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Abstract—The effects on driver performance of blood alcohol concentrations below 50 mg% were studied in two contexts: (1) in a critical car driving situation involving emergency braking and evasive maneuvers and (2) in a “surprise” situation that followed the first one and featured the sudden appearance of a man-shaped obstacle blocking the roadway. The results indicate the detrimental effects of alcohol at a total BAC-average of 42 mg%. In the braking and maneuvering task, drivers under the influence of alcohol hit significantly more pylons and took significantly longer distances to stop. There was also a strong tendency for alcohol to impair performance in the surprise situation. Under the influence of alcohol five drivers out of ten collided with the obstacle; this was the case for only one driver out of ten in the control (non-alcohol) condition.

INTRODUCTION

As far back as the beginning of this century, alcohol was recognized as a hazard in connection with traffic. In 1914 a report was published pertaining to the determination of blood alcohol levels of car drivers [Widmark, 1914]. Since that time many scientific studies have been carried out to investigate the impairing effects of alcohol on driver performance. Research has evolved along four major lines: (1) The comparison of accident rates for drivers having driven while intoxicated with those free from alcohol; (2) The indirect method of studying performance on laboratory tasks that have an assumed relation to traffic safety; (3) Studies of the effects of alcohol on tasks which resemble driving—particularly the operation of driving simulators; and (4) Experiments relating alcohol consumption to performance in driving real cars on closed courses.

The level of blood alcohol concentration (BAC) at which impairing effects become distinguishable has been studied within all four investigative lines. All the research points to the same general conclusion, namely that alcohol does impair driving performance. In the case of some studies, especially those done with low levels of BAC, the justifiability of this conclusion is questionable, due to loose ties between the tests used and real world traffic situations.

With regard to accident statistics, it is usually concluded that from a 80 mg% and up there is a steep increase of risk although some studies find an increase in the threshold of risk in the interval between 10–16 mg% [Fox, 1967; Holcomb, 1938; Smith and Popham, 1951].

Results from laboratory tasks indicate that perceptual functions as well as coordination and reaction times are affected at low doses of alcohol [Goldberg, 1970; Kelly *et al.*, 1970].

In a simulator study, Drew *et al.* [1958] have shown negative correlations between BAC and simulator performance. Significant impairment of performance in simulators was also noted by Loomis and West [1958] and Stening and Dureman [1974], using doses of alcohol producing BACs below 50 mg%.

The impairing effects of alcohol have also been detected in real car driving on closed courses at BACs well above 80 mg%. Bjerver and Goldberg, however, in a now classical study [1950] where they compared the performance of a control group with that of a group of drivers who had consumed beer or distilled spirits, found a 27.9% impairment at 48 mg% BAC as compared to the control group. The driving task involved a series of backing, parking and starting maneuvers requiring very accurate positional control of the vehicle. The authors concluded that “the threshold of impairment of driving ability in expert drivers... is an alcohol concentration of ... 35–40 mg% in the blood”. Huntley and Perrine [1971] in a closed course, gymkhana study found that 44% more poles and pylons were upset in the alcohol than in the no-alcohol condition. The difference, however, was not significant at a mean BAC of 43 mg%. Another often cited study was carried out by Lovibond and Bird [1970], who showed non-competition drivers to be markedly impaired at a BAC of 50 mg%. Unfortunately, they fail to provide any

statistical analysis to prove any significant difference from a control group. Many other studies on closed course driving have also established significant degradation of performance due to alcohol consumption. These results, however, have been obtained at higher BACs, e.g. Coldwell *et al.* [1958], Longhetti and Barnett [1965], Kielholz [1969].

Although considerable energy seems to have been spent on finding measures that might detect the effects of alcohol, many studies bear little resemblance to real world traffic situations in which alcohol-associated accidents occur, other than the fact that a real car is used. Parking, precision maneuvering and low speed have been predominant characteristics of these studies. A technique attempting to remedy this deficiency was employed by Huntley, Perrine and Kirk [1973]. The driving task included an emergency stopping situation and an evasive maneuver and was shown to be sensitive to the effects of alcohol. However, the BAC of their subjects was 90 mg%. According to Goldberg [1970], in emergency situations the critical BAC is estimated to be 20–40 mg% whereas in a task requiring less complicated performance the critical level is estimated to be 40–50 mg%. BACs around 50 mg% are of special interest because some countries already have adopted laws prohibiting driving at or above that level of alcohol concentration, and others are considering laws to that effect.

