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THE EFFECTS OF ALCOHOL ON DRIVER PERFORMANCE IN A DECISION MAKING SITUATION*

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ABSTRACT

This paper reviews the results of driving simulator and in-vehicle field test experiments of alcohol effects on driver risk taking. The objective was to investigate changes in risk taking under alcoholic intoxication and relate these changes to effects on traffic safety.

The experiments involved complex 15 minute driving scenarios requiring decision making and steering and speed control throughout a series of typical driving situations. Monetary rewards and penalties were employed to simulate the real-world motivations inherent in driving. A full placebo experimental design was employed, and measures related to traffic safety, driver/vehicle performance and driver behavior were obtained.

Alcohol impairment was found to increase the rate of accidents and speeding tickets. Behavioral measures showed these traffic safety effects to be due to impaired psychomotor performance and perceptual distortions. Subjective estimates of risk failed to show any change in the drivers' willingness to take risks when intoxicated.

INTRODUCTION

Alcohol has been shown to be overrepresented in accident statistics (Refs. 1 and 2). Recent surveys have subdivided accident causation into a variety of factors including vehicle, environmental and driver factors (Ref. 3). Driver behavior can be further subdivided roughly into perception, psychomotor skill and higher cognitive factors including decision making. Alcohol effects on driver psychomotor skill in steering control have been previously studied in some detail (Ref. 4), and the objective of the work reported here was to investigate the alcohol impairment in driver decision-making situations.

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An important aspect of this research was to determine whether driver risk taking changes with Blood Alcohol Concentration (BAC) and, further, to partition the changes in risk taking into changes in driver perception, psychomotor factors and the acceptance of risk. These three factors combine to determine performance in a decision-making task and, singly or in combination, give rise to performance that we objectively observe as risk taking. Take, for example, the situation where a driver has run a red light. This could be due to the driver's having misperceived his speed or the time interval of the amber light; it could also be due to the fact that he took too long in making a decision and thus his reaction time for accelerating or braking to a safe stop was delayed; or the driver may merely have elected to accept the risk of running a red light because he was motivated to minimize the delays caused by stopping.

In previous research on driver risk taking, no consistent approach has been used to differentiate between the various factors contributing to decision task performance. Several studies have measured driver risk taking, which has been found to increase with BAC (blood alcohol concentration) (Refs. 5-7). More recently, however, it was found in a gap acceptance task using significant rewards and penalties that intoxicated subjects did not consciously accept greater risks (Ref. 8). Impaired psychomotor skill did result in degraded performance, however.

The inconsistency in past research has been in the definition and simulation of driver risk taking, the analysis of all behavior components in risk taking, and the use of tangible risks. Based on a review of the literature, the following elements were felt to be essential to adequately determine the effects of alcohol on driver decision making: 1) division of driver behavior into perceptual, psychomotor and cognitive components; 2) use of rewards and penalties to simulate real-world risks (e.g., accidents, tickets, lost time); 3) use of tasks which simulate the temporal pressure of normal driving. The experimental methods for accomplishing these goals are discussed below.

EXPERIMENTAL METHODS

Approach

This research was accomplished in two separate experiments, the first a simulator study and the second involving field validation trials. The two experiments were designed to be as similar as possible in order to allow direct comparison of results. The specific setup for each was as follows.

Simulation. The simulation was configured to present a plausible driving scenario, requiring both steering and speed control in driving decision-making situations. The functional details of the simulation have been described previously (Ref. 9). Basically, the simulator consisted of an actual car cab and controls with a two lane roadway drawn on a 0.25 x 0.32 m

(10" x 12")* CRT mounted on the cab cowl 0.76 m (30 in.) in front of the driver as illustrated in Fig. 1. Equations of motion for the car steering and speed control were solved on an analog computer, which generated car heading angle, lateral position, and forward speed in response to steering wheel, accelerator and brake commands. The car motion variables drove special purpose electronic circuits which generated a dashed line two lane roadway [3.65 m (12 ft) lane width] with 0.76 m (2.5 ft) shoulders. The roadway was presented in correct perspective, but reduced scale (roughly two-thirds) in order to fit on the CRT and yet subtend a 22 degree perceptual field of view.

Driving events were controlled by a paper tape programmer at a rate proportional to forward speed. From a cross section of the many typical driving decision-making situations three events were selected that could be easily implemented in a laboratory simulation. The functional details of each event and related measurements are described further on.

Field Validation. This study was conducted in an instrumented vehicle described elsewhere (Ref. 10). Special equipment was added to allow the car to interact with the test course. A photo detector mounted on the vehicle sensed reflective strips on the test course and triggered a programmer which controlled event sequences in the field course driving scenario. Instrumentation was also added to allow experimenter feedback in scenario conditions and subject progress. Details of the field setup are illustrated in Fig. 2.

Driving Tasks and Measurements

The driving scenario was designed to allow implementation both in the simulator and on the field course. A variety of events were considered, and events that could be conveniently mechanized were selected for each experiment as indicated in Table 1 (Ref. 11). A signal light situation was selected as a classical single stage decision event. Vehicle control in a curve was selected to investigate the large number of single vehicle loss of control accidents that occur with alcohol involvement (Ref. 12). The remaining situations selected from Table 1 involve divided attention, a driver behavior factor which has been shown to be sensitive to alcohol impairment (Ref. 13). Details of the driving tasks and overall scenario were as follows.

Signal Light. A model signal light was mounted directly above the horizon of the roadway display in the simulator (Fig. 1a), and an actual signal light was set up on the test course in the field validation study (Fig. 2a). Signal timing was controlled as a function of car speed and distance from the intersection in order to control the time-to-go to the intersection. Several timing conditions were used ranging from a sure stop to a sure go. Details of the signal timing and task kinematics have been presented elsewhere (Ref. 11).

*Customary units were used for the measurements and calculations of this study.

