Assessment of Driver Impairment: Evaluation of a Two-Choice Tester using Ethanol

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Abstract

Fifteen healthy volunteers aged 18-35 years took part in this three period crossover study evaluating a portable performance tester designed for roadside use. They received by mouth placebo and two doses of ethanol on separate days. Doses were calculated to produce blood alcohol levels or 50 and 80 mg/100 ml. Testing was carried out before the drink and starting at 40 minutes after the drink. Breathalyser readings showed peak blood alcohol levels of 54.4 mg/100 ml (S.D 11.1) for the smaller dose and 83.0 mg/100 ml (S.D. 8.4) at the larger dose. Significant impairment was seen with the larger dose of ethanol. Response time was increased for the arrow flankers test (attention in the presence of distractors), and errors were increased for paired associates (visuospatial working memory) and for length estimation (judgement). A composite measure showed a clear dose-related pattern of impairment. These results indicate that a short test battery taking about ten minutes to complete can reliably show the effects of ethanol under controlled laboratory conditions. Further work is needed in the field, and with a more varied population to assess the use of such a device to assess impairment due to alcohol and drugs at the roadside.

Keywords: Automobile driving; Cognitive impairment; Drugs and driving; Ethanol; Psychomotor impairment;

Introduction

It has been known for many years that impairment of driving due to ethanol is a major factor in road traffic accidents (Borkenstein, 1964; Robertson and Drummer, 1994). More recently, epidemiological evidence has indicated that daytime use of benzodiazepines (Barbone et al., 1998; Longo et al., 2000) and cannabis (Drummer et al., 2003) may also constitute driving risks.

Ethanol and benzodiazepines, as well as a wide range of other types of drug, produce impairments in laboratory tasks related to driving, or in actual driving performance (see e.g. Hindmarch, 1980; Swift et al., 1988; O'Hanlon and Ramaekers, 1995; Mattila et al., 1998; Ramaekers et al., 2000; Farquhar et al., 2002; Ramaekers, 2003). Such data indicate that residual impairment can occur after night time medication, and that both legal and illicit drugs are likely to cause such problems.

Progress has been made in replacing sedative medications with newer drugs which are less likely to cause impairment, particularly in the areas of antihistamines and antidepressants (O'Hanlon and Ramaekers, 1995, Ramaekers, 2003). However, sedative drugs continue to be prescribed to substantial numbers of patients who are likely to wish to drive, and the scale of the involvement of illicit drugs in traffic accidents remains unclear, though it is likely to be substantial (Mercer and Jeffet, 1995; O'Kane et al., 2002).

In the case of ethanol there is a well-established legal framework for prosecuting drivers based on the measurement of the drug in breath, blood or urine. Legal limits (80 mg/100 ml blood in the UK, 50 mg/100 ml in much of continental Europe) have been established which are justified by the demonstrations of significant impairment to driving-related functions and by increased risk of accidents at these levels. For other types of drug there is no comparable body of evidence on which to

base such empirical limits. Some countries, particularly in Scandinavia, adopt a "zero-tolerance" approach to illicit drugs, making any detectable amount of a scheduled substance in a driver grounds for prosecution (see e.g. Ceder and Jones, 2001), but this still does not deal adequately with the problem of impairment due to prescribed drugs (probably a greater problem than illicit drugs). In any case most jurisdictions require evidence for impairment if not in the individual then at least on a population basis, as is the case for ethanol.

The question therefore arises as to whether impairment due to drugs can be reliably detected in a particular individual. Measures of psychomotor performance, attention, and other functions relevant to driving can be shown to be impaired by drugs in placebo-controlled laboratory studies. Can measurements of such functions demonstrate that a particular individual's performance is impaired, and if the person has taken a drug provide evidence that the impairment is due to the drug(s) shown to be present?

