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Ethanol, errors, and the speed–accuracy trade-off☆

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Abstract

Ethanol has been shown to have a relatively greater effect on error rates in speeded tasks than temazepam, and this may be due to a differential effect on the speed–accuracy trade-off (SATO). This study used different instruction sets to influence the SATO. Forty-nine healthy volunteers (24 males, aged 18–41 years) were allocated at random to one of three instruction conditions — emphasising accuracy, neutral, and emphasising speed. After familiarisation, they took part in two sessions spaced at least 4 days apart in which they received either ethanol (0.8 g/kg, max 60 g males, 50 g females) or placebo in randomised order. Tests were administered starting at 30 and 75 min postdrug. Instructions significantly affected performance. In two maze tasks, one on paper, the other on a pen computer, the pattern of instruction effects was as expected. A significant increase in errors with ethanol was seen for both maze tasks, and there was a tendency to speed up with ethanol (significant only for the pen computer task). Responses to fixed stimulus sequences on the Four-Choice Reaction Test also showed a tendency to speed up and an increase in errors with ethanol, while all other tests showed both slowing and increases in errors with ethanol compared to placebo. Error scores are consistently increased by ethanol in all test situations, while the effects of ethanol on speed are variable across tests.

Keywords: Speed–accuracy trade-off; Ethanol; Psychomotor performance; Errors

1. Introduction

Ethanol is a CNS-depressant drug, and impairs performance on a wide range of abilities. Reaction times are generally slowed, and attention, cognitive function and memory are all affected (Hindmarch et al., 1991; Millar et al., 1995; Wallgren and Barry, 1970). Such a global effect on performance is also seen with other types of CNS-depressant such as benzodiazepines, antihistamines, and anticholinergic drugs (Curran et al., 1988; Hindmarch, 1980; Rusted et al., 1995).

Recent work comparing ethanol directly with temazepam has suggested that the effects of these two drugs on performance may differ in some respects. Firstly, in speeded tasks where significant numbers of errors occur, volunteers on ethanol show a smaller increase in reaction times than those on temazepam, while making a greater number of errors. This dissociation is illustrated for the digit–symbol Yes/No task in Fig. 1, and a similar pattern is found for a four-choice reaction test (Tiplady et al., 1998). Secondly, in a section of the four-choice reaction test designed to examine performance in an underloaded situation, volunteers taking ethanol tended to speed up, and to make substantially more errors compared to placebo, while those on temazepam slowed down, with little or no increase in the error rate.

Taken together, these data suggest that the two drugs may be having different effects on the speed–accuracy trade-off (SATO) that is being made by the volunteers in these tasks. Volunteers in these studies were working under the normal (ambiguous) instructions: ‘‘Work as fast and as accurately as

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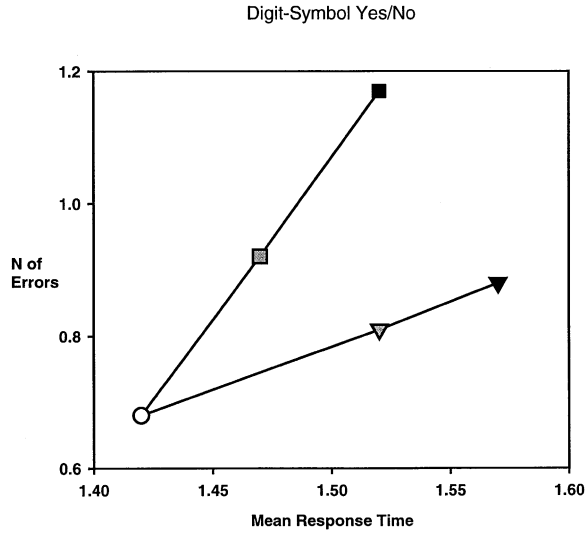

Fig. 1. Speed–accuracy plot of the effects of temazepam and ethanol on the digit–symbol Yes/No task. Open circle: placebo; grey square: ethanol 0.6 g/kg; black square: ethanol 0.8 g/kg; grey triangle: temazepam 15 mg; black triangle: temazepam 20 mg. Data redrawn from Tiplady et al. (1999).

you can." In this situation, they must make their own judgement as to the relative importance of speed and accuracy. In general, speed and accuracy can be traded-off against each other over a range of values, longer response times being associated with fewer errors.

