSIS

Figure 1 shows the control loop structure which represents the driving simulator. The driver is assumed to use heading angle (ψ) and lateral position (y) inputs to steer the driving simulator. The nested loop structure shown, an inner loop operating on heading angle and an outer loop on lateral position, has been successfully fitted to data from experienced drivers by Weir and McRuer (reference 7). By keeping the inner loop closed the driver can operate on lateral position error with a simple gain, i.e., corrections of lateral position may be facilitated by means of heading angle corrections. The sum of sines disturbance, denoted ψ_d, contained the following seven frequencies: 0.553, 0.916, 1.288, 2.023,

2.947, 4.235 and 5.705 radians per second, i.e., the spacing was at approximately equal intervals over a logarithmic scale.

$G_\delta^V(jw)$ and $G_\delta^\psi(jw)$ represent the vehicles dynamics for lateral velocity and heading angle respectively (jw is the complex frequency variable). In the simulator the vehicle dynamics are simulated digitally by differential equations. These equations represent a mid-size American sedan and were drawn from a study determining vehicle dynamics of various cars by McRuer et al. (reference 8).

Using Figure 1 it may be seen that the system equations can be written as:

$$\psi = Y_\psi \, G_\delta^\psi \, (n - Y_y y - \psi) + \psi_d$$

and

$$y = \frac{U_o}{s} \psi + Y_\psi \frac{1}{s} G_\delta^V \, (n - Y_y y - \psi)$$

where U_o represents the forward speed of the simulator and n, the remnant, that part of the driver's steering input uncorrelated with the heading angle disturbance.

The next steps in the derivation of the car-driver transfer function are:

1) substitute for lateral position, y, in the first equation using the second equation.
2) write the equation with the effective open loop system gain,

$$\frac{\psi - \psi_d}{\psi}$$

on the left side. The heading disturbance ψ_d, is considered the system input and the heading angle ψ, is considered the output.
3) cross-correlate each side of the equation with ψ_d to obtain

$$\frac{\Phi_{\psi_d \psi} - \Phi_{\psi_d \psi_d}}{\Phi_{\psi_d \psi}}$$

The cross-correlation function $\Phi_{\psi \cdot \psi_d}(jw)$ describes the general dependence of the heading angle signal ($\psi(t)$) on the heading angle disturbance signal ($\psi_d(t)$) in terms of amplitude and phase relationships. The process of obtaining the cross-correlation function involves converting $\psi(t)$ and $\psi_d(t)$ to the frequency domain using Fast Fourier transforms. The heading angle and heading angle disturbance signals were recorded during the

wind-gust control task at a rate of 7.5 times per second. (Analysis techniques are described in detail by Bendat and Piersol (reference 9).) Cross-correlating the remnant, n, with ψ_d causes all remnant terms to disappear as $^{\Phi}\psi_{d.n}=0$ by definition. After cross-correlation, the effective open loop system gain is represented by the function $\frac{^{\Phi}\psi_{d}.\psi - ^{\Phi}\psi_{d}\psi}{^{\Phi}\psi_{d}\psi}$.

By definition the open loop gain equals the product of the driver transfer function Y_p and the car (simulator) transfer function Y_c;

that is, $Y_pY_c = \frac{^{\Phi}\psi_{d}\psi - ^{\Phi}\psi_{d}\psi}{\psi\ \psi}$.
d

RESULTS

Obtained blood alcohol concentrations were 0.06% and 0.11% in the diazepam-alcohol interaction study, and 0.05% and 0.08% in the marihuana-alcohol interaction study.

Car-driver transfer functions were calculated and averaged for each group of 15 subjects for each drug, and for each alcohol level tested (in some cases fewer subjects were available). For all drug and alcohol treatments there were significant increases in tracking error ($p<0.05$). Considering the results for each of the three drugs under the no alcohol, or placebo alcohol condition, the largest increase in tracking error was found for the high dose of secobarbital, the sedative hypnotic (see table 1). The increases in tracking error produced by the high doses of diazepam (sedative tranquilizer) and marihuana were approximately equivalent, and half that found for the secobarbital high dose.