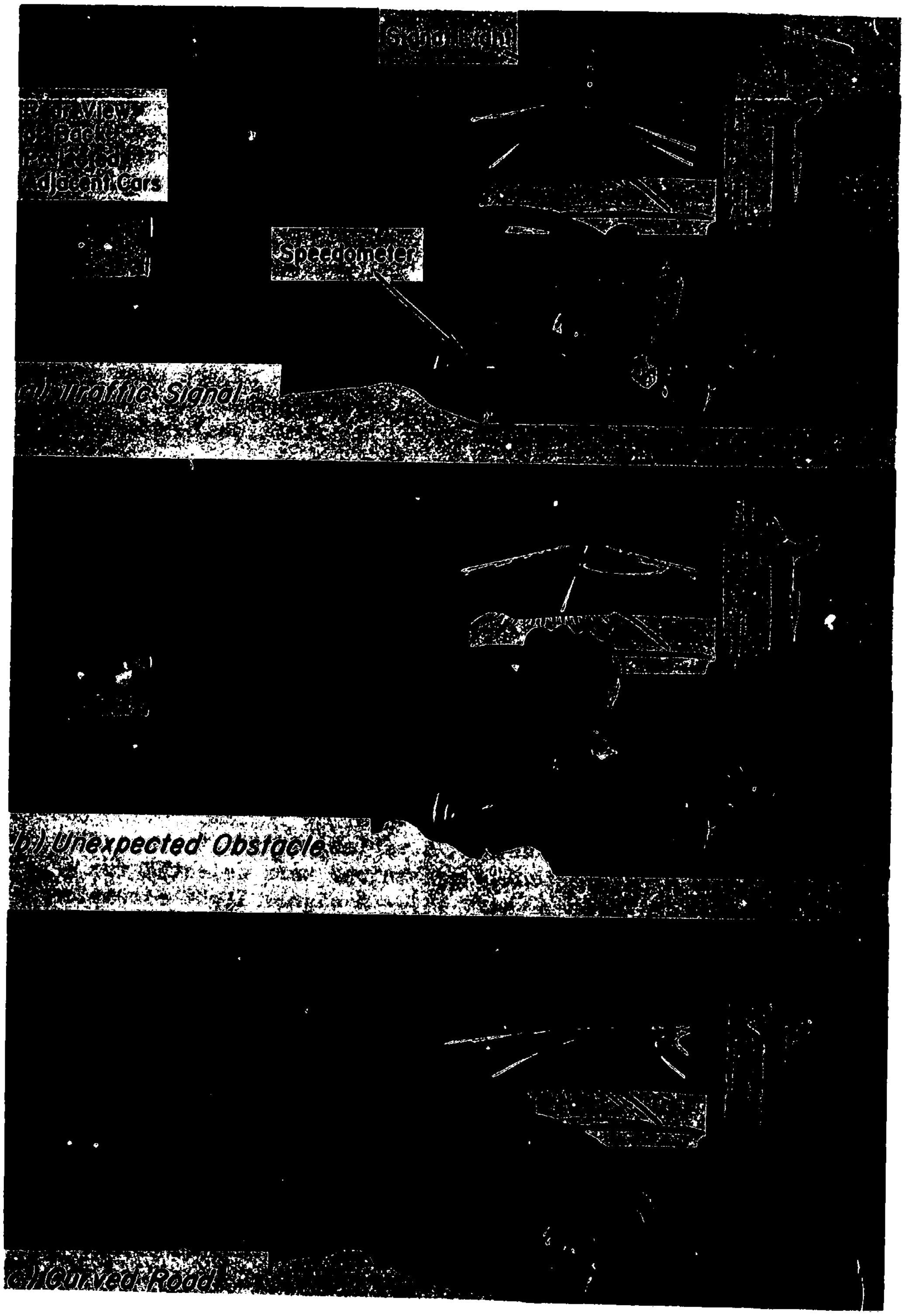
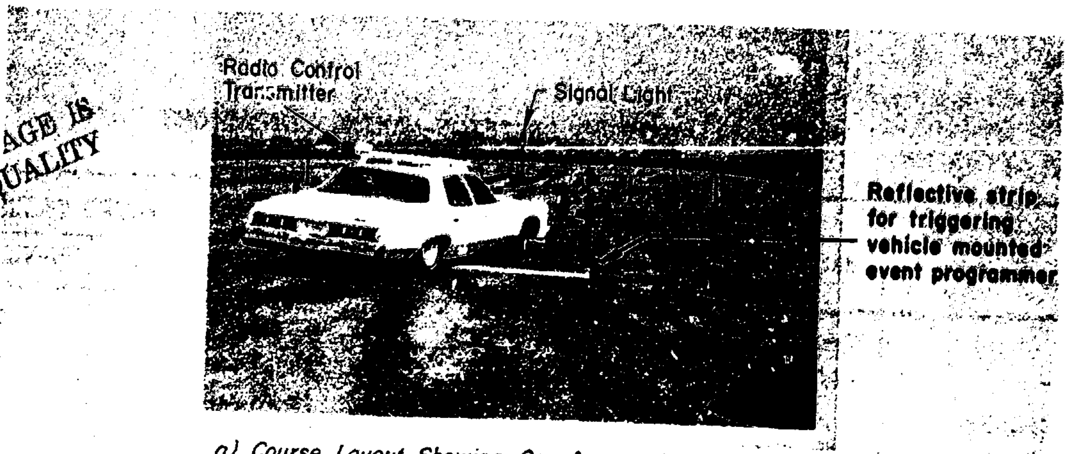
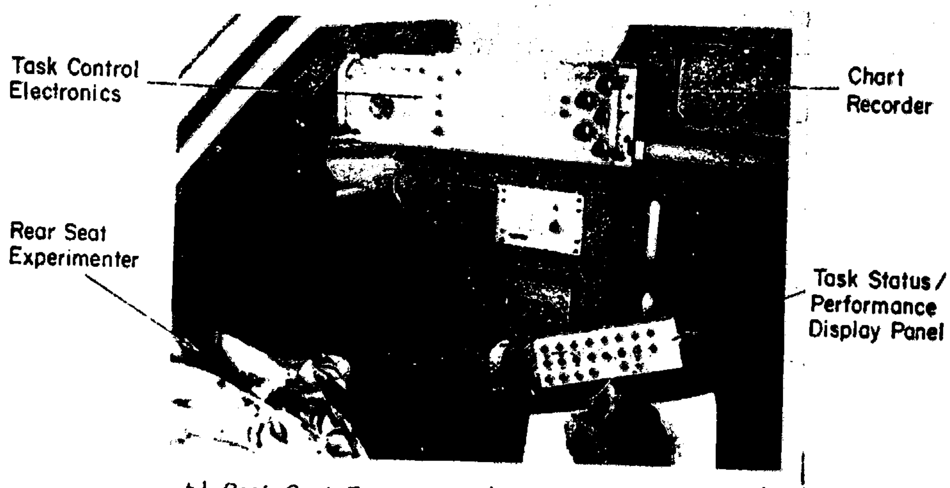


Figure 1. Simulation Setup



a) Course Layout Showing Car Approaching Signal Light



b) Back Seat Experimenter's Station

c) Front Seat Experimenter's Station

Figure 2. Equipment Setup for the Field Validation Study

TABLE 1. DRIVING DECISION-MAKING SITUATIONS

DECISION CLASS	BASIC TYPE	SPECIFIC SITUATIONS	SELECTED TASKS	
			SIMULATION	IN-VEHICLE
Single Stage	Traffic Control	• Signal light	X	X
		• Course navigation		X
	Unexpected Threats	• Car, pedestrian, object unexpectedly enters roadway	X	
		• Object in/on roadway		
Sequential	Maneuvers	• Speed and steering control in a curve	X	X
		• Lane changing and merging		
		• Road entry and merging		
		• Over[illegible]ng and passing		

The perceptual requirements of this task were to estimate car speed and distance to the intersection which the driver then uses to determine the probability of making the light. Driver perception is based on motion of the dashed lines and the intersection, auditory feedback of car speed, and position of the intersection when the light changes from green to amber. The driver does not separately estimate speed and distance, but makes a "Gestalt" estimate of the chance of entering the intersection before the light turns red. The amber light interval was held constant at 3 seconds which is typical of urban signal timing.

