Quantitative Similarity between the Cognitive Psychomotor Performance Decrement Associated with Sustained Wakefulness and Alcohol Intoxication.

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Running Title: Sustained Wakefulness and Alcohol Intoxication

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INTRODUCTION

Since the industrial revolution shiftwork has become an increasingly common work practice. It has been estimated that 15-20% of the working population in industrialised countries are currently employed on some form of non-standard work schedule (Knauth, 1993; Baker, 1980). While the economic benefits of shiftwork are self evident (Harrington, 1978), the benefits are accompanied by significant health and social costs (Mitler at al, 1988; Moore-Ede et al, 1985; Spelton et al, 1993). Research studies over the last 20 years have clearly identified shiftwork as an occupational health and safety risk factor (Akerstedt, 1995a).

Reduced opportunity for sleep and reduced sleep quality are generally considered to be the major risk factors associated with shiftwork related accidents (Mitler et al, 1988; Leger, 1994; Akerstedt et al, 1994). Not surprisingly, the combination of these factors leads to increased fatigue, lowered levels of alertness and impaired performance on a variety of cognitive psychomotor performance tasks (Harrington, 1978).

Experimental studies have shown that sustained wakefulness (SW) impairs several components of performance including hand-eye co-ordination, decision-making, memory, cognition, visual search performance and speed and accuracy of responding (Linde et al, 1992; Fiorica et al, 1968; Babkoff et al, 1988). In addition to cognitive factors, affective components of behaviour such as motivation, and mood are altered as the duration of SW increases (Babkoff et al, 1988; Bohl, 1993).

From the studies cited above it is clear that there is a general consensus that cognitive psychomotor performance is impaired by the sleep disruption and extended wakefulness associated with shiftwork (Akerstedt et al, 1994). Moreover, this performance impairment is associated with an increased risk of accident (Dinges, 1995).

Surprisingly, however, policy makers in western industrialised countries have generally not legislated to manage and control fatigue in a manner commensurate with the statistical risks associated with it. This attitude is in stark contrast to the response to alcohol-related performance impairment. Policy makers and the community have frequently proscribed work and/or the operation of dangerous equipment under the influence of alcohol. Given that the effects of SW are qualitatively similar to the effects of even moderate alcohol intoxication (Klein et al, 1970), it is paradoxical that fatigue-related performance impairment has not been subject to similar levels of regulatory intervention. This failure to address the occupational, health and safety impact of fatigue may, in part, reflect a failure to provide policy makers with a readily understood index of the relative risk associated with sleep loss and fatigue.

The current studies sought to express the impairment associated with fatigue equivalent to those currently accepted by policy makers and the community. That is, by expressing the performance impairment as its equivalent level of alcohol intoxication. By expressing the performance impairment associated with fatigue in terms of its equivalent BAC it is hoped to provide an easily-grasped index of comparative impairment.

METHODS

Study One

Subjects

Forty subjects (27 male; 13 female) gave informed consent to participate in the study. Subject ranged from 18 years to 32 years of age (mean 21.1 (± 3.7) years). The subjects selected were recruited using advertisements placed around the University of Adelaide. Volunteers were required to complete a general health questionnaire prior to the study. Subjects who had a current health problem, a history of psychiatric or sleep disorders were excluded. Subjects who smoked cigarettes or who were taking medication known to interact with alcohol or affect sleep patterns were also excluded. Subjects who did not drink alcohol, or who habitually consumed more than 6 standard drinks per day were excluded.

Procedure

All investigations were conducted at the Centre for Sleep Research at the Queen Elizabeth Hospital. Subjects participated in a randomised cross-over design involving two experimental conditions,

1. A sustained wakefulness condition (SW).

2. An alcohol condition (A).

with the assessment procedure and to minimise improvement in performance resulting from learning.

Sustained Wakefulness Condition

Subjects arrived at the sleep laboratory at 8:30 p.m. on the night prior to the commencement of the study period and completed a training session before going to sleep at approximately 11:00 p.m. Subjects were woken at 7 a.m. the following morning, after breakfast at approximately 7:45 a.m., 9 practice OSPAT tests were completed. Subjects then completed three performance tests at half hourly intervals from 8:00 a.m. until 12:00 p.m. the following day. In between tests, subjects were allowed to read, watch television and play games. Careful monitoring by research staff ensured wakefulness over the entire 28 hour period.

Alcohol Condition

Subjects arrived at the sleep laboratory at 8:30 p.m. on the night prior to the commencement of the study period and were required to complete a training session before going to sleep at approximately 11:00 p.m. Subjects were woken at 7 a.m. the following morning, after breakfast at approximately 7:45 a.m, 9 performance tests were completed. From 8:00 a.m. subjects underwent a breath test, completed three OSPAT tests and consumed an alcoholic drink at half hourly intervals. If a BAC of 0.1% was reached no further alcohol was given. Subjects were not informed of the BAC at anytime during the test period. All drink consumption and performance testing ceased at 4:00 p.m., but subjects were required to stay in the sleep laboratory under supervision until their BAC returned to 0%.

Subjects ate standard hospital meals during the study, although food and drinks containing caffeine were prohibited. Subjects were required to sit quietly and watch television or play boardgames during their time in the laboratory. Subjects were not permitted to exercise, shower or bath.

