Effects of Low and Moderate Levels of Alcohol on Steering Performance

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The role of alcohol in degrading highway safety has been clearly documented in many previous studies (6, 11, 29). About 50 per cent of the drivers and pedestrians involved in fatal collisions have significant levels of alcohol in their blood. These trends, found in the United States, also occur in other countries (7, 10, 22, 23). While there is no longer any doubt that the presence of alcohol in the blood of drivers and pedestrians renders them highly susceptible to highway accidents, there is less known about the nature of the impairment of alcohol on human behavior. While studies have been made to evaluate the effects of alcohol on specific perceptual and simple motor tasks, the findings are generally not clear-cut, and the relevance of such tasks as components of the skills required for driving is not understood. However, a potential application for this type of research is in the development of tasks that can be used as ignition interlocks (27) which would prevent intoxicated drivers from starting their vehicles. Some potential tasks that have been examined include: tracking, complex reaction time, and divided-attention tasks, which tend to be impaired at a blood alcohol concentration of 0.10% (g/100 ml) or less.

The evaluation of the effects of alcohol on skills required in driving has also been done using stimulations at various levels of sophistication. Drew et al (5) found that tracking performance deteriorated at low BACs, of the order of 0.03%. Another tracking study, made to stimulate the illumination and glare of headlamps in night driving, found decrements in tracking performance at BACs of less than 0.02% (12).

By contrast, some studies using driving simulators (3) have not found decrements in various performance measures. In a subsequent study by Moskowitz (17) using the same simulator as used by Case et al (3), there were differences in tracking attributable to alcohol when a side-task was added. The effect of alcohol in tasks requiring time-sharing has also been documented in other experiments (8, 9, 16, 18, 19).

Other studies have used automobile driving tasks, usually at quite low speeds. Studies such as those carried out by Bjever and Goldberg (2) and Perrine and Huntley (20) have found some differences in driver performance attributable to BACs as low as 0.05%.

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$^{2}$This study was supported by the National Institute on Alcohol Abuse and Alcoholism, Grant No. 5 R01 AA00295-02.

329
A study by Cohen et al. (4) indicated that alcohol degrades the ability to make judgments (in this instance, judgments of the adequacy of the size of gaps to drive through), which was interpreted as an increase in risk acceptance. An experiment by Snapper and Edwards (24) found, however, that alcohol impairs a vehicle control task, but not the judgment as to the likelihood of success in a severe handling maneuver.

Thus, studies have been carried out that indicate that alcohol impairs a number of abilities as measured in laboratory, simulation and actual driving tasks, and in the performance of drivers on the roads as measured by the ultimate criterion of collision frequency and severity (28).

There is still a lack of information, however, of which specific aspects of driver behavior are impaired by alcohol. The studies of Moskowitz (e.g. 16) and others have shown that alcohol affects the manner in which the driver processes information. Studies conducted to evaluate the manner in which the driver acquires visual information, such as by Belt (1) and Mortimer and Jorgeson (15) have shown some narrowing in the lateral field-of-view scanned by drivers, an increase in the mean fixation time of glances, and a reduction in the distance of the eye fixations ahead of the vehicle, attributable to alcohol. Such findings also show that the manner in which the driver acquires information for controlling the vehicle and avoiding obstacles, is different when he is under the influence of alcohol than when he is sober.

There are a number of basic cues available to drivers which can be used for steering a vehicle along the road. Previous studies of tracking performance under alcohol have not attempted to isolate these components of the driver's cue structure. Weir and McRuer (32) have suggested that the primary guidance cues used by drivers consist of the lateral position and path angle or heading angle of the vehicle (Figure 1). The derivatives of these measures may also provide important cues to drivers.

By isolating the components of the cue structure drivers use for controlling the path of a vehicle, it may be possible to define the effects of alcohol on the steering task more clearly by noting its influence upon them. This is the strategy that was used in this experiment.