Driver signal timing perception was measured by having the subjects verbally report their chance of failing to make a given signal situation immediately after passing through the intersection. Failure was defined as entering the intersection after the light had turned red. This amounts to measurement of a subjective probability in decision theory context, and care was taken to insure that these estimates were unbiased by task performance (Ref. 11). Psychomotor performance was measured in terms of brake reaction times in the situations where the driver stopped.

<u>Curve</u>. The curved portion of the simulation and field test driving scenarios (Figs. 1c and 2a, respectively) required specific steering and speed control in order to avoid loss of control. Tire forces were limited in the simulator equations of motion such that peak curvatures could not be negotiated at speeds greater than about 45 km/h (28 mph) although the

scenario legal speed limit was set at 72 km/h (45 mph). Also 40 km/h (24 mph) speed advisory signs were displayed to the simulator drivers in advance of the curves.

In the field test a special circuit was set to activate an alarm at greater than 0.5 g lateral acceleration in order to simulate a loss of control accident. The car was capable of 0.7-0.8 g turns but actual loss of control had to be avoided for safety reasons. The field course speed limit was 40 km/h (25 mph) and the curve radii were such as to require significantly lower speeds in order to avoid exceeding the imposed g limit.

The critical perceptual task in the curve situation was speed judgment. Speed was represented by visual field motion and auditory feedback, as in the signal event, plus quantitative readout on the speedometer. Use of the speedometer is more appropriate here than for the signal event because of the quantitative nature of the curve limit speed and a lower time pressure on perception and psychomotor action. Perception in this task was again measured by driver-reported subjective probability of crashing which was solicited directly after curve exit. Speed at peak curvature was obtained as an objective measure of risk, i.e., the higher the speed, the greater the risk. Comparison of subjective risk estimates with speed then gives a measure of driver risk perception in the curve situation.

Divided Attention. In the simulator the divided attention situation involved obstacle avoidance. This task consisted of a circular object at the right side of the displayed roadway which sometimes remained stationary at the side of the road or, more frequently, moved laterally into the subject's (right) lane (Fig. 1b), requiring either stopping or steering avoidance. The subject also had to contend with adjacent cars in the left lane which were simulated by a projected slide viewed in the side view mirror (Ref. 9). Changing lanes in the presence of an adjacent car led to a crash as simulated by a buzzer and display jitter. Crashes also resulted from striking the obstacle or running off the road shoulder.

The obstacle avoidance task was a conflict situation. The subject was encouraged by a time reward to continue going if possible, but was penalized for crashing as described further on. This task primarily provided a measure of the driver's visual monitoring and steering control. Comments were solicited from subjects on monitoring behavior in the event of an adjacent crash.

Mechanization of the obstacle avoidance task was deemed too difficult for the field study so a simple route guidance task was substituted. A dashboard mounted indicator was used to direct the subject either left, right or straight after he had passed the signal light intersection. The course layout and timing were such that the route decision was made under a reasonable amount of time pressure.

Driving Scenario and Reward/Penalty Structure

Each run in the simulator and field tests consisted of an approximately 15 minute drive which included a pseudo-random sequence of the above tasks. Program starting points were varied and counterbalanced between subjects in order to avoid learning the event sequences. Circuits for detecting red light and speeding violations were activated at approximately 30 percent of the events to simulate occasional police surveillance.

Audio alarms were activated when violations were detected, and when the lateral g limit for loss of control was exceeded in the field test. A crash buzzer was activated in the simulator when subjects exceeded the road shoulder limits, or ran into obstacles or adjacent cars. Accidents in the field test were further defined by striking the tires and cones used to define the edge of the course (Fig. 2a). Thus subjects were given complete feedback on traffic safety related variables (accidents and tickets) as they would in the real world. In addition the number of accidents and tickets were used as traffic safety measures on the overall driving scenario and were also accounted for in the reward/penalty structure as described below.

Subjects were instructed to behave as they normally would in a driving situation with a reasonable motivation for timely progress while avoiding traffic violations and accidents. In addition, the monetary reward/penalty structure given in Table 2 was used to simulate real-world driving motivations and risks (Ref. 14), and provide a quantitative value structure for expected value modeling of decision-making behavior (Ref. 15). The overall

TABLE 2. REWARD/PENALTY STRUCTURE FOR SIMULATING REAL-WORLD MOTIVATIONS IN DRIVERS

COMPONENT	LAB SIMULATION	FIELD VALIDATION
Run completion bonus	$10	$10
Time saved reward	$2/min	$2/min
Low ticket penalty group	$1/ticket	$1/ticket
High ticket penalty group	$2/ticket	$4/ticket
Accident penalty	$2/crash	$2/crash
Route error penalty	—	$0.50/error

scaling of the structure was made large enough to be meaningful and comparable to the subjects' hourly wages. The run completion bonus was included to insure subjects completing each run, and the time saved reward was set to encourage the subjects to make timely progress on the drives and not become excessively cautious. Penalties were assessed for tickets, accidents and route errors (traffic safety factors). Ticket penalties are one factor that can be manipulated in the real-world (i.e., traffic court fines) and a between group comparison was included for two levels of this variable. Results of the simulator study showed no significant differences between the $1 and $2 penalty groups so the high ticket penalty was increased to $4 for the field experiment. Results on the ticket penalty variation are fully discussed in Ref. 14.

Design, Treatments and Procedures

Subjects were selected from the male licensed driving population through a newspaper ad and screened to insure heavy drinking tendencies (defined as the capability for reaching a peak BAC of 0.15). Based on age and scores on a hostility test (Ref. 16) and betting test (Ref. 17), subjects were matched and divided into the two penalty groups. During training sessions subjects were given several one-half hour exposures to the simulated driving scenarios and reward/penalty structure in order to minimize learning effects during the formal data sessions.

The experimental design shown in Fig. 3 was completed by 12 subjects in the simulator experiment and at a later date by a different group of 14 subjects in the field tests. Session order was counterbalanced between subjects. Performance was measured in four separate runs during sessions of nominally eight hours in length. During alcohol days runs were administered at sober, ascending, peak and descending levels of Blood Alcohol Concentration (BAC) in the simulator tests. The ascending BAC runs were subsequently dropped in the field tests based on minimal differences in simulator performance levels on the ascending and descending portions of the BAC curve. During placebo days runs were administered at roughly the same times as on the alcohol days. Thus subjects served as their own controls for alcohol effects, and penalty structure was between group effect.