The present study centered on subjects with BACs below 50 mg% in a demanding emergency type task—a task that any driver could have to face any day. The driving task was also designed to rule out possible effects of momentary compensation for the impairing effects of alcohol. Such efforts can often be suspected in experiments where the subjects know the precise point or instance of measurement. This bias could be avoided by employing a technique which leaves uncertain where and when the stimuli will appear. By adding a situation which is a total surprise in a relaxed phase of the experiment, it was hoped that motivational and related experimental bias effects could be reduced.

METHODS

The reported investigation was carried out in three stages: a pilot study with 6 subjects and a target BAC of 50 mg%, and two main experiments (A and B), with 10 subjects in each and target BACs of 50 mg% and 30 mg%, respectively.

Procedure

The driving task consisted of a situation which required emergency braking and an evasive maneuver (e.g., where the roadway is suddenly blocked). In order to be able to perform correctly the driver had to: (1) brake hard; (2) release the brake pressure in order to be able to . . . (3) swerve; (4) realign the car; and (5) brake hard to a full stop. All subjects practiced the driving task for a total of two hours. Correct behavior and the consequences of incorrect behavior were demonstrated by the experimenter, who also gave the subjects feedback as to their performance and instructions for improvement.

All training was carried out in daylight. During the training sessions emphasis was also placed upon the subjects' learning to maintain the prescribed 50 km/h.

The subjects served as their own controls by taking part in two experimental sessions on two consecutive nights, one without alcohol and the other after having consumed alcohol. The order of conditions was rotated so that half of the subjects drove with alcohol on the first night and without alcohol on the second and vice versa with the other half.

The experimental sessions started as soon as it was completely dark. Four drivers were tested each night. All four subjects were, for practical reasons, taken together to a caravan at the test track and were given instructions neither to try to watch nor to discuss each other's performance before, during, or after the experiment. The subjects were told that the number of experimental trials "could" vary. Each subject however had to go through a total of 18 experimental trials (i.e. 8 emergency actions and 1 trial with no emergency stimulus presented with or without alcohol on the first night and the same number in the opposite condition on the second night). In addition, all subjects got one "warm-up" trial preceding the test each night.

As the drivers were returning to the starting point after their ninth trial on the second night, they were suddenly, without warning, confronted with an object blocking their path. Their reactions, either braking or swerving, triggered a camera to take a picture of the obstacle at the moment of reaction. In order to test the possibility of momentary compensation for the

impairing effects of alcohol in a forewarned situation the "surprise" was repeated with the instruction to the drivers to brake as soon as they could see the man-shaped obstacle. Instructions were also given not to reveal the surprise to the other subjects. Blood and breath sampling then completed the subjects' participation and they were taken to a railway station for the journey home.

Course

A 500 m closed section of four-lane motorway was used as the experiment site. On this closed course an arrangement of rubber pylons was set out. It was used for training as well as for testing and consisted of three parallel lanes forming 8 emergency openings along the path as seen in Fig. 1.

The subjects' task was to drive in the middle lane at 50 km/h and as soon as two red brake lights came on to brake and make an evasive maneuver. For this maneuver the driver should use the first available emergency opening either into the left or into the right adjoining lane.

All specifications as presented in the figure were adapted to the vehicle and to the road surface conditions so as to make the task difficult enough to provide a fine-graded measure of performance (i.e. no driver should be able to negotiate the course without hitting pylons and requiring some stopping distance). The obstacle for the surprise situation was made matte dark gray 1 m high and 40 cm wide.