![Vehicle trajectory diagram](image.png)

Figure 1  Vehicle trajectory diagram.
METHOD

Subjects
A total of 18 subjects, eight females and ten males, were paid to participate in the experiment. They were administered the “Mortimer-Filkins” test (14) which consists of a self-administered questionnaire and a structured interview to assess problem-drinking. The test also obtains background and driving experience information. The subjects were randomly assigned, by sex, to either placebo or alcohol treatment groups.

Ages, years of driving experience and “Mortimer-Filkins” test scores of the subjects did not differ significantly according to analyses of variance. Means and standard deviations are shown in Table I. Three of the subjects in each group were diagnosed as problem drinkers or presumptive problem drinkers, representing a rate higher than would be expected in the population of drivers.

<table>
<thead>
<tr>
<th>Group</th>
<th>Age Mean</th>
<th>SD</th>
<th>Driving Experience Years Mean</th>
<th>SD</th>
<th>Mortimer-Filkins Test Score Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placebo</td>
<td>25.6</td>
<td>3.5</td>
<td>9.5</td>
<td>3.7</td>
<td>45.5</td>
<td>25.8</td>
</tr>
<tr>
<td>Alcohol</td>
<td>29.4</td>
<td>8.4</td>
<td>11.7</td>
<td>8.8</td>
<td>50.6</td>
<td>28.6</td>
</tr>
</tbody>
</table>

The Closed-Loop, TV Display Driving Simulator
The tests were conducted using a driving simulator which provides a visual display of the lateral and longitudinal motions of a simulated vehicle, which are controlled by steering inputs from the subject-driver. A straight two-lane roadway, delineated on a continuous belt, 48 in. (122 cm) wide and 40 ft. (12.2 m) in length, is supported by a wooden table. The belt is 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 made at a fixed, simulated speed of 40 mph (64.4 kph). A video camera mounted on a gantry at one end of the belt (Figure 2) 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 TV monitor, which measures 25 in. (63.5 cm) across the diagonal (Figure 3).

Driver steering inputs are translated through an electronic vehicle-response analog to the camera-gantry system, resulting in realistic yaw and lateral movement of the simulated vehicle.

Analog performance data (steering wheel angle, lateral position error, path angle) are recorded on an FM tape recorder for subsequent digitization and computer analysis.

The use of electronic circuitry to control yaw and, thus, lateral position of the video camera makes it possible to electronically introduce path angle errors which
produce lateral position errors to be controlled by the driver. Figure 1 defines the lateral position error and path angle that can be assumed by the vehicle. It should be noted that a motor vehicle, normally equipped with tires, will produce path angles that are made up of two components consisting of the heading angle and the side-slip angle. Side-slip angles are generally of small magnitude, but depend upon the mechanical characteristics of the tires and the lateral forces to which they are exposed. In the simulator, side-slip angles are ignored since the vehicle response that is displayed to the driver is the sum of the heading angle and side-slip angle, to produce the path angle. No attempt was made to measure individually both heading angle and side-slip angles.

In this experiment, disturbances in path angle were introduced as continuous, pseudo-randomly varying electronic steer angle disturbances which simulated cross winds of varying magnitude, frequency, and direction. Each driving session lasted about 30 minutes, and included four trials of 40 seconds when the continuous
disturbance was applied, interspersed with other conditions.

**Administration of Alcohol Doses**

The procedure followed on both days of the experiment was identical for placebo and alcohol subjects. Only the contents of the drinks administered on the second day differed. On both days, the subjects were tested during the afternoon. On the second day, after having received instructions to fast for at least an hour and a half prior to reporting to the laboratory, the subjects were given 15 minutes to consume a drink containing either a low-calorie carbonated soft drink and 200° alcohol or the soft drink with a small amount of alcohol floated on top to simulate the alcohol dose flavor.

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. Twenty minutes after consuming the second drink, a second simulated driving test was made. 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 subjects in the alcohol treatment group 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. The first alcohol dose was formulated to provide BACs of $\approx 0.07\%$, the legal cut-off for impaired driving in the State of Michigan. The second alcohol dose was formulated to produce a mean BAC of $\approx 0.10\%$.