A schematic illustration of the relationships between speed, accuracy, and impairment is shown in Fig. 2. The solid line shows the basic SATO curve, with shorter response times being associated with more errors. Impairment to performance on the task is represented in this type of plot by a shift upwards and/or to the right. The vertical arrow in Fig. 2 shows errors increasing while response time remains the same, while the horizontal arrow shows response time increasing with no change in error rates. In practice, the change will often be between these two cases, with both slowing and an increase in errors, as indicated by the two dotted arrows, which illustrate patterns of impairment very similar to those seen with ethanol and temazepam (cf. Fig. 1).

These differences between ethanol and temazepam suggest that it may be of interest to investigate the relationship between speed and accuracy of performance with ethanol in more detail. One possibility is that ethanol leads to a tendency towards speeding of responding, perhaps associated with feelings of confidence and well being, while at the same time causing an overall impairment of performance. An alternative is the 'alcohol myopia' suggested by Steele and Josephs (1990). Their hypothesis suggests that ethanol leads to a narrowing of attention, with the person concentrating on the most salient aspects of the situation, and ignoring or neglecting less salient aspects. In the context of a reaction time task, speed would generally be considered more salient than accuracy, since speed is involved in every response, while errors occur only occasionally. In other circumstances, such as flying a plane, accuracy would be most salient, and impairment found mostly in tasks that had to be carried out occasionally such as checking fuel levels or weather reports (Billings et al., 1973).

It is known that one way of changing the SATO a person makes is to vary the instructions given. Instructions that emphasise either speed rather than accuracy or vice versa lead to corresponding shifts along the SATO curve. Since such instructions are effective in changing the behaviour in the performance task, this provides a means of distinguishing between the two accounts of ethanol effects given above (Wickelgren, 1977; Wong and Gilpin, 1991). Instructions leading to greater accuracy in performance should increase the salience of accuracy in the task. Thus on the alcohol myopia account, volunteers working under instructions which emphasise accuracy should focus particularly on accuracy when on ethanol. Thus they should slow down more and make fewer errors on ethanol than those given standard instructions or instructions emphasising the importance of speed. Ethanol should exaggerate, or amplify the effects of the instructions. The other possibility, that ethanol simply has a constant effect on speed, should lead to no such exaggeration. The changes in speed and accuracy produced by ethanol should be similar whatever the instructions given to the subjects.

The present study investigates performance on a variety of tasks in which speed and errors are both important outcome measures. Three sets of instructions were used, the standard ambivalent instructions, and ones emphasising speed, or accuracy. These instructions were piloted before the main study started to ensure that they were indeed effective in influencing test performance. Volunteers were allocated to one of the three instruction sets,

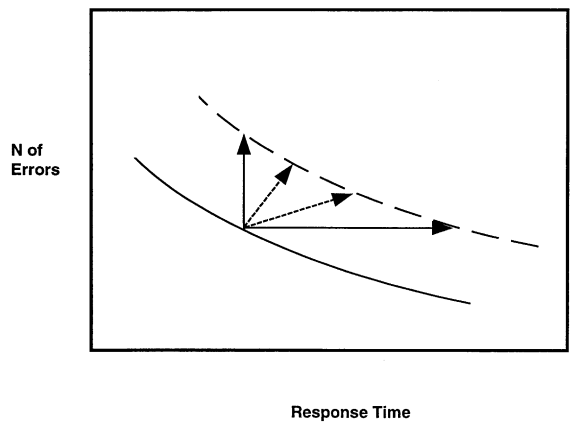

Fig. 2. Schematic representation of a typical speed–accuracy function (solid curve). The dashed curve above it represents impaired performance. The vertical solid arrow shows impairment that takes the form of an increase in errors with no change in response time, while the horizontal arrow indicates increase in response time with no change in errors. Intermediate cases with increases in both errors and response times are shown by the dotted arrows.

and then took part in a crossover comparison of ethanol with placebo.