The tracking error results for the various alcohol doses are not as clear because different groups of subjects are being compared. Also initial differences between groups, exacerbated by running the active alcohol groups some months after the placebo alcohol group had been completed, make the alcohol results from the marihuana-alcohol interaction study less reliable than they might be. In the diazepam-alcohol interaction study tracking performance under the 0.06% BAC-placebo drug condition was about the same as under the high dose diazepam-placebo alcohol condition. Tracking error appeared to be linearly related to alcohol dose, and doubled for the 0.11% BAC condition in comparison with the 0.06% BAC condition.

Figure 2 shows average car-driver transfer functions obtained for the three dose levels of secobarbital. There were large drops in gain and phase angle with increasing dose. Gain at all frequency points, and crossover

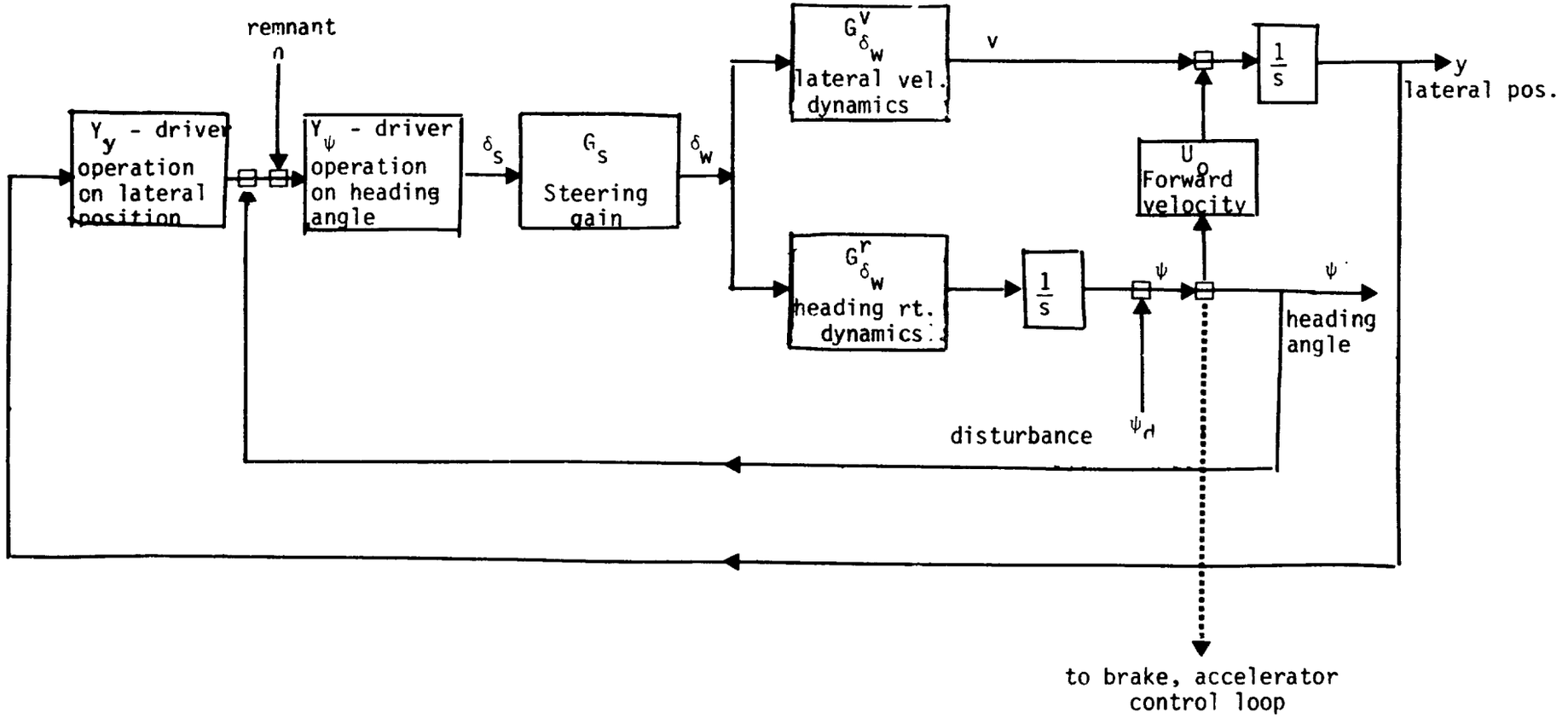


FIGURE 1: Control loop diagram for driver/vehicle system

frequency, were significantly reduced ($p<0.05$). Coherence between the heading angle disturbance and the heading angle signal was significantly reduced ($p<0.001$). Phase margin, which is an indicator of system stability, was unaffected (see Table 1).

The diazepam results for the placebo alcohol group are shown in Figure 2. Again there were significant drops ($p<0.05$) in gain at all frequency points and in crossover frequency. However, the average drop in gain was less for diazepam than for secobarbital treatment. Coherence was also significantly reduced by the diazepam treatment.

