

# Alcohol and Cognitive Function: Assessment in Everyday Life and Laboratory Settings Using Mobile Phones

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**Background:** Mobile phone (cellphone) technology makes it practicable to assess cognitive function in a natural setting. We assessed this method and compared impairment of performance due to alcohol in everyday life with measurements made in the laboratory.

**Methods:** Thirty-eight volunteers (20 male, aged 18–54 years) took part in the everyday study, completing assessments twice a day for 14 days following requests sent by text messages to the mobile phone. Twenty-six of them (12 male, aged 19–54) took part in a subsequent two-period crossover lab study comparing alcohol with no alcohol (placebo).

**Results:** Everyday entries with 5 or more units of alcohol consumed in the past 6 hours (inferred mean blood alcohol concentration 95 ml/100 ml) showed higher scores for errors in tests of attention and working memory compared with entries with no alcohol consumed that day. Response times were impaired for only 1 test, sustained attention to response. The laboratory comparison of alcohol (mean blood alcohol concentration 124 mg/100 ml) with placebo showed impairment to both reaction time and error scores for all tests. A similar degree of subjective drunkenness was reported in both settings.

**Conclusions:** We found that mobile phones allowed practical research on cognitive performance in an everyday life setting. Alcohol impaired function in both laboratory and everyday life settings at relevant doses of alcohol.

**Key Words:** Ethanol (Alcohol), Everyday Assessments, Mobile Phone (Cellphone), Neuropsychological Assessment, Speed Accuracy Trade-Off.

THE COGNITIVE AND performance impairments due to acute consumption of alcohol (ethanol) and their implications for everyday tasks such as driving have been well documented. For example, alcohol tends to increase reaction times (RTs) and errors in psychomotor and attention tasks, and to impair memory. Most information comes from experimental administration or epidemiological methods. Experimental studies generally use standard doses of alcohol which are compared with placebo on performance measures, often selected on the basis of their relevance to driving (for reviews, see Moskowitz and Robinson, 1988; Ferrara et al., 1994; Koelega, 1995). Such studies are usually carried out in a laboratory, although some investigate actual driving performance either on test tracks or on public roads (Damkot et al., 1983; Kuypers et al., 2006). Epidemiological studies report the relationship between traffic accidents and alcohol either by relating the frequency of accidents to blood alcohol concentration (BAC) (Borkenstein et al., 1964; Perrine et al., 1989) or by making more detailed analyses of crash characteristics, as

with the method of responsibility analysis (Robertson and Drummer, 1994).

The laboratory models have given important insights into some aspects of alcohol effects, for example, that performance on divided tasks is impaired more than single-component tasks (Maylor et al., 1990; Moskowitz and DePry, 1967), and that narrowing of attention occurs with alcohol (Clifasefi et al., 2006; Steele and Josephs, 1990). They have also indicated the quantity of alcohol that causes clear impairment, which has helped to inform decisions about legal limits for driving. However there have been criticisms of lab-based studies as artificial, both because of the setting and the way the alcohol is administered. Laboratory studies of alcohol differ from the normal way alcohol is consumed in several ways. The physical environment and the social setting are different, with the individual often being assessed alone, whereas most drinking is in the company of others who are drinking. The alcohol is generally given in standard form and quantity over a short period, whereas normal drinkers consume a beverage of their own choice, and decide how much and how quickly to drink. Finally, lab studies often use blind, placebo-controlled designs, whereas normal drinkers know what they are taking.

These differences between what has been called the “pharmacological model” and everyday life drinking could affect outcomes in a number of ways. Some observational studies have assessed the differences in consumption between solitary and social drinkers, and found that those in a group drink more than those who are alone (Lindman, 1982). Mood

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changes can also be influenced by social setting, with lone drinkers reported less euphoria and more aversive subjective effects of alcohol than those drinking in company (Lindman, 1982; Pliner and Cappell, 1974). Responses to alcohol in the lab may also be influenced by the instructions/information given by the experimenter. Thus, drinkers who believe they are taking alcohol but actually receive a placebo may respond in a more "alcohol-like" way than those who believe they are receiving no alcohol. While such effects have been shown for social behavior and some aspects of self-report, they have not been shown for performance on cognitive and psychomotor tasks, which are impaired by alcohol, but in general little influenced by expectancies (see, e.g., Hull and Bond, 1986; Lyvers and Maltzman, 1991; Nelson et al., 1986).