2. Methodology

2.1. Design

A mixed design, using:

(1) between-subjects allocation to three different instruction conditions, viz.: emphasising speed (S), emphasising accuracy (A), and neutral (N)

(2) a two-period within-subjects crossover in which all volunteers received either an ethanol or placebo drink in randomised order. Administration was double-blind. Sessions took place in the afternoon or early evening. At least 4 days elapsed between study sessions. Performance on a range of tests of psychomotor speed and accuracy was assessed over a 2-h period following the drink.

2.2. Volunteers

A total of 49 volunteers, 24 males and 25 females, aged 18–41 years (mean 21.7) and weighing 48–94 kg (mean 67.3) took part in the study. All were healthy as assessed at initial screening. Alcohol consumption ranged from 1–50 units per week (mean 13.2). Volunteers gave written informed consent to participate in the study, which was approved by the Ethics Committee of the Lothian Health Board.

2.3. Assessments

The following tests were administered.

2.3.1. Gibson spiral maze

This paper and pencil maze consisted of a white path bounded by a black spiral, with circular obstacles. The pencil 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 and the error scored obtained (Gibson, 1978).

2.3.2. Rectangular maze

A light path appeared on the pen computer screen against a dark background: The pen was placed on the starting position. When a bell sounded, the volunteer traced the path to the finishing position as quickly as possible, while trying stay within the light track. Time taken and number of errors (times when the pen left the track) were recorded (Cameron et al., 2001).

2.3.3. Digit–symbol substitution

Nine symbols were matched to the digits 1–9 in a key at the top of the page. A random sequence of digits was printed in a grid on the sheet, and the task was to write the corresponding symbol under each digit as quickly as possible. The task lasted for 90 s (Wechsler, 1958).

2.3.4. Digit–symbol Yes/No

In this computerised version of the digit–symbol substitution test, there was key on the screen which matched nine symbols to the digits 1–9. Below this were two boxes in which were presented a symbol–digit pair. If the pair corresponded to a match in the key table, the volunteer tapped a Yes button, if not, a No button, as quickly as possible. The mean response time and the number of errors were recorded (Mattila and Mattila-Evenden, 1997).

2.3.5. Rapid visual information processing

A sequence of digits appeared one at a time on the pen computer screen at a rate of 100/min. The task was to detect three consecutive odd digits or three consecutive even digits and respond by a tap on the screen as quickly as possible. The number of correct responses, the response times for correct responses, and the number of incorrect responses (false alarms) were recorded. The task lasted 10 min (Bakan, 1959; Wesnes and Warburton, 1983).

2.3.6. Four-choice reaction task

An array of four squares on a monitor screen corresponded to four buttons on a response box. The squares ‘lit up’ in sequence, and the volunteer responded by pressing the appropriate button as quickly as possible. Some of the time the sequence of stimuli was random, at other times the same sequence of four lights was repeated 8–12 times. The mean response times and the number of errors for the blocks of repetitive and random sequences were recorded (Wilkinson and Houghton, 1975; Tiplady, 1991).

2.3.7. Subjective assessments

These were made using visual analogue scales set up on the pen computer. Each scale consisted of a 10-cm line, the ends of which were marked with antonyms, e.g., alert–drowsy, sober–drunk. Volunteers made a mark on the line to indicate how they felt at that moment. Two factors, similar to those previously described (Herbert et al., 1976), were used as follows — Functional integrity: drowsy, feeble, muzzy, clumsy, lethargic, mentally slow, dreamy, incompetent, bored; Mood: excited, discontented, troubled, tense, sad, antagonistic, unsociable. In addition, the sober–drunk scale was analysed individually.