Actual times and blood alcohol levels are illustrated in Fig. 4. BAC was measured with a gas chromatograph breath analyzer. Placebo drinks were made by floating a small amount of liquor on top of mixer. Subjects were allowed to select their own mixed drinks in order to maximize subject morale; however, combinations which would not allow credible placebos were tactfully avoided. Alcohol was administered proportional to body weight in three drinks.

The facility layout and personnel assignments were designed to maintain subject motivation and experimental efficiency. Recreational areas were set up adjacent to the simulator and included a bar, breath test area, lounge and dining area, and a restroom. This provided a relaxing atmosphere for the

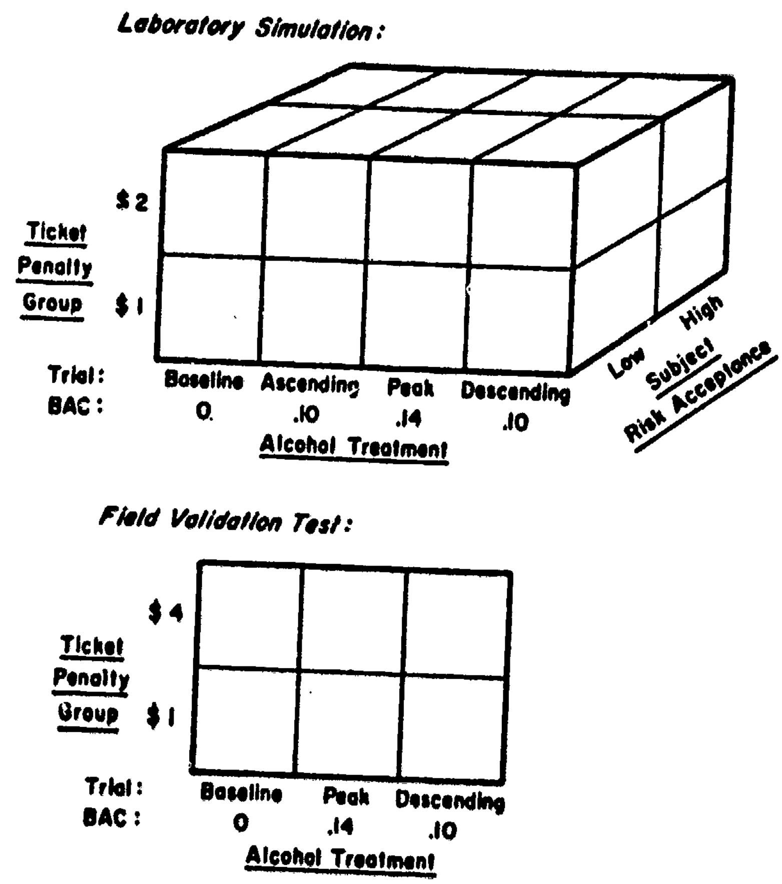


Figure 3. Experimental Design

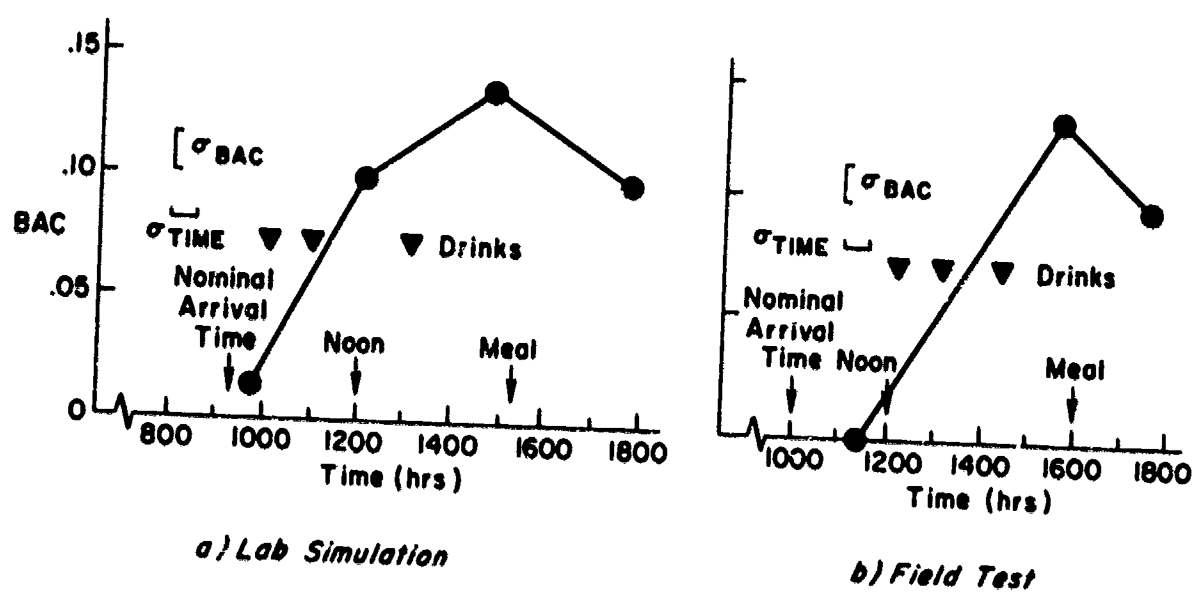


Figure 4. Alcohol Treatment Procedure Summary

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subjects between experimental trials and isolated them from laboratory activity other than when they were being tested.

RESULTS AND DISCUSSION

Overall Performance

Performance measures accumulated over the whole driving scenario are plotted in Fig. 5, which show excellent agreement between the simulation and field test experiments. The total payoff per run gives an overall combined performance measure of the reward/penalty structure components. Average payoff was appreciably affected by BAC as illustrated in Fig. 5a. Sober subjects were making an average $12.50 per run, which dropped to $5 at the peak BAC condition. Analysis of variance procedures (ANOV) proved these results to be reliable ($P < 0.01$), but showed no significant difference between the two ticket penalty groups. The payoff levels were quite substantial, as the average sober subject made roughly $30-50 during his placebo session, and subject comments indicated these payoff levels motivated performance.

Component measures of the reward/penalty structure are also given in Fig. 5. Average driving time to complete the driving scenario (Fig. 5b) was remarkably insensitive to BAC, while speeding tickets and accidents were appreciably elevated with BAC (Figs. 5c and 5d). Since driving completion time was constant, the increased incidence of speeding tickets with BAC implies increased speed variability. Subjects were well aware of the speed limit and speeding penalty, and feedback of speed was available both visually and aurally. Thus, increased speed variability suggests decrements in perception and/or speedometer monitoring.