Another approach is to carry out research in a natural setting. There are many aspects to this. Some workers set up their research labs to look and feel like normal social settings, for example as a bar (see, e.g., Clifasefi et al., 2006; Lang et al., 1975). However, volunteers are clearly still in an experimental context—drinks are given in doses calculated to achieve the desired BAC, and must usually be drunk within a stated time. Some studies have investigated the hang-over effects of alcohol following nonexperimental drinking. In these studies volunteers have been taking alcohol in the amounts and in a location corresponding to their normal drinking patterns, and were then tested the following morning in a laboratory (Finnigan et al., 2005; McKinney and Coyle, 2004). These studies clearly showed hang-over effects in terms of both performance and subjective measures.

Very few studies report the immediate effects of alcohol on performance in a nonlaboratory setting. Curran and Travill (1997) studied the effects of 3,4 methylenedioxymethamphetamine (MDMA, Ecstasy) with performance testing in a quiet room in a club or in the volunteers' homes. They used an alcohol group as a control, but the pattern seen clearly suggests the effects of alcohol on performance. Several recent field studies have taken a cross-sectional approach, measuring performance in persons at music festivals or pubs, and correlating this with measured BAC and reported alcohol consumption. Two of these, at music festivals, were evaluating portable methods designed to assess impairment in drivers at the roadside (Degia et al., 2006; Tiplady and Degia, 2004). These festival studies also took illicit drugs into account. Two other studies have been carried out in pubs, one using a handheld device (Mayes et al., 2005), the other using tests set up on a mobile phone (Tiplady et al., 2006). All these studies clearly showed the performance impairments due to alcohol.

The development of inexpensive portable computing devices, such as palm-tops and mobile phones, has opened up new possibilities for data capture in field settings. Electronic diaries have been used to collect data about symptoms and events in a patient's daily life for more than a decade (Hyland et al., 1993; Shiffman et al., 1995; Tiplady et al., 1995). Handhelds and Personal Digital Assistants have been also been used to present cognitive and psychomotor tests (see, e.g., Frings et al., 2008; Thorne et al., 2005; Tiplady, 1994).

Using devices with wireless technology, an integrated data collection system can be set up to allow real-time transfer of data to a central server and integration of different types of data. Communication from the central service to the individual devices is also possible, for example, using texting (Short Message Service, SMS). The availability of fully featured programming languages such as Java<sup>®</sup> (Sun Microsystems, Inc., Santa Clara, CA) on wireless devices allows the development of applications such as cognitive/performance tasks and graphic subjective ratings for field use (Tiplady, 2005a,b).

Mobile phones make it possible to carry out assessments on a regular basis in the context of a person's normal life. Cognitive performance can be compared with other factors, such as sleep, diet, and consumption of drugs such as caffeine and alcohol. This creates a new possibility—to compare effects of such factors between everyday life assessment and a laboratory setting. Volunteers can be studied over a period of days or weeks in their own home or work setting, and the effects of factors evaluated using correlational methods. The factors can then be studied in the same volunteers in an experimental lab setting, and the outcomes of the 2 approaches compared.

In the present study, we used this approach to compare the effects of alcohol in daily life and in the laboratory, using measures of psychomotor speed and accuracy, attention, and working memory. We selected tests which assessed aspects of performance which are known to be affected by alcohol, and which are likely to be relevant to everyday life performance. Attention was considered relevant because of findings that attention failures and distraction were important in a large proportion of vehicle crashes (Allen et al., 2009; Ranney, 2008; Shinar, 1993; Stutts et al., 2001). We were particularly interested in the relationship between speed and accuracy of test performance in view of previous findings that alcohol had particularly marked effects on errors, while speed was less affected, relative to other central nervous system (CNS)-depressant drugs (Tiplady et al., 2003).

Two attention tasks were selected, one using flankers, the other with a go/no-go component. Both tasks allowed assessment of speed-accuracy trade-off. The flanker paradigm (Eriksen and Eriksen, 1974) has a number of variants, with stimuli such as numbers, letters, and arrows. In all cases there is a target, which is flanked by distractor stimuli which can be either congruent, matching the target stimulus, or incongruent, in conflict with the target. Flanker tests are commonly used in studies of error processing (for review, see Overbeek et al., 2009). Performance on flanker tests is impaired by alcohol and other CNS-depressant drugs (Mensinga et al., 2006; Ramaekers et al., 1992, 2000), and such tests have been evaluated for possible use in assessing impairment of driver performance at the roadside (Dixon et al., 2009; Tiplady et al., 2005a). The task we included uses numeric stimuli, and has been shown to be sensitive to the effects of alcohol and other depressants (Farquhar et al., 2002; Tiplady et al., 2005c).