2.4. Equipment

Pen computer tasks were set up on the Apple MessagePad MP2000 (Cameron et al., 2001). The four-choice reaction test was set up on a BBC model B microcomputer with a custom response box (Tiplady, 1991). Digit–symbol substitution and Gibson spiral maze used paper and pencil.

Table 1
Results from measures of performance and mood

	Treatment			Instructions				Interaction: treatment × instructions
	Placebo	Ethanol	S.E.	Accuracy	Neutral	Speed	S.E.	
Gibson spiral maze (paper)								
Time taken (s)	35.6	35.2	0.80 n.s.	40.7	34.9	30.6	0.99***	n.s.
Error score	6.6	11.4	0.90***	5.3	8.4	13.3	1.13***	n.s.
Rectangular maze (Newton)								
Time taken (s)	25.0	22.9	0.87*	27.6	24.1	20.2	1.06***	n.s.
No. of errors	2.16	4.81	0.40***	2.04	3.79	4.62	0.50***	$P<.05$
Rapid visual information processing (Newton)								
No. correct (max 80)	53.4	45.4	1.4***	53.4	53.6	41.1	1.7***	n.s.
Reaction time (ms)	597	639	6.5***	610	620	624	8.0 n.s.	n.s.
No. incorrect	4.3	12.9	2.7**	9.0	4.7	12.1	3.4 n.s.	n.s.
Digit–symbol substitution (paper)								
No. correct (in 90 s)	72.8	65.7	0.90***	68.8	70.6	68.2	1.11 n.s.	n.s.
No. incorrect	0.40	0.78	0.14**	0.57	0.72	0.47	0.17 n.s.	n.s.
Digit–symbol Yes/No (Newton)								
Response time (s)	1.41	1.53	0.018***	1.47	1.46	1.49	0.023 n.s.	n.s.
No. incorrect	0.88	1.90	0.20***	1.13	1.33	1.72	0.25 n.s.	n.s.
Four-choice reaction time (BBC)								
Response time (ms) — random sequences	309	329	4.0***	315	316	327	4.9 n.s.	n.s.
No. of errors — random sequences	2.5	5.2	0.45***	3.0	3.3	5.3	0.56***	n.s.
Response time (ms) — fixed sequences	222	218	5.8 n.s.	209	221	230	7.2*	n.s.
No. of errors — fixed sequences	0.70	1.42	0.21**	0.72	0.87	1.60	0.26**	n.s.
Visual analogue scales								
Factor I: Functional integrity	34.8	50.1	2.8***	39.6	41.5	46.4	3.4 n.s.	n.s.
Factor II: Mood	27.8	24.2	1.5*	23.1	26.5	28.4	1.8*	n.s.
Sober–drunk	9.3	65.5	2.9***	35.4	36.7	40.1	3.5 n.s.	n.s.

Figures in the condition columns are means values. S.E.: Standard error of differences between mean values.
n.s.: not significant.
* $P<.05$.
** $P<.01$.
*** $P<.001$.

2.5. Procedures

Each volunteer first took part in a familiarisation session in which the test procedures were demonstrated and all tests were carried out at least twice. They then took part in two main sessions, spaced at least 4 days apart. The same test instructions were used for a particular volunteer on all three occasions, and were presented both on printed sheets and repeated verbally before each individual test in the battery. The instructions used were:

Speed
It is important that you go very fast in these tests, completing them in the shortest possible time, while trying to avoid errors.
Neutral
Work as fast and as accurately as you can in these tests
Accuracy
It is important that you work very accurately in these tests, and make no errors, while going as fast as you can.

Thus the speed and accuracy instructions emphasised the salient feature by referring to it twice in different ways. Allocation to instruction set was randomised.

Volunteers were instructed not to use tobacco during test days from 2 h before the beginning of the test session until the end of all procedures, and to take no alcohol from 24 h before the start of the test session until the end of the day. They were instructed to drink a maximum of one cup of tea or coffee at breakfast (to be the same on each test day), and thereafter to abstain from caffeine-containing drinks until the completion of the session. No food was to be consumed for at least 4 h before the beginning of the session.