Considering a speed versus accuracy paradigm, it is apparent here that these subjects maintained average speed levels (and thus average rate of event occurrence) under alcohol impairment at the expense of accuracy (increased tickets and accidents). Thus risk taking increased with BAC, but the question remains as to whether the drivers were aware of the increased risk and thus were willingly accepting greater risk.

The simulator driving scenario provided for three types of accident exposure, and these accident results are plotted in Fig. 6. Crashes on the curve resulted from excessive speed and/or poor steering control and were the most prevalent accident. The adjacent car crashes arose from the driver not monitoring his rearview mirror when he decided to steer around the obstacle (subject reported). This result is consistent with previously reported monitoring failures in driving situations (Ref. 4). Observations during the experiment indicated that obstacle crashes occurred either because the driver took too long to decide to stop and then hit the obstacle, or tried to steer around and clipped it from the side.

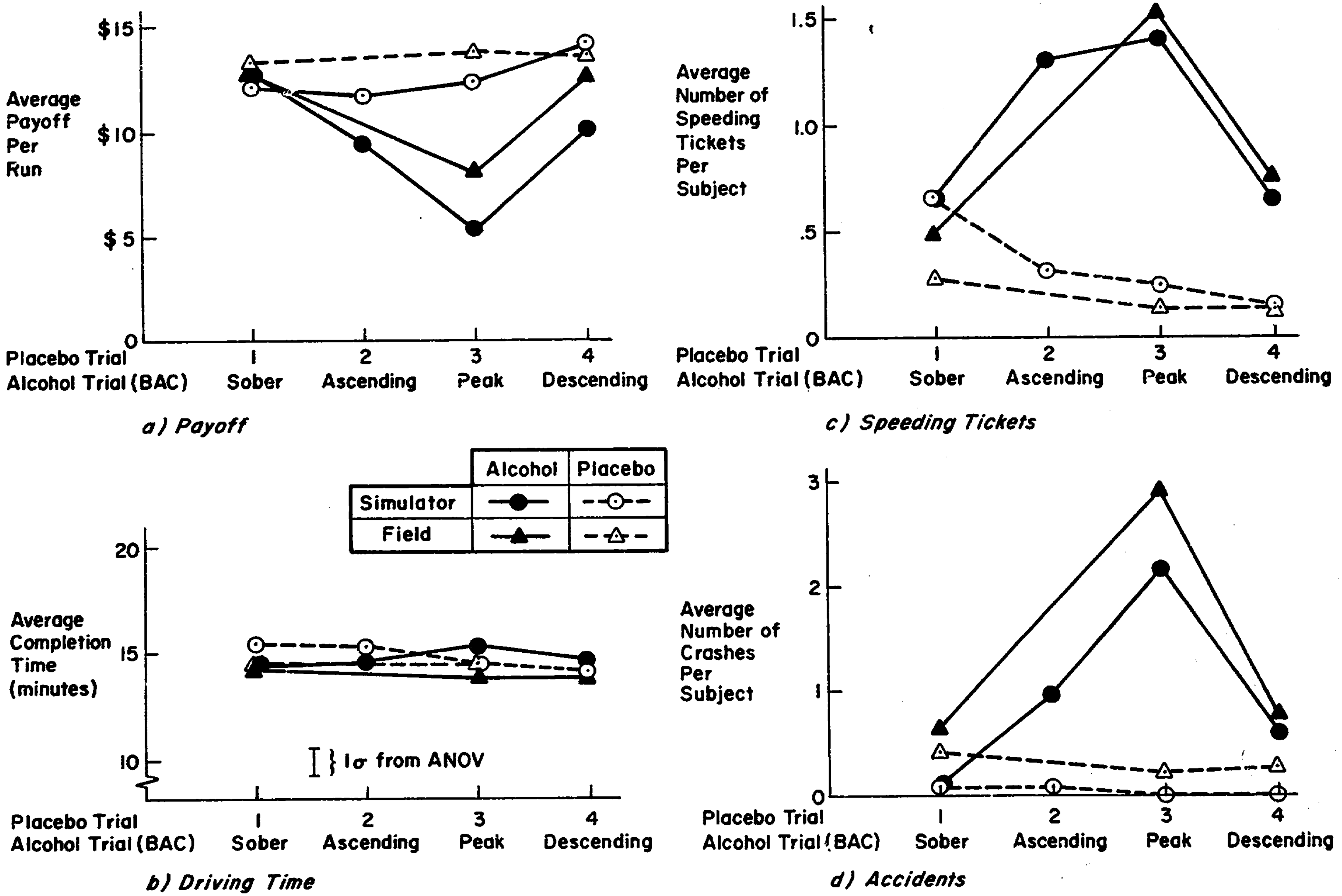

Figure 5. Overall Driving Scenario Performance Measures

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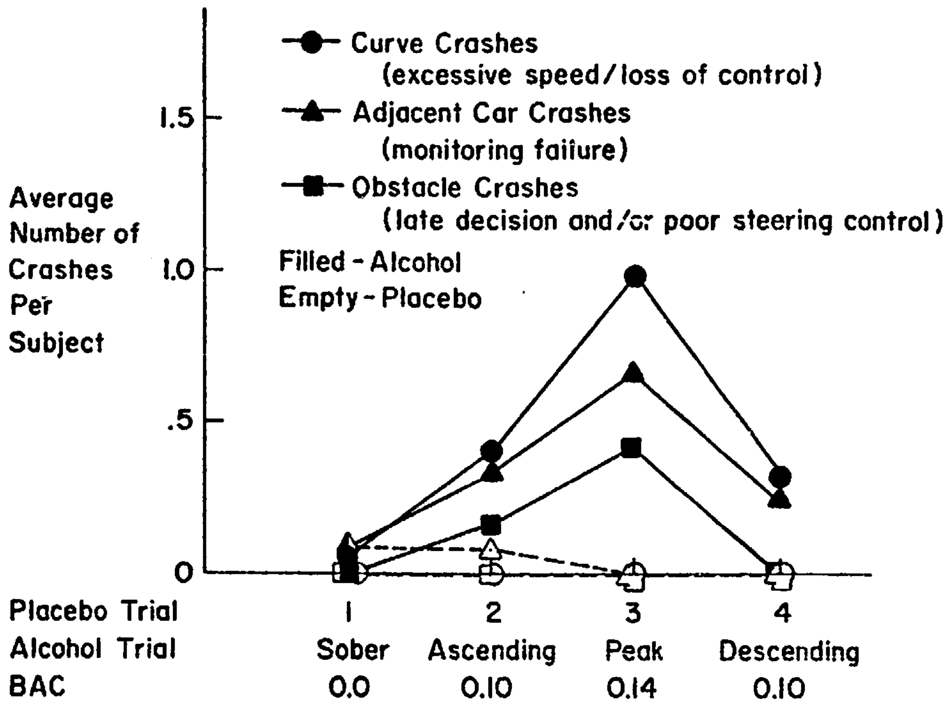

Figure 6. Simulator Curve, Adjacent Car and Obstacle Crash Results

The relative increase in experimental accident rate with BAC is compared with real-world data (Ref. 18) as shown in Fig. 7. Although there is some difference between the two experiments reported here (primarily due to different placebo accident rates), the data are still consistent with epidemiological statistics. The knee of the experimental data occurs in the region of 0.10 BAC and the data bracket the real-world rates. This data thus lend credibility to alcohol sensitivity of our simulated driving scenarios.