The go/no-go paradigm is designed to assess impulsivity/disinhibition, relevant both to the acute effects of alcohol

and to personality studies of addictive behaviors (Fillmore et al., 2009; Finn et al., 1999; Saunders et al., 2008). Disinhibition may be a factor in alcohol-related car crashes (Fillmore et al., 2008). Impulsivity may also result from brain injury, and the sustained attention to response task (SART) was developed initially to assess such effects (Manly et al., 2000). It is a very simple task, in which a response is made to every target digit except the number 3. It thus includes an assessment of psychomotor speed and accuracy as well as the response-suppression component. SART performance is impaired by alcohol, and a SART variant has also been assessed for potential use in assessing impairment of driver performance at the roadside (Degia et al., 2006; Dixon et al., 2009; Easdon et al., 2005).

The working memory task included was Memory Scanning (Sternberg 1975), which has been used in a number of studies both of alcohol and of interactions between alcohol and other drugs. This test requires the volunteer to hold a set of 5 digits in memory, and to determine whether a series of individual digits is in the set or not. Performance has been shown to be clearly impaired by alcohol (Grattan-Miscio and Vogel-Sprott, 2005; Kerr et al., 1996; Patat et al., 1995).

It was also important that tests be suitable for presentation on a mobile phone, given the limited size of the screen. These tests involved displaying a maximum of 5 digits, and these are easily legible on the mobile phone screen. All 3 tests have 2 possible responses, and these are made with the 2 thumbs held on left and right of the phone keypad.

## METHODS

### *Design*

We used a hybrid design, with a 2-week everyday assessment period, followed by a lab-based two-period crossover (within subjects) design comparing single doses of (i) alcohol, calculated to produce peak plasma concentrations in the range 80–100 mg/100 ml or (ii) no alcohol (placebo). Doses were given on separate days at least 2 days apart. The order of administration was determined at random.

During the everyday assessment period, testing was carried out twice each day at different times of day. In the lab-based part of the study, testing was carried out before the dose and at intervals over the next 2 hours.

### *Volunteers*

We recruited volunteers aged 18–65 years, in good general health, who consumed at least 5 units of alcohol on average per week, but excluded those with excessive alcohol consumption (more than 35 units [males] or 25 units [females]), or those who were taking any drug that might interfere with CNS function or alcohol disposition. For female volunteers a negative pregnancy test was required. We set out to recruit 40 volunteers in order to have 30 complete both parts of the study.

### *Assessments*

We used the mobile phone for the following assessments.

*Questions.* How many units of alcohol have you consumed today? In the past 6 hours?

*Number-Pair Matching.* The task was based on the flanker paradigm described by Eriksen and Eriksen (1974). Sets of 5 digits appeared on the phone screen one set at a time. The task was to inspect the second and fourth digits of the set to tap a Yes button if they were the same, a No button otherwise. In some of the stimulus sets, the remaining digits (distractors) were all different from the target digits, while in other sets some of the distractors were the same as target digits. Response times and errors were recorded.

*Memory Scanning.* A set of 5 digits appeared on the phone screen, which the volunteer memorized (Sternberg, 1975). A series of digits then appeared one at a time, and the volunteer pressed a “Yes” button if the digit was in the memorized set, a “No” otherwise, as fast as possible. Response times and numbers of errors were recorded.

*Sustained Attention to Response Task.* A series of digits appeared on the phone screen (Dockree et al., 2005). The volunteer was instructed to respond to each digit by pressing a button, except when the digit was a three, in which case no response was to be made. Response times and the number of responses to the no-go stimulus (3) were recorded.

*Visual Analogue Scales.* Visual Analogue Scales (VAS) were used to assess mood (Bond and Lader, 1974; Tiplady, 2005b). Each scale consisted of a line presented on the screen, the ends of which were marked with antonyms. The scales used were Alert–Drowsy; Calm–Excited; Muzzy–Clear-Headed; Lethargic–Energetic; Happy–Sad; Sober–Drunk. Volunteers adjusted the position of a cursor on each line to indicate how they felt at that moment. The score was taken as the cursor position in % of scale length.