There are several problems in such a project. The first is that the tests will need to be administered before firm evidence is available of the presence of drug in the drivers body, and at the roadside. Thus the test system must be portable, easy to use (for both drivers and police officers) and the test battery must be short. The second is that the system must not have marked practice effects. In laboratory studies, volunteers are given introductory sessions to ensure that they are familiar with the test procedures and to minimise practice effects. This is not possible in the roadside testing situation, and tests must be used which are sufficiently straightforward that little or no practice effects occur. A third problem relates to language – verbal skills vary greatly, and for many people now their first language is not that of the country in which they live . Thus test material should be non-verbal.

Probably the most important issue is that of variability of the population. In laboratory studies, we typically study changes within an individual – a person is tested

before and after drug, and very often in several sessions in which different drugs or doses are given, and a placebo included for comparison. Thus the person's drug-free state acts as a control for the performance in the presence of drug. None of this is possible in the present context. A single measurement of performance is obtained from a (possibly) impaired individual, and can only be compared to the performance of a relevant population, since we do not know how that person performs when not impaired. Given the variability of performance between individuals, it may be difficult in many cases to show from a single measure that a driver is impaired.

In order to test the feasibility of the roadside impairment testing approach, a test system has been developed based on previous experience with investigating the effects of CNS depressant drugs (particular ethanol and benzodiazepines) and of using a portable performance test system (see e.g. Cameron et al., 2001; Tiplady et al., 2003). The system is based on a portable tablet computer (Fujitsu Stylistic LT P-600). Responses are made by pressing on one of two large buttons on either side of the device. Tests were selected on the basis of (1) known sensitivity of the test (or a similar paradigm) to ethanol; (2) simplicity of the task to someone who has never used such a system before; (3) assessment of a variety of abilities relevant to driving, while fitting into the two-choice framework; (4) simple bold images on the screen, suitable for use in varied lighting conditions; and (5) no verbal content in the tests (though instructions and feedback cannot completely avoid verbal material).The tests selected for the system were the Arrow Flanker Task, a measure of attention in the presence of distractors (Tiplady et al., 2003); Paired Associate Learning, a test of visuospatial working memory (Smith and Milner, 1981); and Length Estimation, a test of spatial judgement (Farquhar et al., 2002).

The present study has been carried to provide an initial evaluation of the sensitivity of the test system to ethanol in a placebo-controlled volunteer study.

Although the limitations of such an approach have been outlined above, it is necessary to start with such a study in order to determine the basic properties of the system.

Methods

Design

The study was in two parts. The first part assessed a different set of performance tests, and will be described elsewhere (for preliminary report, see Degia et al., 2004). In the second part volunteers took part in a familiarisation session, and then in three experimental sessions in which they received by mouth one of three treatments: (1) placebo; (2) ethanol low dose (50 mg/100 ml blood); or (3) ethanol high dose (80 mg/100 ml blood). Doses of ethanol in g were calculated for each volunteer using the empirically derived formulae (Watson et al., 1981; A. Parkes, Head of Driving Simulation Centre, TRL Ltd, Crowthorne, Berkshire, UK, personal communication):

$$(3.82-(0.143*A)+(0.168*H)+(0.525*W))*T/100 \text{ for males, or}$$

$$(-3.67+(0.187*H)+(0.432*W))*T/100) \text{ for females,}$$

where A is age (years); H is height (cm); W is weight (kg); and T is the target concentration (mg/100 ml), which was either 50 or 80. The order of administration was randomised in blocks of six volunteers. This allocation, while incomplete, ensured an approximate balance of the six possible treatment sequences in the study. Performance testing was carried out once before and once after treatment.

Subjects

Fifteen volunteers (8 male, 7 female) aged 18-35 years (mean 22) and weighing 56.4 – 104.2 kg (mean 75.2)with body mass index 19.2-30.1 (mean 24.4) took part in the study. All were judged to be in good general health at the initial medical screening, and showed a negative pregnancy test if female. Recruits who consumed more than an

average of 21 units of alcohol per week were excluded, as were those taking any medication other than oral, transdermal or depot contraceptives, non-steroidal analgesics (e.g. ibuprofen), or paracetamol. Volunteers gave their written informed consent to take part in the study, which was approved by the Quorn Research Review Ethics Committee.