Signal Light Behavior

The probability of going on a given signal timing condition and the driver's estimate of failure (i.e., running the red light) are plotted in Fig. 8. There were 5 signal timings randomly distributed throughout the scenario, and the amber light timing was set to change the light when the driver was 3.4 seconds from the intersection (traveling at constant speed) in the simulator and 4.2 seconds in the field test for the data illustrated. The amber light interval was only 3 seconds long so the subjects would invariably run the red light under these conditions if they decided to go. There was some probability of going under this condition, however, which increased under alcohol.

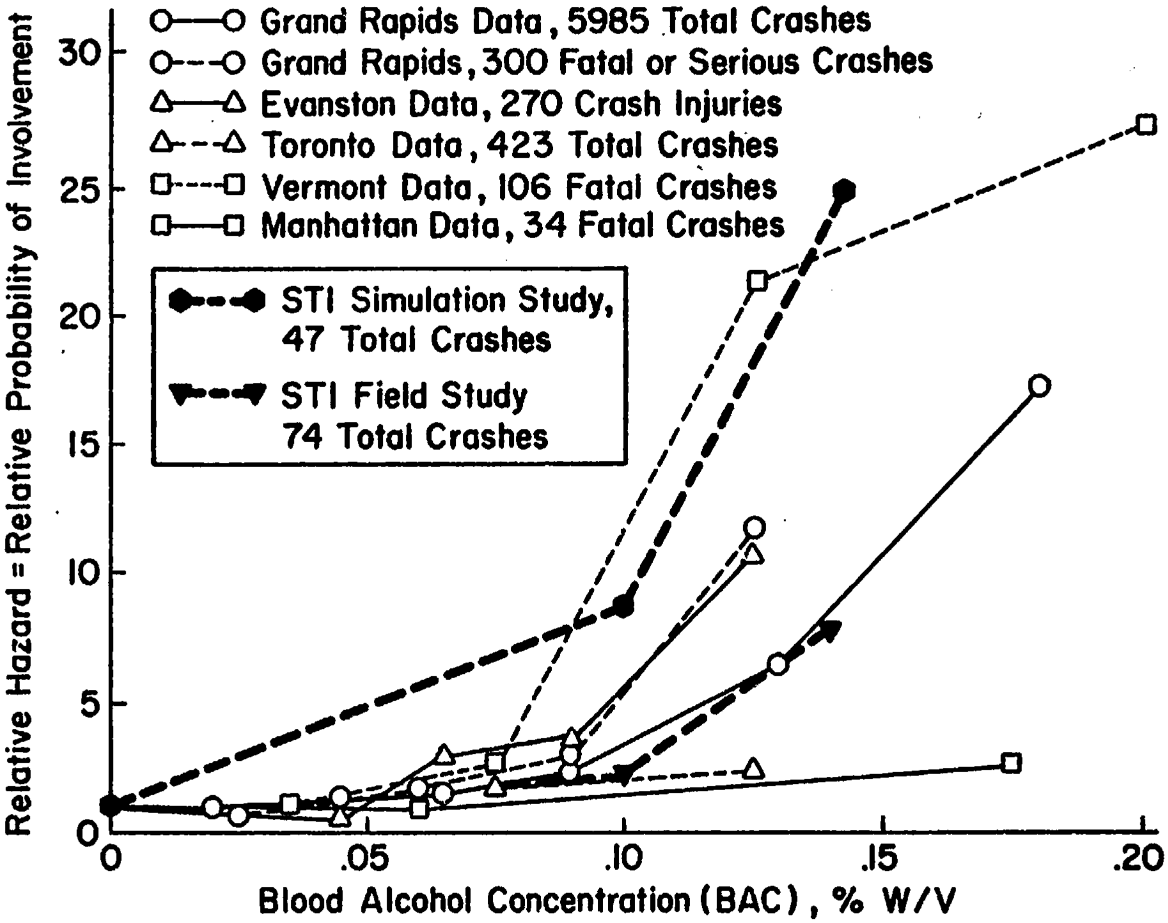

Figure 7. Comparison of Experimental Accidents With Real World Data (after Hurst, Ref. 18)