*Questions.* Where did you carry out the tests (Home, University, Other)? Was there any disturbance while you were carrying out the tests (None, Distraction, Interruption)?

### *Equipment*

Testing was carried out on Nokia mobile phones (models 6610 and 3510i, Nokia Corp., Helsinki, Finland). Both run Java MIDP 1.0, and have similar screen sizes. The same phone models were used for the everyday testing and in the laboratory. Breath alcohol concentrations were recorded using a Lion SD-400 Alcolmeter (Lion Laboratories Ltd., Barry, UK).

### *Procedures*

Each volunteer first had a practice session with the mobile phone. The tests and questions were completed twice. They were also given instructions for calculating the number of units of alcohol they had consumed. One UK unit corresponds to 8 g of pure alcohol (Hedges and di Salvo, 1998). An instruction sheet with examples of the alcohol content of different types of drinks, including wine, beer, and mixed drinks, was given. This was similar to that used in UK health information material (Department of Health, 2008). Printed test instructions were also given. Volunteers were then given the phones to take home for 2 weeks, and asked to complete the tests as soon as possible each time they received an SMS text message on the phone.

Messages were sent twice per day, the first being randomized between 08:00 and 17:00 hours, the second between 18:00 and 22:00 hours. After each set of assessments was complete, data were transmitted by the phone to a central web server over the mobile phone network. Once on the server, data could be reviewed and downloaded.

On completion of the 2-week everyday assessment period, volunteers took part in two and a half day lab sessions spaced at least 2 days apart. Sessions took place in the Clinical Research Facility,

which had hospital beds, laboratory space, and seating areas. On each occasion a set of baseline tests was first carried out. The volunteer was then given a drink containing either vodka or water (placebo) mixed with an equal volume of orange drink concentrate. The volume was calculated to give a dose of 0.8 g/kg body weight for males, up to a maximum of 66 g (200 ml of 37.5% vodka), or 0.7 g/kg for females up to a maximum of 55 g (167 ml). The difference in dose for males and females was designed to compensate for the fact that females have a higher peak alcohol concentration after a given dose based on body weight (see, e.g., Baraona et al., 2001). To mask the taste of vodka, the drink was sprayed with peppermint breath freshener, and the volunteer sucked a Tyrozet® lozenge (Merck and Co., Inc., Whitehouse Station, NJ) (containing the local anesthetic benzocaine) for 1 minute before consuming the drink. They were informed that this was to mask the taste of alcohol. The drink was consumed with 10 minutes. The test battery was then repeated beginning at 30, 60, and 105 minutes after the start of the drink.

Volunteers were instructed to refrain from eating for 4 hours before each session, and to eat only light meals before that time. A maximum of 1 cup of tea or coffee was to be drunk at breakfast time, to be the same on each test day. No further caffeine was permitted until the completion of all test procedures. They were instructed not to consume any alcohol from 24 hours before the start of the test session until at least 24 hours after, or any tobacco from 2 hours before the start of the session until the completion of all test procedures. At the end of each lab session, volunteers were dropped at home by taxi.

#### Statistical Analysis

**Everyday Data.** Compliance was assessed over the 2-week period as the percentage of text messages that were followed by test completion before the next scheduled message. In addition, the times elapsed between the sending text and the start of the tests was recorded.

Each entry was initially allocated to the hour in which the entry was started. Hours were then combined into periods (time windows) so that sufficient records could be averaged to obtain useful comparisons. The five time windows chosen were 05:00–12:59; 13:00–15:59; 16:00–18:59; 19:00–21:59; and 22:00–04:59 hours. Diurnal patterns were analyzed by applying a two-way analysis of variance (ANOVA, PROC Generalized Linear Model in SAS) model including the class variables volunteer and time window.

For the main analysis of effects of alcohol, entries were classified as *no alcohol*, where no alcohol was reported having been consumed during the day; as *significant alcohol*, where 5 or more units had been consumed in the past 6 hours; or as *intermediate*. The main analysis used only the no alcohol and significant alcohol conditions. As all but one of the significant alcohol entries were in the 19:00–22:00 hours; and 22:00–00:05 hours windows only entries in these 2 windows were included. For each volunteer the mean of all significant alcohol entries was calculated for each window, and then the mean of the 2 time window scores was taken. A similar procedure was applied to no alcohol scores, so that scores were matched approximately by time. The effects of alcohol were then assessed using a paired *t*-test.