Alcohol results for placebo diazepam condition only are shown in Figure 3. These results are not as quite clear cut as for the other drugs. Here the lowest gains were for the 0.06% BAC alcohol condition. The effect of alcohol was significant ($p<0.05$) on the gains at the second, third and fourth frequency points only, with the Newman-Kuhls comparison of means test showing the placebo alcohol gains to be significantly higher than for either the 0.06% or 0.11% BAC conditions. Coherence was significantly reduced by the alcohol treatment, the greatest drop being for the 0.11% BAC condition. Mean crossover frequency also was significantly reduced ($p<0.05$). (It should be noted that the alcohol comparison was between different groups of 15 subjects while the drug comparison were based on repeated measures with 45 subjects. Thus the test of the alcohol effect was not as strong as the test of the drug effect.)

In summary, the results from the secobarbital, diazepam and alcohol treatments are much the same. Gains were significantly reduced as were crossover frequency and coherence. Phase margin was unaffected.

The effects on the car-driver transfer function for the marihuana treatment were very different from the other drugs (see Figure 3). There were no noticeable effects on gain, crossover frequency or phase margin. The main effect appeared to be on coherence which was significantly reduced ($p<0.05$), at the high dose level only. Tracking error was also significantly affected at the high dose only. Despite the fact that tracking error increased the same amount for both diazepam and marihuana, the effects on the car-driver transfer function were very different.

DISCUSSION AND CONCLUSION

The alcohol effects found in this experiment are supported by Allen et al (reference 1) and Reid and Ibrahim (reference 2) who also showed alcohol to reduce gains and coherence in driver transfer functions. Reid and Ibrahim found marihuana to have little effect on amplitude or phase margin but to decrease coherence, similar to the results obtained in this study. No comparative data are available for the secobarbital or diazepam treatments.