Impairment Tests

The following tests were included in the test system:

Arrow Flanker Task

Five symbols appeared on the screen. The central symbol was an arrow, pointing either right or left, and the task was to press the button corresponding to the direction of the central arrow as quickly as possible. The other symbols could be either *congruent* – arrows pointing in the same direction as the central arrow; *non-congruent* - arrows pointing in the opposite direction to the central arrow; or *neutral* – squares. (Figure 1). Feedback was given to incorrect responses. Response times and numbers of errors were recorded. This task is based on the flanker paradigm described by Eriksen and Eriksen (1974).

Paired Associate Learning

Two shapes appeared on the screen, one on the left, the other on the right. A series of these shapes then appeared in the centre of the screen, and the volunteer pressed the left or right button as quickly as possible to indicate the side on which the shape initially appeared (Figure 2). If an incorrect response was made, the pair of shapes appeared again. After eight trials using two shapes, a second pair of shapes appeared, and then single shapes now drawn from the set of four appeared in the centre of the screen, and the volunteer continued to respond in the same way. This continued until

eight shapes were in the response set. Response times and numbers of errors were recorded. This test was based on the spatial memory task introduced by Smith and Milner (1981).

Length Estimation

In each trial, a vertical line was presented, with a gap to its right. The volunteer pressed the right button (Yes) to indicate that the line fitted through the gap, the left button (No) if not (Figure 3). Feedback was given for correct or incorrect Yes responses, but not for No responses. The size of the gap, the difference between the line length and the gap length, and the distance between the line and the gap all varied between trials. This test was based on the length estimation task described by Farquhar et al. (2002).

Spiral Maze

The maze consisted of a white path bounded by a black spiral, with circular obstacles. The pen was placed at the centre of the spiral and the path traced around the spiral as rapidly as possible while avoiding the black sides and the obstacles. Time taken was recorded with a stopwatch. The error score was calculated as described by Gibson (1978), scoring minor errors (line touching the side or obstacle) as 1 point, and major errors (line penetrating the side or obstacle) as 2 points.

Equipment

The spiral maze used pen and paper. All other tests were administered on the impairment tester, a handheld device based on a Fujitsu LT-P600 tablet running Windows 2000. Responses were made using the two buttons, as illustrated in Figure 4. The test system was programmed in Java®. The complete impairment tester battery

(not including the spiral maze) took about 10 minutes to complete. The breathalyser used was the Lion Alcolmeter SD-400 (Lion Laboratories, Barry, U.K.)

Procedures

Each volunteer first took part in a training session in order to minimise learning effects, during which each test was carried out at least twice.

Volunteers then took part in three sessions separated by a washout period of at least 24 hours. They were not permitted to use any nicotine-containing products whilst in the Unit, and were instructed to take no alcohol or caffeine for 24 h prior to an assessment visit. Volunteers were requested to go to bed at their usual bedtime the night before an assessment day, and to have a low fat breakfast on the test day.

Sessions started at either 10:00 or 13:00 , each volunteer always starting at the same time. They were first breathalysed, then completed a set of baseline performance tests. At approximately 60 minutes after arrival alcohol or alcohol placebo was administered in the form of a drink containing vodka (40% by volume) with an equal volume of mixer, or just mixer. Mixer was tonic, diet cola, or diet lemonade as preferred by the volunteer. Volunteers were breathalysed at 40 minutes post-drink, completed a second set of performance tests, and were breathalysed again. They were then provided with a light meal, had a final breathalyser reading and were then transported home by taxi.

Statistical Analysis

Differences between placebo and the two doses of ethanol were tested for each performance test measure using ANOVA (Proc GLM in SAS). The model included the effects of subject, session (I – III) and treatment (placebo, low dose, high dose).

Differences from placebo were assessed using pairwise t tests, comparing each dose of ethanol to placebo.

A measure of overall performance was constructed by converting each test measure into a z-score using the mean and standard deviations of the pre-dose (unimpaired) scores. These z-scores were then summed for all measures showing a trend to impairment, and then re-normalised, to form a composite measure of overall effect size. This was also analysed using ANOVA.