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 BACs. Sturgis (25) administered alcohol to 16 subjects in a study concerning the effects of alcohol on psychomotor skills and found great variation in peak BACs 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%, actual values of 0.075 to 0.13% were attained. Wallgren and Barry (30) have noted that alcohol is only slightly soluble in tissue lipids. At body temperature, lipids absorb only about 4 per cent 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 (according to Wallgren and Barry (30)) 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 a standard deviation of 0.085. Clearly, $r$ must be taken into account for accurate calculation of doses.

Snapper and Edwards (24) employed a dosage formula designed to provide BACs of 0.10% which required visual estimates of subjects’ body fat, and had considerable success in reducing the variance in resultant peak BACs. An adaptation of their formula is shown in Figure 4. The formula is based on empirical findings that a dose of 0.48 ml of absolute alcohol per pound of body weight (or 0.83 g/kg) results in an average peak BAC of 0.10% in fasting subjects. In addition, it enables correction for different amounts of body fat by estimates in standard deviation units of the divergence subjects’ body fat from ‘average’. One standard deviation is equal to $\approx 8.5\%$ of the average dose. Thus, a subject weighing 154 pounds (70 kg) could receive a dose of from 61 to 86 ml (0.69 to 0.97 g/kg; ± 2 SDs.) of absolute alcohol depending upon his estimated body fat.
Figure 4  Alcohol doses required for peak BAC of 0.10% (g/100 ml) by total body weight and experimenter's estimate of body fat in standard deviation units.

In this study, a similar formula was used, but the average first alcohol dose was 0.34 ml of absolute alcohol per pound of body weight (0.58 g/kg), mixed 1:6 with a low-calorie carbonated soft drink. The second dose contained a mean of 0.24 ml alcohol per pound (0.42 g/kg) mixed in the same ratio.

Instructions and Incentive Structure

The subjects were instructed to drive the straight road, maintaining the vehicle in the center of the roadway lane as well as they could at all times.

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 one who obtained the lowest cumulative lateral position error score in driving the simulator would receive a bonus payment of ten dollars.

Experimental Design

Since large learning effects were known to exist in steering performance in the driving simulator, the subjects were given two practice sessions prior to receiving treatment doses.
The study incorporated a between-groups design, in that subjects were tested under one treatment condition only. Statistical analyses of treatment effects, however, were made through both between-and within-groups tests of the interaction of test session (control/practice vs treatment) and treatment condition (placebo vs alcohol). On the first day, all subjects received two practice sessions in the driving simulator. On the second day, the alcohol group's three driving sessions were conducted at target BACs of 0.07% during uptake; 0.10% and 0.07% during alcohol elimination.

RESULTS

BAC Levels

The means and standard deviations of the BACs achieved by the placebo and alcohol groups in the three test sessions on the second day are shown in Table II. The values shown are the means of readings taken at the start and end of each of the testing periods.

<table>
<thead>
<tr>
<th>Session</th>
<th>Target BAC (g/100ml)</th>
<th>Achieved BAC (g/100ml)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>3</td>
<td>0.07</td>
<td>0.076</td>
</tr>
<tr>
<td>4</td>
<td>0.10</td>
<td>0.098</td>
</tr>
<tr>
<td>5</td>
<td>0.07</td>
<td>0.067</td>
</tr>
</tbody>
</table>

Means of Steering Performance Variables

Mean lateral position error was found by analysis of variance to be significantly greater at 0.10% BAC than in the placebo condition (Figure 5). No significant differences were found between the placebo and alcohol groups for steering wheel displacement, path angle and yaw rate.

Time-Series Analyses of Driver Performance

Time series analyses of these data were also made. Examples of these are shown in Figures 6-9, for the power spectra of steering wheel displacement, lateral position error, path angle, and yaw rate used by a placebo and an alcohol subject in two separate sessions. Session 2 indicates performance on the last practice series of trials on day 1, and session 4 shows performance on day 2 under 0.10% mean BAC for the subject in the alcohol group and the equivalent trial for the placebo subject. Figure 6 shows the power spectra of steering displacement in sessions 2 and 4 for subject D in the placebo group and subject F in the alcohol group. It will be noted that the steering wheel frequency response 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 total RMS (root mean square) power of steering wheel displacement, which is the square root of the area under the curve was less in session 4 than 2, showing a reduction in steering wheel activity attributable to practice between sessions 2 and 4.