Subjects

The subjects were 26 men, their ages ranging from 19 to 31 with a mean age of 24.5 (st. dev. = 3.3, median = 23.5); the majority were university students. Six subjects took part in the pilot study and ten in each of the two parts of the main study (experiments A and B). Their mean distance driven during the last twelve months was approximately 12,000 km with a range 2,000–20,000 km. Seven of the subjects did not own a car. The drinking habits were quite similar for all subjects: consumption of alcohol a couple of times per month and at each occasion an amount equivalent to approximately 8 cc. of ethanol 100%. Their payment was made dependent upon performance in the two experimental sessions in a manner described under "measurement of dependent variables".

Vehicle

The experimental vehicle was a 1966 Volvo Station Wagon. For presentation of the emergency signal to the driver, two red brake lights were placed on the fenders. The car was also equipped with a 35 mm camera inside the windshield and an electronic flash unit attached to the front bumper. This equipment was triggered either by braking or turning the wheel 60°. In order to make it easier for the driver to maintain the required speed, the accelerator pedal was equipped with an extra spring making it hard to press the pedal beyond a point corresponding to 50 km/h in third gear.

Emergency action stimulus

The two red brake lights were triggered at a distance of 7 m from the emergency opening by a photocell system placed inconspicuously among the pylons. The photocell was placed at random at one of the eight emergency openings. The subjects were told to use the very first available opening as soon as the lights came on.

Alcohol—administration and measurement

The subjects had a light meal 4–5 hr before the experimental sessions. Alcohol was served in the form of scotch whiskey without ice or water. A dose of 1.5 ml of whiskey per kg of body-weight† was used in the pilot study and experiment A, whereas in experiment B a dose of 1.3 ml/kg‡ was ingested. The time allowed for consumption of the alcohol was 15 min. Immediately prior to driving, three capillary samples were taken from the fingers. No attempt

†The equivalent of 0.6 ml 100% ethanol/kg.

‡The equivalent of 0.52 ml 100% ethanol/kg.

Measurement of dependent variables

(1) Emergency situations: *Angle of car*: Both bumpers were marked into quarters. Each quarter protruding into the adjoining lane from the correct position after the car had come to a full stop rendered a 2 Sw. cr (\$0.40 U.S.A.) reduction of payment from the initial value of 22 Sw. cr (\$4.40 U.S.A.) per trial. *Stopping distance*: Stopping distance was measured from the first pylon in the emergency opening to the front of the car, minus 7 m. Payment was reduced by 1 Sw. cr (\$0.20 U.S.A.) per meter. *Pylons hit or moved*: Each pylon knocked down or moved rendered a reduction of 1 Sw. cr (\$0.20 U.S.A.) *False action*: No evasive maneuver, turning in the wrong direction or at the wrong place each resulted in a reduction of 15 Sw. cr (\$3.00 U.S.A.).

(2) Surprise situations: *Distance of reaction*: Distance of obstacle from the front of the vehicle at the moment of reaction (as determined photographically).

RESULTS

The means and ranges of payment reductions on three measures in the three different parts of the study are presented in Fig. 2. In addition, the figures present the BAC-means of three blood samples taken immediately prior to driving and the means of three samples taken directly after the driving. They also show the total mean, taken to be the estimation of BAC during the actual driving.

Pilot study

In the pilot study, performance, as far as *pylons hit* and *stopping distance* are concerned,

Fig. 2. Pilot study: per trial-means and ranges of reduction of payment in Swedish crowns. BAC-means.

deteriorated for all subjects between control and alcohol conditions. Tests of significance of the difference between conditions, made with the Sign test [Siegel, 1956] give $p = 0.015$ for both measures. The same method applied on *angle of car*, where three subjects showed deteriorated performance and three subjects improved performance, yielded no significant difference. Figure 2 also shows BAC during actual driving to have been fairly close to the intended 50 mg%, and indicates decreasing BAC from before- to after-measurement. This was the case for all six subjects.

Experiment A

In Experiment A eight subjects out of ten were affected in a negative way by alcohol in two measures: *pylons* and *stopping distance* (Fig. 3). This shows a significant difference ($p = 0.055$), whereas *angle of car* again did not reveal any significant difference between conditions. Five subjects improved their performance, and five had their performance impaired. As for BAC the same tendency as was shown in the pilot study is again evident. All ten subjects had lower BACs after driving—a mean reduction of 9 mg% in 25 min.