In order to investigate the ability of each test to discriminate impaired performance compared to the distribution of unimpaired scores, a discrimination index was constructed as follows: for each test measure the values for the three pre-dose assessments were pooled, and the 75th percentile in the direction of impairment was obtained. The percentage of the values from the high ethanol post-dose assessment that showed greater impairment than this 75th percentile was taken as the index of discrimination.

Results

All volunteers had zero breathalyser readings at the start of the sessions. For the low dose sessions, the mean blood ethanol concentrations were 54.4 mg/100 ml (S.D. 11.1) before the post-drink testing, 47.2 (S.D. 8.2) after the testing, and 27.4 (S.D. 9.3) at the end of the session. For the high dose sessions the concentrations were 81.7 (S.D. 15.8); 83.0 (S.D. 8.4); and 64.2 (S.D. 5.8) respectively. These results indicate that ethanol levels close to the targets (50 and 80 mg/100 ml) were obtained.

Data from the performance tests are shown in Table 1. All test measures except Length Estimation Response Time and Spiral Maze Time showed changes in the direction of impairment, particularly at the larger dose of ethanol, and the results from the larger dose were significantly different from placebo for the Arrow Flanker Task

(Response Time: t=2.11; p<0.05); Paired Associates (N Incorrect: t=2.32; p<0.05); and Length Estimation (N Incorrect: t=3.46; p<0.01).

The overall impairment measure was constructed from the five tests that showed changes in the direction of impairment. Results are shown in Figure 5. There was a clear dose-related increase in impairment score, and the difference between high dose and placebo was significant (p<0.01).

The results from the measure of discrimination are shown in Table 2. The maximum discrimination for a single test was 40% (Paired Associates N Incorrect and RT; Length Estimation N Incorrect). The discrimination for the overall impairment measure was 60%.

Discussion

The impairment tester was clearly capable of detecting the effects of ethanol in the context of a crossover controlled study, all three of the tests having one measure that gave significant effects with the larger dose of ethanol and a corresponding trend with the lower dose. Given the short duration and simplicity of the tasks included, compared to those frequently used in laboratory studies, this is a promising outcome.

The ability of ethanol to impair psychomotor performance and memory is well-established (Heishman et al., 1997; Tiplady et al., 1999; Mintzer and Griffiths, 2002). Less work has been done on the effect of ethanol on judgement, although this is likely to be important in real risk-taking situations (Cohen et al., 1958; Flanagan et al., 1983; Farquhar et al., 2002). The confirmation that a short simple measure of length estimation can show reliable effects of ethanol will facilitate further work in this area.

The overall impairment score, combining the test results into a single measure, gave greater sensitivity than the individual test scores, as expected. However, the ability of the tests to discriminate performance impaired by ethanol from the normal

range of performance in the absence of ethanol was not very great. The problem is the range of scores obtained in the normal alcohol free group. This is illustrated in Figure 6. which shows the distribution of scores for the overall impairment measure for all the pre-dose assessments. The values range from −1.4 to 3.2, a total range of 4.6, and the interquartile range is 1.2. Given that the mean change in score from placebo to high dose is 1.48, this clearly gives plenty of scope for a person at the high end of the ability range to still be within normal performance limits when impaired.

The discrimination index used here is not very demanding, the cut-off being at the 75th percentile of the alcohol free distribution. To use test results as evidence of impairment a higher level, perhaps 95% would be more appropriate. However with sample sizes of 15 individuals and 45 observations, the 95th percentile is not a robust parameter, hence the choice of the 75th percentile. When larger samples are available it will be appropriate to use a stricter measure.