TABLE 1

Summary of Means and Analysis of Variance Results

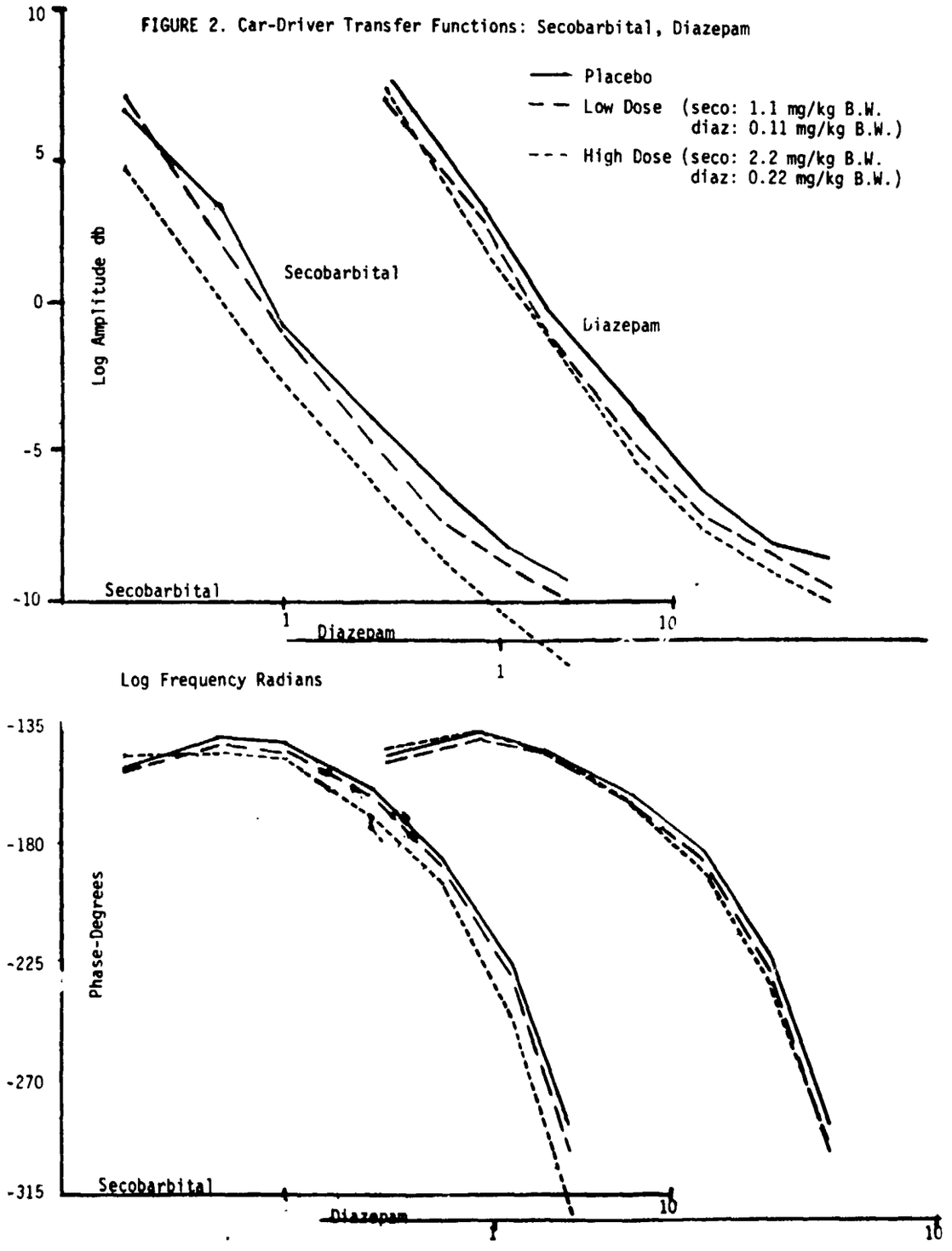
	Secobarbital		Diazepam - Alcohol					Marihuana - Alcohol				
		$p_2$value	BAC	0%	0.06%	0.11%	p value diaz alc	BAC	0%	0.06%	0.11%	p value mar alc
Standard Deviation Lateral Position	P_1 1.48	***	P	1.36	1.60	1.86	** ***	P	1.41	1.36	1.70	** —
	L 1.59		L	1.42	1.66	2 17		L	1.42	1.55	1.59	
	H 1.96		H	1.55	1.92	2.16		H	1.68	1.47	1.69	
Coherence	P 0.900	***	P	0.913	0.869	0.829	* ***	P	0.907	0.901	0.869	* —
	L 0.905		L	0.904	0.874	0.808		L	0.909	0.884	0.901	
	H 0.846		H	0.876	0.826	0.821		H	0.863	0.879	0.883	
Crossover Frequency	P 0.216	***	P	0.212	0.168	0.193	*** *	P	0.219	0.188	0.168	— **
	L 0.200		L	0.916	0.156	0.142		L	0.208	0.193	0.171	
	H 0.170		H	0.189	0.167	0.146		H	0.863	0.879	0.883	
Phase Margin	P 0.580	—	P	0.594	0.696	0.593	— —	P	0.636	0.696	0.608	— —
	L 0.597		L	0.601	0.640	0.591		L	0.663	0.656	0.699	
	H 0.577		H	0.587	0.571	0.637		H	0.634	0.682	0.655	