In order to check for the possible influence of practice, exploratory analyses were carried out in which data from the first few days were excluded. This did not influence outcomes, and the main analyses included data from all days during the study period.

**Laboratory Data.** The test scores for the 3 postdrink assessments were averaged, and data were analyzed using a three-way ANOVA (PROC GLM in SAS) as described by Senn (1993). The model included the class variables volunteer, alcohol condition (alcohol or no alcohol), and period (session 1 or 2).

## RESULTS

Of the 40 volunteers screened, one decided not to take part after the screening session, and one was found on inspection of the data to have misunderstood the test instructions. Thirty-eight volunteers completed the 2-week everyday assessment period. One volunteer had difficulties with the mobile phone signal, and did not receive many of the texts. He continued to use the system at random times during the day, but has not been included in the compliance analysis. Twenty-six volunteers completed the lab sessions. Demographic details of the 2 groups are given in Table 1.

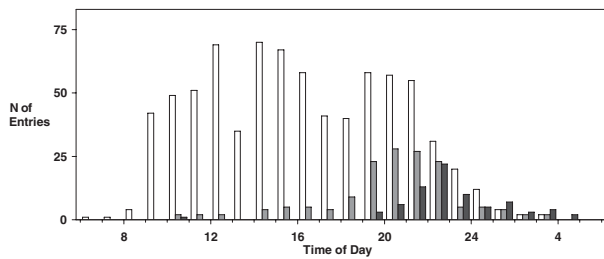
Overall compliance (% of text messages followed by a test entry before the next text was sent) was 80.3%. Fifty-eight percent of entries were completed within 1 hour of receiving the text message. The distribution of entries during the day is shown in Fig. 1. Entries were broadly spread over the day between 9 AM and 10 PM, with entries gradually declining thereafter with a small number of entries between 2 and 8 AM. Nearly all of the entries with significant alcohol were found from 7 PM onwards. Twenty-nine of the volunteers had at least 1 entry where significant alcohol had been consumed.

The responses to questions concerning disturbance during entries are shown in Table 2. About 15% of entries were interrupted, and this proportion was slightly, but not significantly ( $\chi^2 = 4$ ;  $df = 3.19$ ,  $p = 0.5264$ ) higher with significant alcohol. Figure 2 shows how disturbance affected performance in the memory scanning task in the no alcohol condition. Reaction time was increased by distraction and interruption, both conditions were significantly different from the no distraction condition (ANOVA with  $df: 37,2$ ; pairwise comparisons for overall RT; distraction:  $t = 2.77$ ,  $p = 0.0072$ ; interruption:  $t = 4.23$ ,  $p = 0.0001$ ). The RTs for responses to numbers in the initial number set were about 100 millisecond longer than for numbers not in the set. This difference was significant for the whole data set (paired  $t = 9.12$ ,  $p < 0.0001$ ) and for each distraction condition separately (No disturbance:  $t = 8.86$ ,  $p < 0.0001$ ; Distraction:  $t = 8.25$ ;  $p < 0.0001$ ; Interruption:  $t = 3.01$ ,  $p = 0.0051$ ). The difference between inset and non-set responses was not significantly affected by disturbance (overall effect from ANOVA,  $F = 0.24$ ,  $p = 0.7172$ ).

Significant diurnal effects on performance with no alcohol were seen for several measures. ANOVA with  $df$  of 37,4 showed effects of memory scanning RT ( $F = 2.58$ ,

**Table 1.** Demographic Details of Volunteers in the Two Parts of the Study

Group	<i>n</i> (M/F)	Age range (mean)	Height range (mean)	Weight range (mean)	Smokers, <i>n</i>
Everyday tests	38 (20/18)	18–54 (22.8)	156–194 (172)	52–115 (71.8)	5
Laboratory sessions	26 (12,14)	19–54 (23.1)	156–174 (169)	52–115 (71.1)	4