There are a number of possible approaches to obtaining measures which will perform better in detecting impairment from a single administration of the test battery. The first is to vary the choice of tests. The battery used here assessed a reasonable variety of abilities (Attention, Working Memory, Visual Estimation) that are known to be affected but other aspects of performance could be considered. One example is hand eye coordination. The Spiral Maze was used here as a reference, but was not considered suitable for inclusion in the main test battery in its standard form. The results here were not significant, but the trend from the error scores were in the expected direction, and previous studies have shown this test to be sensitive to ethanol (Cameron et al., 2001; Tiplady et al., 2003). Some form of tracking task (Jex et al., 1966; van Steveninck et al., 1991) might be useful here. Another possibility is to use a divided attention or dual task paradigm (Moskowitz and DePry, 1967). Such tasks show good sensitivity, but were not included in the present design because they tend

to have marked practice effects, and instructions for use are rather more complex than with the tests used here.

Another approach is to develop the methods of combining scores into a single measure. It may be that certain combinations of impairment are particularly indicative of impairment, and that more efficient methods than simple summing of z scores could be useful.

Future work will need to address these issues of discrminablity, as well as extending the use to larger populations and situations more closely related to the intended roadside use of the system.

Acknowledgement

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Table 1.

Effects of ethanol on measures of performance

Test Measure	Placebo	Low Ethanol	High Ethanol	F(2,26)	Treatment Effect p =
Arrow Flanker Test					
N Incorrect	0.80	1.09	1.38	1.07	0.3364
RT Correct (ms)	450	461	475*	2.26	0.1248
Paired Associates					
N Incorrect	1.79	2.59	4.49*	2.86	0.0754
RT Correct (ms)	630	663	694	0.84	0.4416
Length Estimation					
N Incorrect	6.15	7.44	8.94**	6.00	0.0072
RT Correct (ms)	959	882	860	1.06	0.3598
Spiral Maze					
Error Score	15.5	15.3	19.9	2.24	0.1265
Time Taken (s)	22.9	23.6	23.1	0.84	0.4430
Overall Impairment Score					
Effect Size†	-0.03	0.57	1.48**	5.05	0.0140

Key: * $p<0.05$; ** $p<0.01$ compared to placebo (t test)

RT: Response Time. Scores are mean values

†The overall impairment score is normalised so that the pre-treatment values have a mean of 0 and standard deviation of 1. The values thus correspond to effect sizes.

Table 2

Ability of test measures to discriminate ethanol-impaired performance from general variability of performance in the absence of ethanol

Test Measure	Index of Discrimination
Arrow Flanker Test	
N Incorrect	20%
RT Correct (ms)	27%
Paired Associates	
N Incorrect	40%
RT Correct (ms)	40%
Length Estimation	
N Incorrect	40%
RT Correct (ms)	13.%
Overall Score	60%

Key: The index of discrimination is defined as the proportion of individuals' scores on high dose ethanol that exceed the 75th percentile (in the direction of impairment) for scores in the absence of ethanol. Thus 25% is chance level (no discrimination) and 100% represents maximum discrimination

Captions to Figures

Figure 1. Examples of stimuli used in the Arrow Flanker Test. In each trial, five symbols appeared on the screen. The volunteer was instructed to respond by pressing the button corresponding to the central arrow, and to ignore the other symbols.

Figure 2. Examples of stimuli used in the Paired Associate Learning Task. Two stimuli initially appeared (top). These disappeared and were replaced by a series of single stimuli in the middle of the screen. The volunteer pressed the button corresponding to the side in which the stimulus initially appeared.

Figure 3. A sample stimulus from the Length Estimation Task. The volunteer pressed the right button if s/he thought the line would go through the gap, the left button if not.

Figure 4. Schematic layout of the impairment tester. The system was based on a Fujitsu LT-P600 tablet computer, with a diagonal screen size of approximately 20 cm.

Figure 5. Effects of ethanol on the Overall Impairment Index. Mean scores of the index together with standard errors are shown.