Drug Dose Levels: 1. P = placebo, L = low dose (seco: 1.1mg/kg B.W.; diaz:0.11 mg/kg B.W ;mar 100mcg/kg B.W.
H = high dose (seco: 2.2mg/kg B.W.; diaz:0.22mg/kg B.W ;mar: 200 mcg/kg B.W.

2. p values * $p<0.05$, ** $p<0.01$, *** $p<0.001$

ORIGINAL PAGE IS
OF POOR QUALITY

FIGURE 2. Car-Driver Transfer Functions: Secobarbital, Diazepam



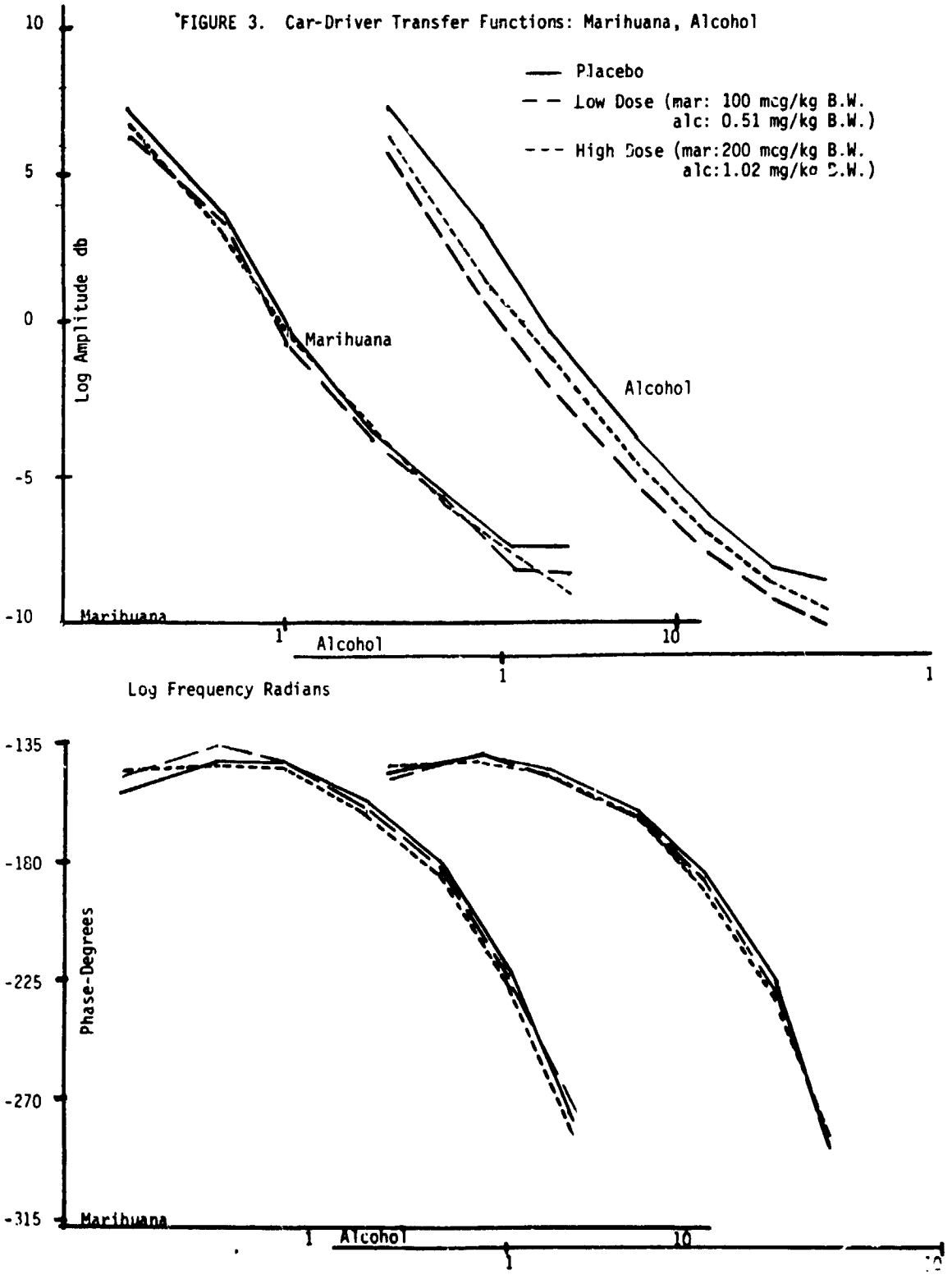


FIGURE 3. Car-Driver Transfer Functions: Marihuana, Alcohol

Both secobarbital and diazepam act as sedatives, however, secobarbital is generally prescribed at a high enough dose level that it acts as a hypnotic (induces sleep) while diazepam's anti-anxiety properties become evident when it is prescribed at a lesser dosage. Both drugs are CNS depressants as is alcohol. In contrast to these three drugs, marihuana is classified as a psychedelic, i.e., affecting the thought processes. The transfer function analysis clearly distinguished between these two classes of drugs. The analysis also discriminated the degree of sedative effect in that gains were reduced much more for the secobarbital treatment than the diazepam treatment at the dose levels used in this experiment. In addition it is interesting to note that the one drug of the four which is supposed to most affect thought processes is the one whose only transfer function effect was an increase in non linear behavior.

REFERENCES

1. Allen, R.W.; Schwartz, S.; Stein, A.; Magdelano, R. and Hogge, J.: The Effects of Alcohol and Marihuana on Driver Control Behavior. Volume 1 Laboratory Simulation Experiment. Report submitted to National Highway Traffic Safety Administration, under contract No. DOT-HS-501257, April, 1978.