Experiment B

In Experiment B the number of *pylons* that were hit increased in eight cases, decreased in one case and remained the same in one, as calculated from control to alcohol conditions (Fig. 4). The difference between conditions is significant ($p = 0.02$). This is also true of *stopping distance* ($p = 0.055$), where two subjects improved their performance and eight took longer *stopping distances*. As for *angle of car*, nine subjects showed impaired performance, and one improved his performance with alcohol—a significant difference ($p = 0.011$). In this part of the

Fig. 3. Experiment A: per trial-means and ranges of reduction of payment in Swedish crowns. BAC-means.

Fig. 4. Experiment B: per trial-means and ranges of reduction of payment in Swedish crowns. BAC-means.

study two subjects were shown not to have reached the elimination phase of the blood alcohol curve. The other eight subjects had lower BACs after driving than before.

False actions

The small absolute number of false actions carried out during the experimental sessions did not provide a basis for statistical testing. However, the number of false actions carried out in the control condition—all three parts taken together—was 4 as compared to 10 in the alcohol condition (Fig. 5).

Illustrated in Fig. 6 is the performance of the ten subjects with the lowest BACs on three measures. Eight subjects hit more *pylons* in the alcohol condition, whereas two subjects hit fewer *pylons*. The difference between the alcohol and no-alcohol conditions is significant ($p = 0.055$). Exactly the same relation also holds true for *stopping distance*. The measure *angle of car*, however, does not reveal any significant differences between conditions. Performance deteriorated for six subjects and improved for four from control to alcohol conditions.

A comparison was made of possible differences due to the order of presentation of the two conditions. This comparison showed that if the results from the total number of subjects driving with alcohol in the first session and no alcohol in the second are grouped together and compared with the ones of the reverse order, there are no significant differences.

The overall mean of rank order correlations between performance in control and alcohol conditions was 0.69, as calculated via Fisher's Z [Guilford, 1974].

Fig. 5. Absolute numbers of false actions in alcohol and control conditions. Sums over all three parts of the experiment.

Surprise situation

As for the surprise situation, a series of circumstances (i.e. strong wind gusts blowing the obstacle away) reduced the number of tests successfully carried out. Other circumstances (such as repeated camera failure) also made the use of the photographic distance measuring method impossible. Thus, only collisions or safe stops could be registered. A total of ten subjects were tested while under the influence of alcohol and another ten subjects in the control condition. The results are presented in Fig. 7. Since repeated measurements could not be made, the results of the two groups of subjects in the emergency situation were tested for possible differences, in the other measures, however, no significant differences between the two groups were found.

When the procedure was repeated to test for a "pull-onself-together-effect" all subjects made safe stops.

DISCUSSION

The results give clear evidence of the degrading effects of alcohol upon driving performance in emergency situations. Detrimental effects are found to exist at blood alcohol concentrations below 50 mg%—the overall mean of BACs being 42 mg%. The ten subjects who happened to reach BACs in the range between 24 and 40 mg% show the same impairment of performance. The differences between conditions are significant for two measures: *pylons* and *stopping distance*. The variations in sensitivity of the third measure—angle of car—both between subjects and between parts of the study, probably could be attributed to variations in importance assigned to this variable by the subjects. Admittedly it could be considered somewhat artificial and was originally used in order to standardize the driving behavior of the subjects.