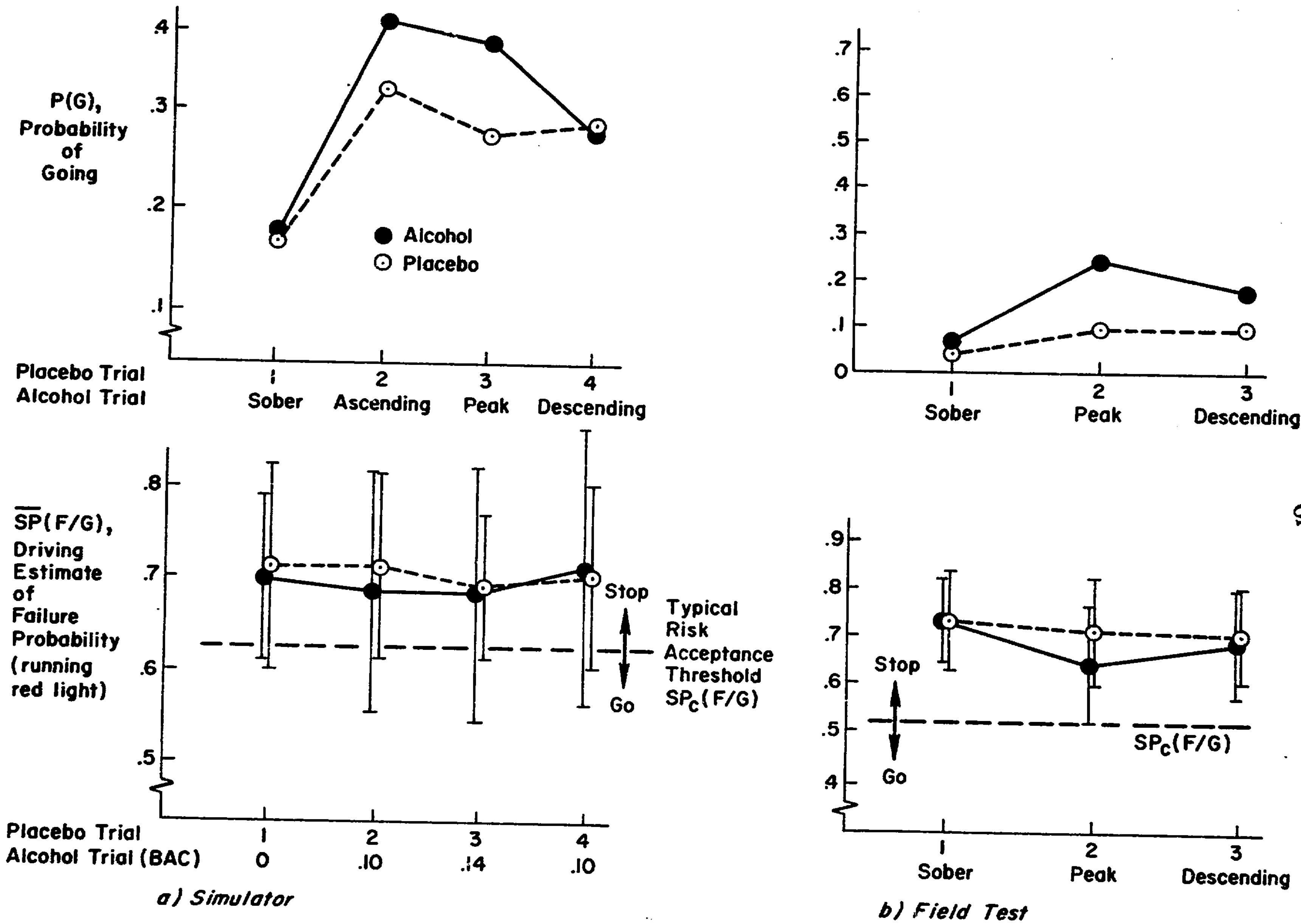

Figure 8. Signal Light Behavior Probability of Going and Driver Estimates of Failure (Running the Red Light) Given a Go

The drivers' subjective estimates of failure given that they decided to go, SP(F/G), are consistent with the probability of going. In the simulation experiment variability in the estimates increased with BAC. If we hypothesize a risk acceptance threshold for going, we see that the increased variability leads to an increased probability of going. In the field test a combination of increased variability and lower mean estimate of risk led to increased probability of going.

The subjects' failure probability estimates were obtained as soon as possible after passing through the intersection on randomly selected events where the subject did not receive a ticket (the police circuit was activated only 30 percent of the time). In order to check for performance biasing (probability estimates influenced by events after the decision point), a separate set of runs were conducted in the simulation where the whole roadway display and signal light were blanked at the end of the amber light interval. The estimates were no different under these circumstances than when the task was carried to completion. These results indicate that the failure estimates were a reflection of the drivers' perception or "Gestalt" of the time distance relationship existing at the appearance of the amber light and the decision point. These points and a complete decision theory analysis of the signal light behavior is given elsewhere (Ref. 15).

Brake response time on the signal light task was used as a measure of signal task psychomotor behavior. The results in Fig. 9 show no effect of alcohol on either the mean or variability in response time.

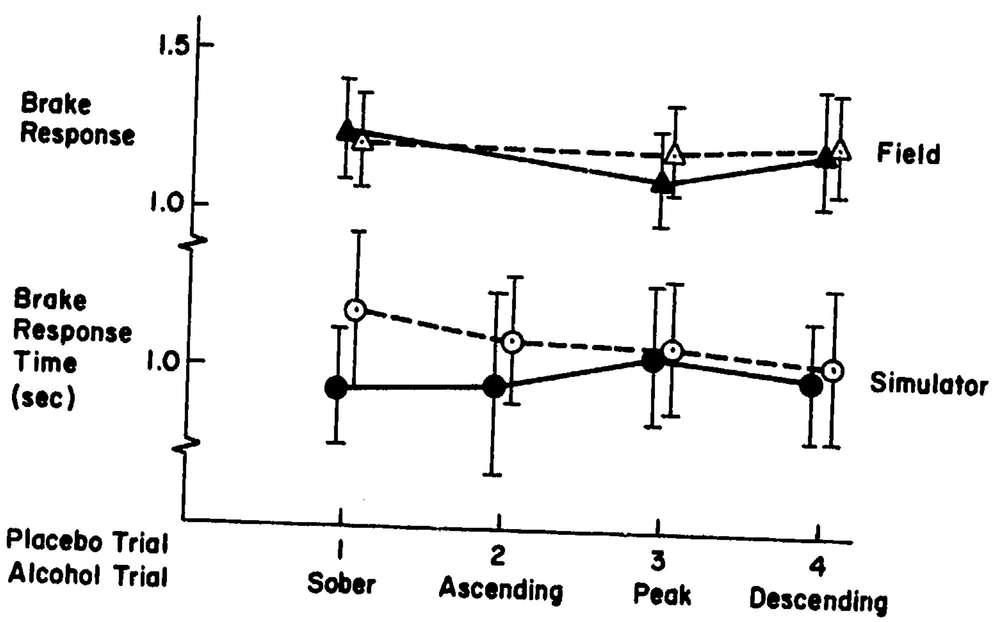

Figure 9. Alcohol Effects on Brake Response Time in the Signal Light Task

Curve Behavior

Drivers had to carefully control speed on the curves to avoid loss of control. As illustrated in Fig. 10, drivers did maintain safe speeds on the average with no significant effect due to BAC level. However, speed variability between curves (computed across several repeat curves/run/subject) did significantly increase under peak BAC. ANOV procedures showed this effect to be significant at the 0.05 level. By taking into account the speed mean and standard deviation values and assuming a normal distribution, we can compute the probability of exceeding the critical curve speed, which should equal the probability of crashing. In Fig. 11 computed and measured crashed probabilities for the simulator data are compared. The computed probabilities show an increase in the region of peak BAC, but are generally lower than the data by 30 percent. In the field test the mean and variability does not explain the increase in accident rate (field accidents were primarily due to g limit exceedences in the curves). However, experimenters noted that g exceedence often occurred with steering corrections. Steering actions by the driver can exceed the g limit at speeds below the critical speed. In the linear region of tire force characteristics, lateral acceleration for a neutral steer car can be expressed approximately as a function of the car's speed (U_o), wheelbase (a + b), and front wheel steer angle, δ_w:

$$a_y = \frac{U_o^2}{a + b}\,\delta_w < a_{y_{max}}$$

The driver could enter a curve and establish safe steady-state conditions (i.e., constant U_o and δ_w), then provide steering corrections which command lateral accelerations beyond the acceleration limit according to the above. As noted, the higher the speed (U_o), the less additional steering angle can be tolerated before the tires reach their acceleration limit. Errors in this mode might result from the driver not establishing a large enough steering angle at the beginning of the curve, then having to make a correction in midcourse which is beyond the acceleration limits of the tires.

Subjective estimates of risk or 'crash' probability were obtained in both studies at the end of selected curves. No effect of alcohol was noted on these estimates. Thus in spite of the increased accident rate under alcohol which was primarily due to loss of control on curves, drivers did not exhibit any perception of the elevated risk.