The subject (F) 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, which resulted in a reduction of his peak steering wheel frequency to about 0.20 Hz, as well as a reduction in the steering wheel response frequency bandwidth. There was also a change in the RMS of the steering wheel displacement, with an increase in the alcohol condition.

Comparing the behavior of the placebo and alcohol subjects shows that alcohol 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.

Figure 7 shows similar comparisons for the lateral position error power spectra, and Figures 8 and 9 for path angle and its derivative, yaw rate, respectively. In each case, the dominant peak frequency and bandwidth of the subject in the placebo group are not changed, but there is a reduction in the RMS values, indicating a reduction in steering wheel displacement, lateral position error, path angle and yaw rate deviations, showing that performance in vehicle control improved as a function of practice.

The alcohol group subject performed similarly to the placebo subject in the practice session 2, while there was a reduction in his peak frequency and bandwidth of all signals under alcohol. This was accompanied by an increase in 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. Of course, individual differences in the responses of subjects under alcohol are to be expected.

Analyses of this type were made for 16 subjects because of some missing data for two subjects. The means of the frequency bandwidths of the signals for eight placebo and eight alcohol group subjects over the five test sessions are shown in Figure 10. Sessions 1 and 2 are practice sessions which were made on the first day. Sessions 3, 4 and 5 were given on the second day. Session 3 is the 0.07% BAC session during uptake, session 4 is at 0.10% BAC and session 5 is at 0.07% BAC, during alcohol elimination, for the alcohol group. For the placebo group, the same temporal sequence of ordering of the sessions was used, but the drinks contained only a trace of alcohol.

Figure 6  Steering wheel displacement power spectra of a placebo and alcohol group subject in sessions 2 and 4.
Figure 7  *Lateral position error power spectra of a placebo and alcohol group subject in sessions 2 and 4.*

Analyses of variance of the values of the frequency bandwidths showed that there were significant treatment group by session interactions for steering wheel displacement, path angle and yaw rate. Individual comparisons of means between treatment group, within sessions, showed:

1. The mean steering wheel displacement frequency bandwidth was reduced at 0.10% BAC and at 0.07% BAC in the elimination phase.
2. The mean path angle frequency bandwidth was reduced at all alcohol dose levels.
3. The mean yaw rate frequency bandwidth was reduced at all alcohol dose levels. The means of the RMS values of the performance measures are shown in Figure 11.

Figure 8 Path angle power spectra of a placebo and alcohol group subject in sessions 2 and 4.
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 path angle RMS was increased at 0.10% BAC and at 0.07% during alcohol elimination.
DISCUSSION

That information processing is affected by alcohol has been amply demonstrated. The results have sometimes been used (17) to infer that studies that are conducted without overt subsidiary tasks should not expect to find effects of alcohol, or at least only minor ones. In addition, the same comment has been used to suggest that tracking tasks, with their demands on perceptual and motor skills, are probably not much affected by alcohol.
However, an argument can be made that the findings concerning the effects of alcohol on time-shared tasks are applicable to the driver’s steering control task and that this should be affected by alcohol even when no overt subsidiary task is used. This is because the steering task has a number of components, which can be defined by the various elements (e.g., lateral position, path angle) of the cue structure used by drivers for safe vehicle control. Secondly, there is now sufficient evidence to indicate that when simulators were used in alcohol studies that have presented a display which
resembles, in its basic elements, the road viewed by a driver, decrements in tracking performance were found at quite low BAC levels (5, 12). In addition, performance on a quite simple pursuit tracking task has also been impaired at low alcohol doses (26).

The present study indicates that low and moderate doses of alcohol do have an effect on the driver's steering performance, and provides additional information concerning those aspects of the driver's cue structure and response behavior which are affected by alcohol.