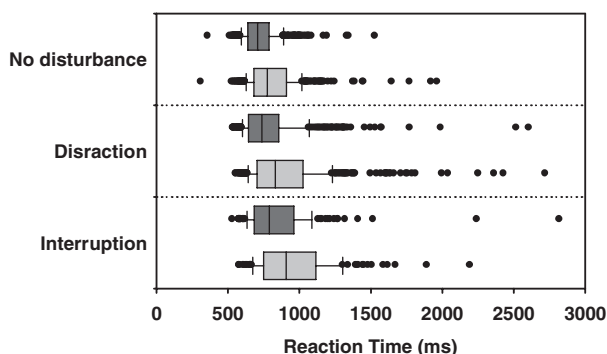


**Fig. 1.** Numbers of entries made by time. Entries are shown for each 1-hour period during the day. White bars: no alcohol during the day; dark bars: significant alcohol, five or more units of alcohol consumed in the last 6 hours; pale bars: intermediate alcohol.

**Table 2.** Responses of Volunteers to the Question “Was there any disturbance while you were carrying out the tests?”

	No. entries (row-wise percentage)		
	No disturbance	Distraction	Interruption
No alcohol	339 (44.1)	319 (41.5)	111 (14.4)
Intermediate	67 (44.7)	64 (42.7)	19 (12.7)
Significant alcohol	27 (35.5)	34 (44.7)	15 (19.7)
Total	433 (43.5)	417 (41.9)	145 (14.6)

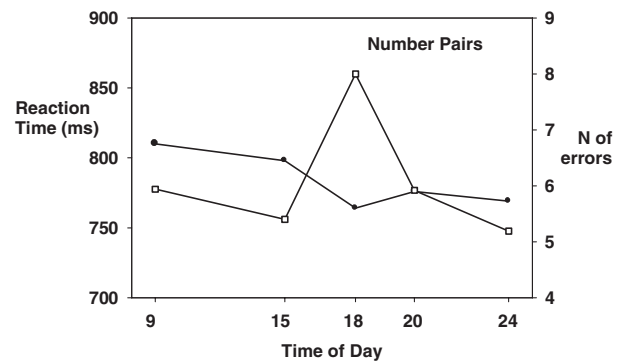
No alcohol: no alcohol consumed during the day before completing the entry; significant alcohol:  $\geq 5$  units consumed in the 6 hours before making the entry; intermediate: not in either category.



**Fig. 2.** Box plots of the effect of disturbance on reaction time performance in the memory scanning test in the no alcohol condition. Dark bars: responses to numbers that were included in the memory set; light bars: numbers not in the set. The total number of observations in the data set was 995.

$p = 0.0404$ ) number pairs (RT:  $F = 4.75$ ,  $p = 0.0013$ ; errors:  $F = 6.37$ ,  $p = 0.0001$ ), and mood (drowsy:  $F = 7.60$ ,  $p < 0.001$ ; energetic:  $F = 4.94$ ,  $p = 0.0010$ ). The speed-based measures showed a general tendency to improve during the day, with shorter RTs in the evening than in the morning, while error scores showed a peak in the early evening. Drowsiness was least in the afternoon and greater in the morning and evening, with energy showing an inverse pattern. The pattern for number pairs is shown in Fig. 3.

The number of drinks consumed in the last 6 hours for the significant alcohol set of entries ranged from 5 (the threshold) to 20 (median 7). Using the relationship between reported



**Fig. 3.** Diurnal patterns for number pairs. Closed circles: RT in millisecond; open squares: no of errors. RT, reaction time.

**Table 3.** Comparison of Scores for Significant Alcohol and No Alcohol (Definitions as in Table 2) in the Everyday Part of the Study

Test/measure	Mean		<i>t</i>	Treatment effect: <i>p</i> value
	No alcohol	Significant alcohol		
Memory scanning				
Reaction time (millisecond)	795	842	1.58	0.1256
<i>n</i> incorrect	7.1	12.6	3.37	0.0022
SART				
Reaction time	471	511	2.66	0.0128
False positives	2.52	2.94	1.26	0.2184
False negatives	0.98	4.48	2.39	0.0241
Number pairs				
Reaction time	771	856	1.13	0.2701
<i>n</i> incorrect	5.6	13.4	2.87	0.0077
VAS (% along line)				
Alert–drowsy	51.0	56.0	1.22	0.2333
Calm–excited	27.7	41.7	3.95	0.0005
Muzzy–clear-headed	46.5	33.6	3.31	0.0025
Lethargic–energetic	36.1	39.4	0.83	0.4116
Happy–sad	35.0	30.3	1.17	0.2519
Sober–drunk	7.8	54.1	13.58	0.0001