In the two main sessions, a short test battery was first administered, and volunteers then received a drink consisting of either ethanol in the form of vodka or water, mixed with an equal quantity of orange concentrate. The dose of ethanol was 0.8 g/kg, up to a maximum of 60 g total for males, 50 g for females. To ensure blind administration, volunteers sucked a Tyrozet lozenge (containing the local anaesthetic benzocaine) before consuming the drink, which

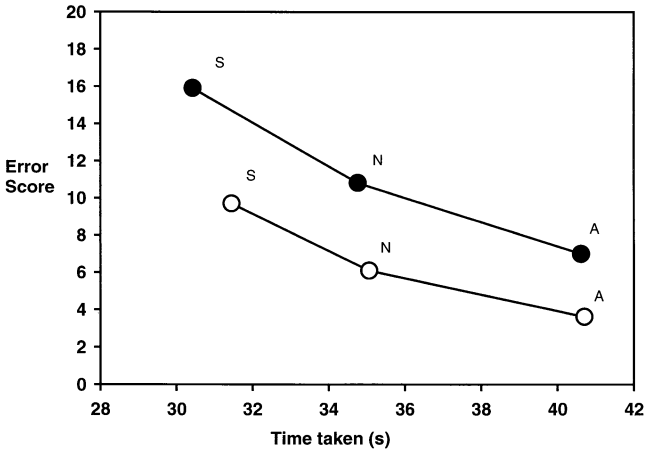

Fig. 3. Speed–accuracy graph for the Gibson spiral maze (pencil and paper). Open circles: placebo; filled circles: ethanol. S: speed instructions; N: neutral instructions; A: accuracy instructions.

was sprayed with a peppermint breath freshener. The drink was consumed within 10 min. The complete battery of tests was then administered starting 30 and 75 min postdrug. These times are calculated to span an approximate plateau of ethanol concentrations, on either side of the peak at about 1 h postdrink.

Breathalyser readings were taken before the drink and at the beginning and end of the each administration of the test battery.

2.6. Statistical analysis

For each outcome measure the mean of the two postdrink values was taken. These two assessment points, the first occurring between 30 and 60 min postdrink, the second between 75 and 105 min span the shallow peak of blood ethanol concentrations, which occurs around 1 h. Taking the mean of these two values allows a more accurate estimate of ethanol effects than can be obtained from a single time-point. The mean value from each test measure was subjected to analysis of variance (PROC GLM in SAS) to compare the effect of instruction set treatment and the instruction by treatment interaction on the measure. The analysis included sequence effect in the model. The critical level of significance was $P=.05$.

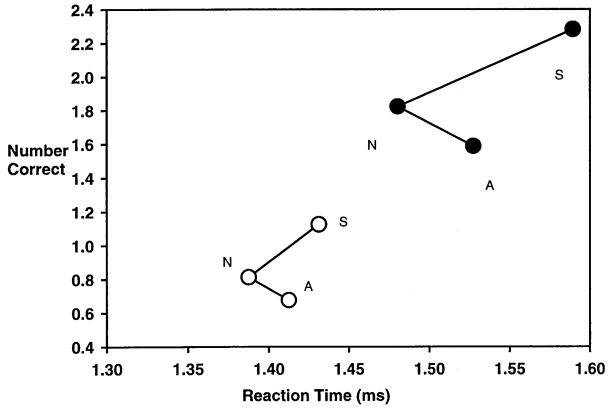

Fig. 5. Speed–accuracy graph for digit–symbol Yes–No (pen computer). Open circles: placebo; filled circles: ethanol. S: speed instructions; N: neutral instructions; A: accuracy instructions.

3. Results

The blood alcohol concentrations estimated from breathalyser readings were (mean with S.D. in brackets) — 30 min: 85.6 (24.0); 60 min: 94.5(19.5); 75 min: 88.6 (14.1); 105 min: 79.9 (13.1). The data for the effects of ethanol and instructions on test performance are shown in Table 1. Ethanol significantly impaired performance on all outcome measures with the exception of Time taken on the GSM and the Fixed sequence response time on the FCRT, which were not significantly affected, and Time taken on the rectangular maze, which was significantly faster in the ethanol condition.