Figure 6. Box and Whisker plot of the baseline (pre-drink) values of the Overall Impairment Index. The plot shows the median, quartiles, 5th and 95th percentiles, and outlying values.
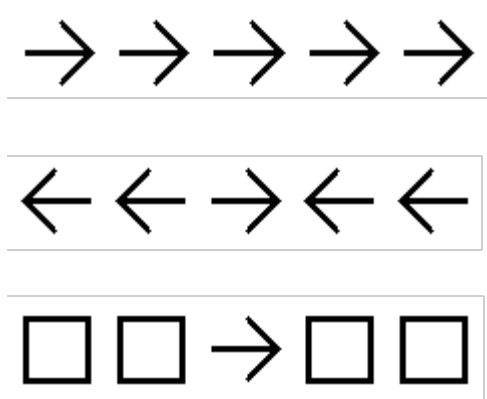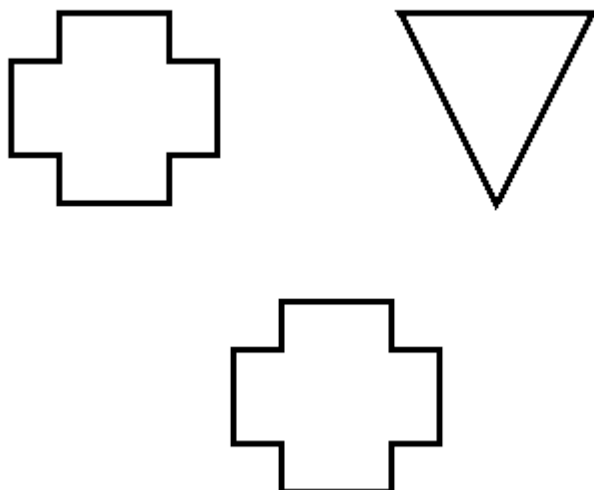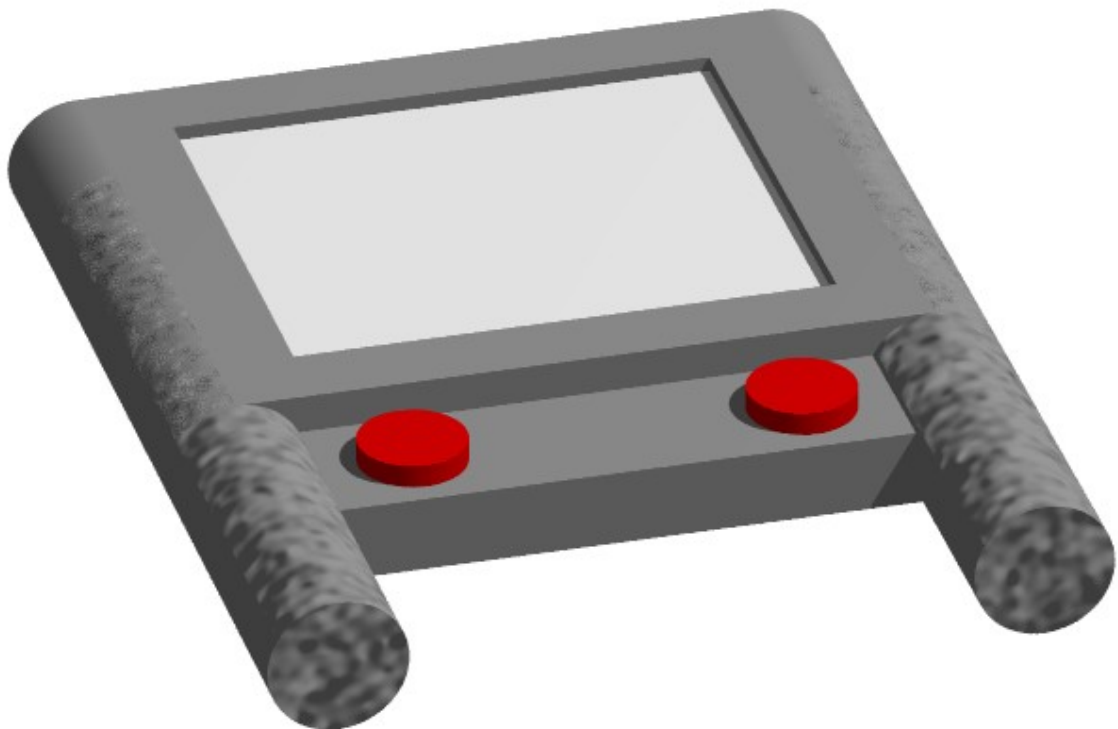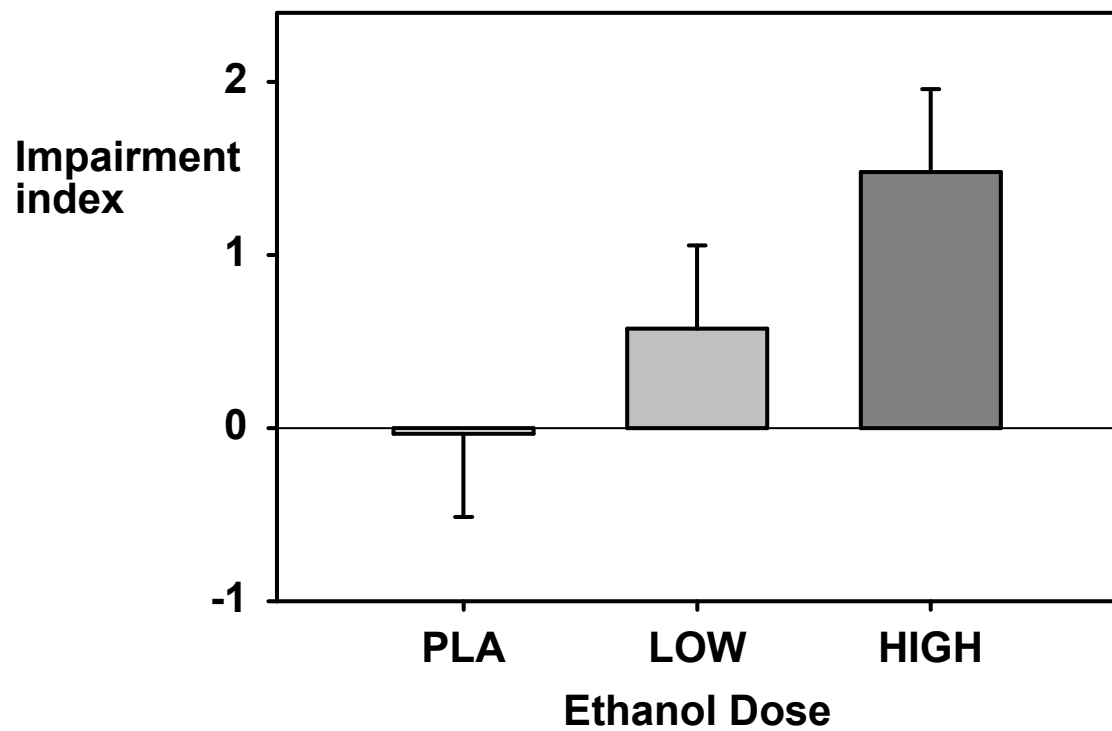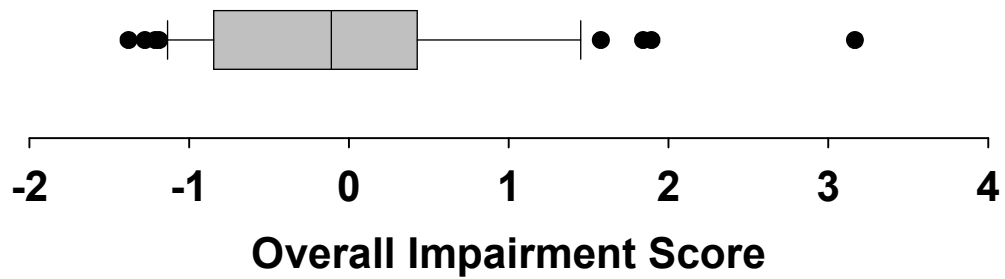
Figure 1

Figure 2

Figure 3

Figure 4.

Figure 5

Figure 6