SART, sustained attention to response task; VAS, Visual Analogue Scales.

alcohol consumption and measured alcohol levels (Tiplady et al., 2006) suggests that this corresponds to a mean BAC of about 95 mg/100 ml. The comparison of performance between these alcohol-positive entries and no alcohol entries in the every day life setting is shown in Table 3. There were significant effects on several of the error measures, with increases in numbers of errors on the memory scanning task and on numbers pairs, and an increase in the number of false negatives (decrease in the number of responses to stimuli where a response should have been made) on the SART with significant alcohol compared with no alcohol. The only measure of speed to show significance was the SART. Alcohol was associated with highly significant increases in subjective drunkenness, with increased ratings of excitement and decreased feelings of clear-headedness.

Results from the laboratory assessments are shown in Table 4. The mean BAC measured during the alcohol sessions was 124 mg/100 ml. All measures from the objective tests

**Table 4.** Comparison of Scores for Placebo and Alcohol in the Laboratory Part of the Study ( $n = 26$ )

Test/measure	Placebo	Alcohol	<i>F</i>	Treatment effect, <i>p</i>
Memory Scanning				
Reaction time	725	758	4.32	0.0485
<i>n</i> incorrect	6.87	8.77	6.05	0.0214
SART				
Reaction time	448	480	4.54	0.0436
False positives	3.02	3.94	9.88	0.0044
False negatives	0.47	1.38	3.05	0.0936
Number pairs				
Reaction time	712	759	8.34	0.0081
<i>n</i> incorrect	6.52	9.28	10.97	0.0029
VAS				
Alert–drowsy	45.1	47.7	0.40	0.534
Calm–excited	32.1	41.2	10.87	0.0030
Muzzy–clear-headed	43.9	38.0	2.40	0.135
Lethargic–energetic	39.9	44.9	1.96	0.175
Happy–sad	28.7	23.4	4.94	0.0359
Sober–drunk	6.2	52.1	165.29	0.0000

SART, sustained attention to response task; VAS, Visual Analogue Scales.

Significance was assessed using ANOVA with volunteer, treatment, and period in the model. Least-squares means from the ANOVA together with the corresponding *F* values are shown.

showed significant impairment after alcohol except the number of false negatives (failures to respond when a response should have been made) in the SART. Subjective reports showed that volunteers felt slightly more happy and excited on alcohol than on placebo, and much more drunk.

## DISCUSSION

We found that mobile phones were a practical and effective means of testing cognitive performance in an everyday life setting. Compliance with procedures was good, although not as high as has been reported for electronic patient diaries (Hufford and Shields, 2002). The tests used here took considerably longer to complete than most diary entries, and it was not considered practical to ask our volunteers (mostly students in term-time) to carry out tests immediately on receiving the text message, especially as they did not know ahead of time when entries were to be made. Some eDiary studies have used repeated reminders to patients to complete entries, or have identified those with poor compliance from the web server and contacted them to offer support. Both methods can improve eDiary compliance (Marino et al., 2008; Welin, 2003), and might also do so in the present context. Even without these procedures, compliance was sufficient to provide a good cross-section of the daily-life situation, and to show clear effects of alcohol.

Because the situations in which entries were made were not controlled, we sought measures of data quality. One approach was to ask volunteers if there had been any distraction or interruption during the entry period. As might be expected there was a substantial amount of distraction, but a relatively small number of reports of interruption were made. There is

also an internal criterion of quality. In the memory scanning test, it has been shown that response speed depends on whether the number presented is in the memory set or not (Sternberg, 1975). This can be used as a measure of task integrity, i.e., that volunteers are attending properly to the task. The difference in RT was maintained across all disturbance levels, and was not significantly affected by disturbance. This suggests that despite distraction, the volunteers were attending adequately to the task.

Another indication that the tests performed as intended is the presence of expected diurnal changes in performance. The RT measures tended to speed up as the day progressed, as has been previously reported (Kleitman et al., 1938; Schmidt et al., 2007), although the pattern was not entirely as expected, as performance did not decline again during the later part of the day. The error scores tended to show an inverse pattern to speed suggesting a shift in speed-accuracy trade-off, rather than an overall change in quality of performance over the day.