The frequency response analyses showed that there were significant reductions in steering wheel displacement frequency bandwidths at 0.10% BAC and 0.07% BAC in the elimination phase. Thus, drivers reduced their responsiveness under alcohol, as reported by Reed et al (21). The drivers' behavior in steering can therefore be considered to be more coarse, and similar to that of drivers in the early stages of the driving learning process. This is further shown by the decrease in the mean path angle and mean yaw rate frequency bandwidths, which were decreased in all the alcohol dose conditions. This shows that the drivers who received alcohol were not utilizing these perceptual cues to vehicle control as much as the placebo subjects. Since no significant changes were observed in the bandwidths of lateral position errors, this indicates that the drivers were utilizing this cue in much the same manner as without alcohol. The drivers who received alcohol, therefore, placed greater reliance on the lateral position error cue than path angle and yaw rate, compared to the drivers who did not receive alcohol.

This change in the cue structure used by drivers under alcohol resulted in an increase in the mean lateral position error RMS and mean path angle RMS at 0.10% BAC and at 0.07% BAC during alcohol elimination, showing that alcohol affected the ability of drivers to control the vehicle about the road lane.

While variability in lateral position error was increased in the last two alcohol sessions, it will be recalled that there was also an increase in the mean lateral position error of the drivers at 0.10% BAC, showing that they accepted a position in the lane that was further from the center of the lane.

In summary, these findings show that alcohol affected the cue structure used by drivers for path control of the vehicle. This is shown by a reduction in their sensitivity to yaw rate and heading angle cues, while they maintained emphasis on the lateral position cues. They became more sluggish in the use of the steering wheel as a means of reducing the perceived errors in the position of the vehicle they were controlling, as shown by a reduction in the bandwidth of steering wheel response frequencies under alcohol. This may have been a result of the greater emphasis that the alcohol subjects were placing upon the lateral position error cues. Since the lateral position error is the second integral of yaw rate and the first integral of path angle, the frequency response of a vehicle in lateral position can be expected to be less than in yaw rate or path angle. The reduction in steering wheel response frequencies may, therefore, be attributable either to the lower frequency cues presented to the driver by lateral position error or to a reduction in the driver's responsiveness. Thus, whether the driver's response behavior in steering under alcohol was a function of the perceptual cues that he acted on or a change in his motor responsiveness, cannot be inferred from these data.

The findings do show, however, that the drivers under alcohol changed their information processing strategy, as might have been expected based on studies carried out employing time-sharing tasks. While this study did not utilize an overt subsidiary task, the need for time-sharing in steering control is intrinsic to that task, in that the experienced driver will selectively utilize the elements of the cue structure available to him.
The basic vehicle control task is that of controlling the lateral position of the vehicle in the lane. It can be readily noticed that novice drivers interpret this task literally, by observing the low frequency steering motions they use and the large deviations which the vehicle they are controlling makes about the road. That lateral position error cues alone are quite inadequate for purposes of vehicle control has been experimentally evaluated by Mortimer (13) in an automobile driving task in which some of the cues presented to the driver could be isolated. Therefore, drivers learn to use additional cues, which are likely to be the path angle or heading angle and yaw rate (31).

The findings of this study indicate that the effect of alcohol on the driver's steering control task is fundamentally one of reducing his overall competence to a level more similar to that of novice drivers. The findings are also consistent with those of other studies which have shown changes in the manner in which subjects acquire information, with increasing emphasis being placed on the basic aspects of the task, which in respect to vehicle lateral control is the vehicle's lateral position in the lane. The study also sheds some light on reasons why, in some studies of tracking behavior, there were not decrements in performance attributable to alcohol. Where the pursuit components of a tracking task are not available to subjects, who are therefore faced with pure compensatory tracking, information such as heading angle is not available, so that the cue structure used by subjects is unidimensional, consisting of position error and, hence, is more resistant to impairment by alcohol. This study also showed that there was generally more indication of impairment in the alcohol elimination phase than at the equivalent BAC level during alcohol uptake, suggesting residual effects of alcohol or interactions with temporal variables, such as fatigue.

The findings of this study are consistent with theories of manual control and are a first step to explanations for the perceptual and motor mechanisms underlying loss-of-control crashes involving alcohol.

REFERENCES

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