The clearest effects of instructions were seen in the two maze tasks which showed speed–accuracy curves with broadly the anticipated pattern. As can be seen from Figs.

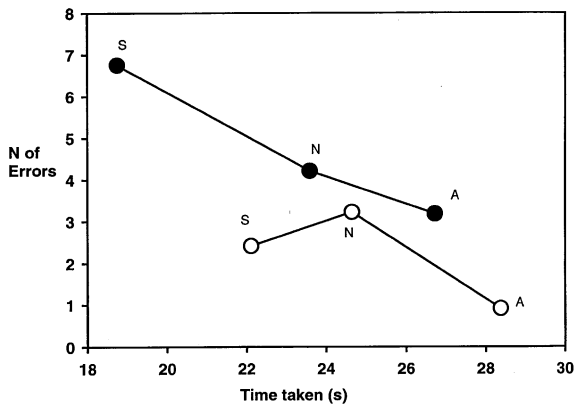

Fig. 4. Speed–accuracy graph for the rectangular maze (pen computer). Open circles: placebo; filled circles: ethanol. S: speed instructions; N: neutral instructions; A: accuracy instructions.

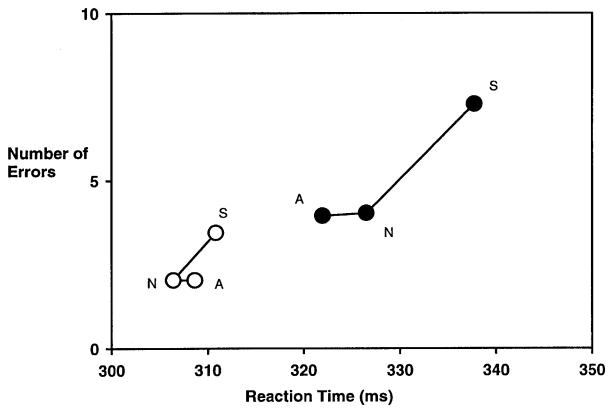

Fig. 6. Speed–accuracy graph for random sequences on the four-choice reaction test (BBC). Open circles: placebo; filled circles: ethanol. S: speed instructions; N: neutral instructions; A: accuracy instructions.

3 and 4 the speed instructions led to faster responses with more errors than the accuracy instructions, with the neutral instructions roughly intermediate between the two. The pattern for the other tests was not as predicted. In a number of cases the speed instructions led to both the slowest and the least accurate performance. This is illustrated in Figs. 5 and 6 for digit–symbol Yes/No and FCRT Random sequences.

The interaction between treatment and instructions was significant for the number of errors in the rectangular maze. For all other test measures the interaction was not significant.

Data for the visual analogue scales are included in Table 1. Clear effects of ethanol can be seen for Factor I (Functional integrity) and for the sober–drunk scale ($P < .001$). Small effects of both ethanol and instruction set were seen for Factor II, (Mood, $P < .05$).

4. Discussion

The mean blood ethanol concentrations obtained were in the expected range, peaking just under 100 g/100 ml at 1 h, and being just over 80 mg/100 ml at the beginning of the test period, and close to 80 mg/100 l at the end of testing.

The instructions given to the volunteers in this study clearly affected their performance on the tests in the battery. However, only for the two maze tasks was the pattern obtained as expected. Therefore these tests will be considered first.