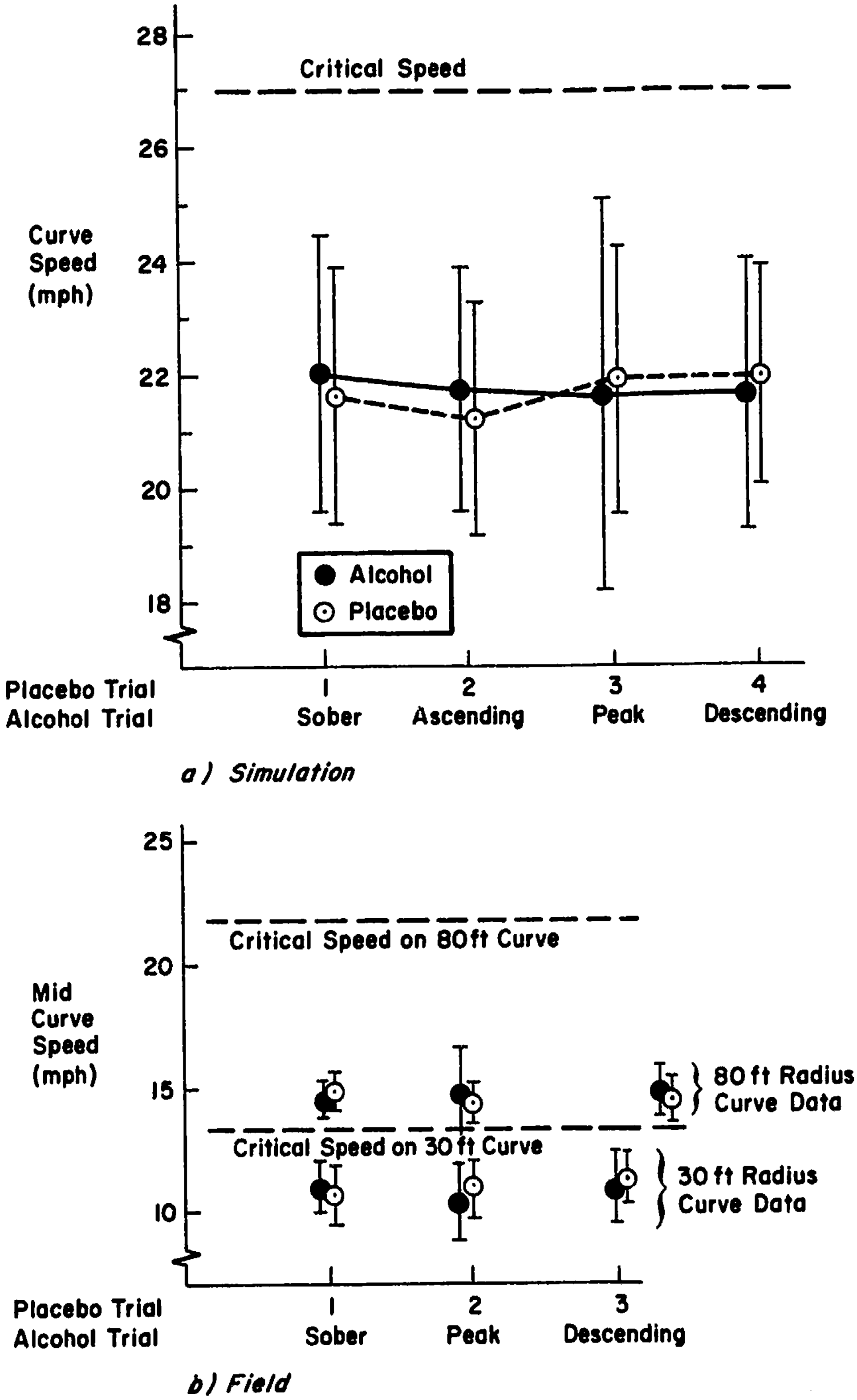

Figure 10. Mean and Variability of Speed on Curves in the Simulator and Field Driving Scenarios

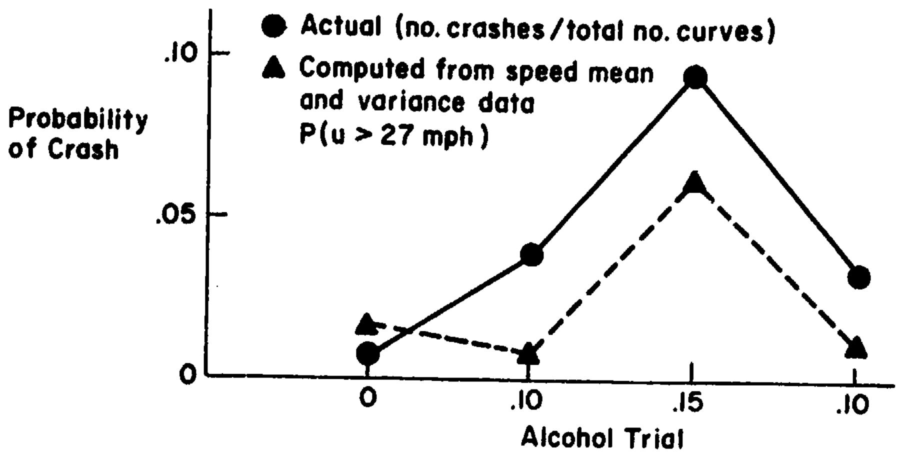

Figure 11. Comparison of Actual and Computed Curve Crash Probabilities for the Simulator Driving Scenario

SUMMARY AND CONCLUDING REMARKS

Overall performance on the driving scenario, as measured by accumulated payoff according to a reward/penalty structure, was appreciably degraded by BAC (blood alcohol concentration). Penalties due to accidents and speeding tickets increased with BAC and were primarily responsible for the decline in payoff.

Increased speed variability under alcohol was responsible for the increase in speeding tickets and curve accidents. On the average drivers did not perceive the increased hazard of the curve task with alcohol impairment as indicated by subjective estimates of risk; however, speed variability did increase, probably due to impaired perception of speed. Similarly, going behavior on the signal task increased under alcohol due to an increase in the variability of risk perception.

The above changes in speed variability and signal risk perception with increased BAC imply perceptual impairment unknown to the drivers. Alcohol increased perceptual variability which increased the driver's risk exposure. However, the mean level of subjective risk estimates was unchanged with alcohol in this experiment, which indicates the subjects were not aware of their increased risk exposure. The incidence of tickets and accidents under alcohol, although increased, was still a low probability event (roughly 1.5 and 1 incident per subject per run, respectively, at the peak BAC level). Although degraded psychomotor skill and perception combined to increase the changes of violations and accidents under alcohol, the subjects were not aware of these changes in risk.

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