As can be seen in the figures, there were tendencies for ranges to be wider and for the maximum values as well as the minimum values to be higher in the alcohol condition than in the control condition. As far as the *pylons* measure is concerned, these tendencies constitute significant differences between the two conditions. The difference in blood alcohol concentrations between parts A and B of the study were too small to justify separate conclusions. No significant difference was found between BACs as tested with the Mann-Whitney U-test. As for the surprise situation, the loss of data and the crude observational method, stating only collision or no-collision, give little justification for safe conclusions in a statistical sense. However, a

BAC before driving 38 mg%, range 26—47 mg%
 BAC while driving 34 mg%, range 24—39 mg%
 BAC after driving 30 mg%, range 18—38 mg%

Fig. 6. Means and ranges for the 10 subjects having the lowest BAC.

tendency for impairment of performance can be observed, much the same as in the rest of the study. The results are in good accordance with those of Bjerver and Goldberg [1950] in that effects of alcohol were demonstrated below 50 mg%, although the driving tasks were different. Taylor and Stevens [1965] came to much the same results at a mean BAC of 66 mg% in a study which also included a surprise situation. Good accordance also exists between these results and the results from several simulator studies, indicating impairing effects of alcohol below 50 mg%.

The same goes for estimations of thresholds of influence and increased accident risks in the BAC-interval between 20–40 mg% in traffic situations [SOU, 1953: 20].

There are reasons to believe that the results underestimate rather than overestimate the true differences between driver performance in emergency situations under the influence of alcohol and performance under sober conditions.

Firstly, the drivers were subjected to stress by taking part in an experiment, by being observed and by knowing that on each experimental trial an emergency situation would occur. This, according to Goldberg and Myrsten [1971], could reduce the effects of alcohol. This interpretation is also in accordance with the Hawthorne effect which indicates that an individual who knows that he is being observed in an experiment may try extra hard to compensate for impairing effects, in this case those of alcohol. Compensation would be especially likely at lower BACs [Perrine, 1973]. In traffic situations it is thus possible that differences between sober performance and performance under the influence of alcohol would be even greater. Secondly, the fact that the subjects had practiced the driving task very thoroughly also indicates a possible underestimation of true differences, and there are also indications that well-learned skills are less vulnerable to the effects of alcohol than unfamiliar ones [Lovibond and Bird, 1970]. Critical

Fig. 7. Absolute number of subjects who collided with the obstacle or stopped safely in the surprise situation.

and emergency situations occur with low frequency in everyday traffic, thus providing very few chances to practice and get used to the handling of such situations. Milner [1972] expressed it this way: "It is likely that if a drug is shown to affect driving skills in an experimental situation, its effects are probably even more pronounced in general driving behavior." Another reason to believe that the observed effects of alcohol by no means constitute a potential maximum is the fact that they were observed in the elimination phase of the BAC-curve in all cases but two, as indicated by the before- and after-driving mean BACs. According to Kielholz, Richter and Hobi [1975] and many others, the impairing effects of alcohol are most pronounced in the absorbing phase of the intoxication.

The reliability of the results is emphasized by the fact that the results are virtually the same in all three parts of the investigation, making them replications of one another as far as procedures and results are concerned.

As for validity, the investigation suffers from the usual setbacks inherent in all situations that are not real traffic but semi-laboratory. The test situation was developed from typical situations which are employed in most driver improvement courses where emergency maneuvering is in the syllabus. The relevance of this evasive maneuver is illustrated by figures presented in the Swedish Experimental Safety Vehicle Programme [Samuelsson *et al.*, 1973; see also Favero 1975]. In a statistical skid accident study they found 10.5% to be locked wheel accidents. Out of these, 19% were running into another vehicle from behind. Almost all of these could have been avoided by evasive maneuvers. 93.8% stayed in the same lane when they were about to run into the car in front of them. Comments from the subjects also indicate that they considered the task relevant to safe driving and its artificiality was not felt.

Unfortunately it was not within the scope or resources of this study to demonstrate what aspect of the driving task was most affected by alcohol intoxication. Rather the purpose has been to study the effects of alcohol in a generalizable situation containing most of the ingredients that could enter a traffic situation that puts heavy demands on the driver. Thus, if one is willing to accept the semi-laboratory driving performance as representative of full-scale driving performance, then this study has shown the detrimental effects of very low BACs in situations demanding fast reactions, attention, rapid decision-making and precise and accurate action on the part of the driver.

It should be pointed out that the absolute figures *per se* are of minor importance since they are dependent to such great extent upon such factors as the vehicle, the lay-out of the pylon setting, the friction between tires and road surface and so on. What is more important is the impairment as such.

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