On both the maze tasks, the speed–accuracy plot showed a curve for ethanol above that for placebo, indicating consistent impairment due to the drug. This impairment was entirely due to the increase in errors. In both tests the performance tended to speed up rather than slow down, and in the case of the pen computer maze, this speeding was statistically significant. The treatment by instruction interaction was significant for the rectangular maze. This is the only one of 18 interactions tested that was significant, and it may be that this is due to the number of statistical tests that were carried out, but the nature of the possible interaction is of interest. As can be seen in Fig. 4, the increase in errors with ethanol was less for the neutral instructions than for the other two instruction conditions. However, there were no suggestion of a divergence of ethanol effects with instruction conditions of the type that would have been predicted by the salience hypothesis. The speeding of performance with ethanol was apparent under all three instruction conditions, and the prediction from the salience interpretation that accuracy instructions should have a greater effect on accuracy in the alcohol condition, and lead to slower performance with fewer errors, was clearly not supported. Thus it seems that the effect of ethanol in tending to speed performance and to increase errors in these tasks is generally similar for all three instruction conditions.

The other measure which showed performance to be faster on ethanol than placebo was the response time on the fixed sequences of the four-choice reaction test. In this part of the test, the same sequence of stimuli is repeated, and performance is therefore underloaded from an information-processing point of view. The speeding on this part of the task with ethanol was not significant, but two previous studies have showed a similar effect (Newman et al., 1997; Tiplady et al., 1998), and this effect is thus probably real. Volunteers again make significantly more errors with ethanol under these conditions.

While the other tasks did not show the expected pattern of changes with instruction condition, it can be seen from Figs. 5 and 6 that the effects of ethanol were to both slow performance and to increase errors in all instruction conditions. Again, no divergence between instruction conditions of the type predicted by the salience hypothesis was seen. Thus there was no suggestion of a relatively greater increase in errors with ethanol in the speed condition, or of a relatively greater slowing with ethanol in the accuracy condition The reason for the different pattern of instruction effect — with slowest performance and greatest errors found in the speed instruction condition — is not clear. It may be that the neutral instructions are in some sense optimal in these tasks, and that emphasising speed beyond this optimum leads to disruption of performance, with effects both on speed and errors.

The most consistent finding in the present study is the increase in error scores with ethanol. While this is by no means the first study to demonstrate significant increases in error scores with ethanol (Billings et al., 1973; Jääskeläinen et al., 1996; Rundell and Williams, 1979; Streufert et al., 1992), it appears to be the first to have used a variety of tests of different kinds in which error scores are a significant outcome measure. Many previous studies, including those concerned with skills relevant to driving, have emphasised reaction times, or if accuracy has been of interest have used the accuracy of a tracking task.

Wickelgren (1977, p. 80) has emphasised the limitations of an approach which makes response time the only or principal measure. Given that people can vary in the SATO they adopt, impairment to function cannot be adequately assessed solely on the basis of changes in response times. Ensuring that overall error rates are low (see, e.g., Sternberg, 1975) does not help. Because of the form of the SATO function, the lower the errors the greater the change in response time associated with a particular change in error rate. And the lower the error rate, the harder it is statistically to detect any changes that may occur. A much clearer picture of drug action can be obtained from the two-dimensional approach taken here. The finding that errors are consistently increased by ethanol in tasks in which speed is affected differently raises the question of the relative importance of response times and errors in accidents. It is after all accidents (at home and at work as well as on the road) that are of primary practical significance here, not performance in tests carried out in the laboratory (or in a real car for that matter).

The most direct way of assessing the validity of laboratory tests as predictors of accident rate is to assess the relationship between test performance of individuals and the number of accidents they have been involved in. There are difficulties with this approach, both in determining exposure and in assessing responsibility for accidents (Lawton and Parker, 1998). Where correlations have been found, they have generally been modest, for example .42 for a simulated driving test involving both tracking and reaction time components (Häkkinen, 1958), and up to .38 for a test of visual attention (Arthur, 1994). If the combination of an impairment to performance with a tendency to speed up could be reproduced with ethanol in a driving simulator, this could provide a possible alternative route to test validation. A great deal of epidemiological data is available for ethanol and driving, not just for overall risk, but for particular types of accident. If circumstances where alcohol produces such 'risky' behaviour can be shown to correlate with types of accident that are particularly associated with ethanol (West et al., 1993), this would provide good support for the validity of the measures obtained.

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