The number of volunteers who completed both laboratory and everyday settings, and who had everyday entries with significant alcohol present was too small for a direct comparison of effect sizes to have useful power, given the variability of alcohol response between individuals. However, comparison of the data from Tables 3 and 4 allows several points to be made. First, the effects of alcohol were seen clearly in both settings. At least 1 measure in all 3 tests showed impairment due to alcohol, and substantial increases in reports of feelings of drunkenness was seen. The effects were generally similar to those seen in other studies (Hindmarch et al., 1991; Tiplady et al., 2004). Second, the response times (whether influenced by alcohol or not) tended to be higher in the everyday than in the lab setting. Third, impairments on the memory scanning and number pairs tasks seemed to be more apparent in error scores than in RTs, whereas both aspects of performance were significantly impaired in the lab setting.

Comparing the amounts of alcohol consumed between the 2 settings is not straightforward. The amounts inferred here for the everyday setting were based on a comparison of reported consumption and measured breath alcohol concentration (BrAC) in a field study carried out in a pub (Tiplady et al., 2006). The substantial correlation obtained in that study between reported consumption and BrAC (0.77) suggest that drinkers are reasonably accurate in remembering and reporting their consumption in this context. The inferred alcohol levels in the everyday setting were on average slightly lower than those measured in the lab study, but the mean values in both cases were somewhat above the UK legal limit for driving. Thus, both laboratory and everyday assessments can assess impairments at relevant alcohol concentrations.

A possible reason for the slower response times in the everyday setting is the degree of disturbance. Around 50% of everyday entries recorded distraction or interruption, and even when no disturbance was reported the everyday environment is likely to be less secluded than the laboratory. Carrying out the tests in such a setting could impose an additional

cognitive load. This could well be ecologically relevant particularly in view of the growing literature on the effects of distraction on driving performance (Horberrry et al., 2006; Strayer et al., 2006). Future work could assess the importance of distraction as a factor using either laboratory or everyday settings, or a combination of the two, and investigate whether this could lead to a change in the pattern of test performance, for example, in the trade-off between speed and accuracy.

Another difference between lab and everyday performance that should be considered is time of day. The lab studies were carried out during the day, while the alcohol-positive performance assessed in the everyday setting was all after 7 PM. Two lab studies have investigated this issue. One (Horne and Gibbons, 1991) showed greater impairment with alcohol in the afternoon than in the evening; the other (Dalrymple-Alford et al., 2003) showed no diurnal effect of alcohol. The diurnal differences observed here within the everyday setting could not explain the differences between lab and everyday assessments, but the possibility of a diurnal influence on alcohol effects could warrant further investigation.

We did not attempt to influence expectancies in the laboratory part of the study, which was a simple comparison of the effects of an alcoholic and matched nonalcoholic drink, which our volunteers knew might or might not contain alcohol. Thus, we were not using placebo to *measure* the effect of the expectancy of receiving alcohol (see, e.g., Testa et al., 2006), but as a way of *matching* expectancies (as far as possible) between the 2 conditions. This latter use of placebos is typical of the pharmacological approach to placebo-controlled studies, whether of alcohol or of medicines, and is appropriate for evaluating the relationship between everyday assessment and many previous laboratory studies using the pharmacological model.

The mobile phone clearly has some limitations with respect to the types of tests that can be presented, mostly due to the small screen size. This would make mental rotation tasks, or for example many kinds of visual search tasks impractical. Nonetheless, a wide range of functions can be included. The tests used here all used numeric displays, but verbal material can be presented, for example, word memory or sentence comprehension tasks, and graphics can also be displayed. An example of the latter is the "Little Man" task of spatial comprehension (Acker, 1983).

Mobile phones can be used to study a wide range of issues concerning everyday performance, including food intake, sleep patterns and of effects clinical conditions and their treatment. The sample used here was fairly small, but the method is ideal for use with much larger samples, for example, with web-based recruitment and the use of volunteers' own phones. The application used here was written in generic Java, so was not tied to any particular brand of phone, and could be downloaded to the phone from a website in the same way as games and ringtones.

We conclude that mobile phones are practical for research in an everyday life setting on performance and factors which affect performance. Impairment is seen with relevant levels of

alcohol consumption in both settings. Patterns of change may not be identical in the 2 settings, and it is important to study everyday settings as well as to conduct studies in the laboratory.

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