2. Reid, D.; Ibrahim. M.K.F.: The Application of Human Operator Describing Functions to Studies on the Effects of Alcohol and Marihuana on Human Performance. IEEE Transactions on Systems, Man and Cybernetics, Vol.SMC-5, No.5, September, 1975.

3. Smiley, A.; LeBlanc, A.E.; French, I.W.; and Burford, R.: The Combined Effects of Alcohol and Common Psychoactive Drugs: Field Studies with an Instrumented Automobile. Canadian Society of Forensic Science Journal, Vol.8., No.2., 1975.

4. Cahalan, D.; Cisin, I.H.; and Crossley, H.M.: American Drinking Practices, A National Study of Drinking Behavior and Attitudes. College and University Press, 1969.

5. Michelson, S.; Niemann, R.; Olch R.; Smiley, A.M; and Ziedman, K.: A Driving Simulator for Human Performance Studies Using All Digital Techniques. Southern California Research Institute Technical Report, January, 1979.

6. Allen, R.W.; Klein, R.H.; and Ziedman, K.: Automobile Research Simulators: A Review and New Approach. Transportation Research Record 706, Simulation Technology and Traffic Accident Records System, Transportation Research Board, National Academy of Science, Washington, D.C., 1979.

7. Weir, D.H.; and McRuer, D.T.: Measurement and Interpretation of Driver Steering Behavior and Performance. SAE Paper No.730098, 1973.

8. McRuer, D.T.; and Klein R.H.: Automobile Controllability-Driver/ Vehicle Response for Steering Control. Sytems Techonology, Inc. Los Angeles, Submitted to National Highway Traffic Safety Administration under contract No.DOT-HS-359-3-762, November, 1974.

9. Bendat, J.S.; and Piersol, A.G.: Random Data: Analysis and Measurement Procedures. Wiley-Interscience, 1971.