Equipment

Cognitive psychomotor performance

Cognitive psychomotor performance was measured using the Occupational Safety Performance Assessment Test (OSPAT). OSPAT is a unpredictable tracking task that subjects perform on a computer workstation. In simple terms, the task required subjects to keep a randomly moving cursor in the centre of three concentric circles, using a standard trackball. After the cursor is 'centred' the cursor moves to a random position away from the centre and the subject is required to 're-centre' the cursor. Subjects were seated in front of the workstation in an isolated room, free of distraction and were instructed to manipulate the track-ball using their dominant hand. Subjects completed three one-minute tests in each testing session and received no feedback between tests in order to avoid the knowledge of results affecting performance levels.

A global performance measure for each test is determined by summing the 'error' distance between the cursor and target and the rate at which the subject adapted to the random changes. This measure indicates how "well" the subject performed the task.

Blood alcohol

During the alcohol condition subjects were given alcohol loaded drinks consisting of 95% ethanol and orange juice at a rate designed to increase their BAC to 0.10% over a 4-6h period. Prior to all breath tests subjects were required to rinse their mouths with water. A standard calibrated breathalyser was used to estimate blood alcohol concentration (BAC) (Lion Alcolmeter S-D2, Wales). The breathalyser was accurate to 0.005% BAC.

Study Two

Subjects

Eight subjects (5 male; 3 female) gave informed consent to participate in the study. Subjects ranged from 19 years to 25 years of age (mean 20.25 (± 1.28) years). Method of recruitment and exclusion criteria were the same as those employed in study one.

Procedure

Subjects participated in a two-condition protocol similar to that in study one. In addition to the two experimental conditions, subjects attended a separate training day.

The two conditions were administered at least one week apart to allow subjects time to recover.

See Figure 1 for a schematic representation of the experimental protocol.

A previous pilot study for this protocol (Dawson et al, 1995) indicated that there was no performance decrement associated with the placebo condition, and that all subjects could correctly identify whether they were intoxicated or not. Since all subjects were regular social drinkers (4-8 drinks/week), and therefore experienced in the effects of alcohol a placebo condition was not included in this protocol.

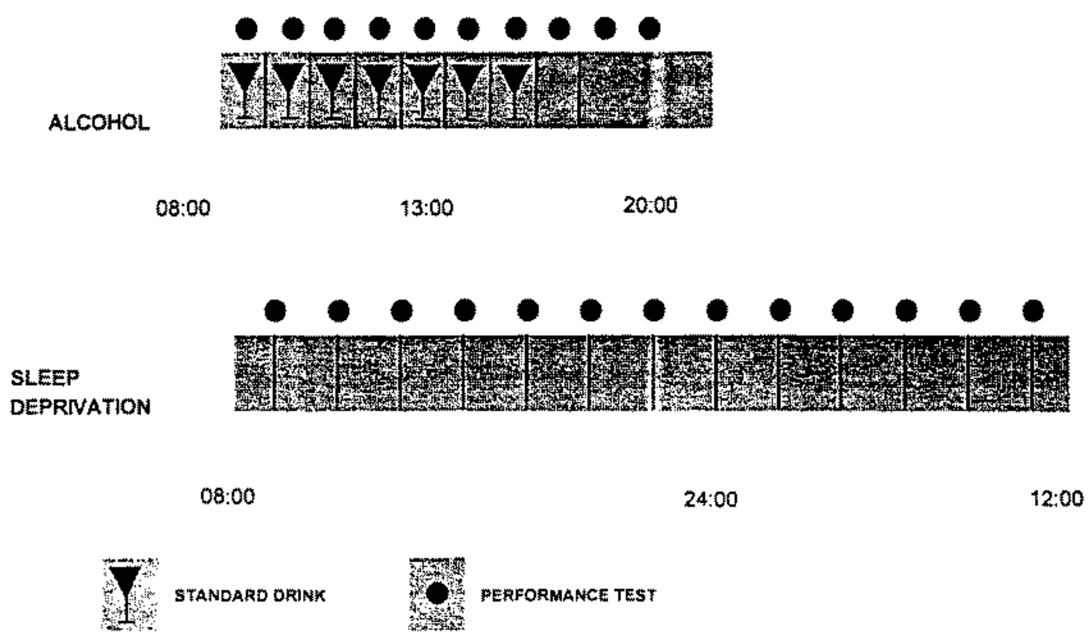

Figure 1. Schematic representation of the protocol for the sustained wakefulness (SW) and alcohol (A) experimental conditions. The alcohol condition commenced at 0800 hours. Subjects consumed 10mg of ethanol in orange juice every half hour until 1600h or until they reached a BAC of 0.10%. Every 30 minutes, subjects were breathalysed, completed three performance tests and then, if necessary, consumed another alcoholic beverage. The sleep deprivation condition commenced at 0800. Subjects completed three performance tests every 30 minutes until 1200h the following day.

Training Session

Subjects arrived at the sleep laboratory at 8:30 p.m. on the night prior to the commencement of each study period. They were required to complete 40 OSPAT tests to familiarise themselves

Training Session

During the week prior to commencement of the experimental conditions, subjects were required to attend the lab for a training session to familiarise themselves with the tasks used to assess performance and to minimise improvement in performance resulting from learning. They were required to complete each test until their performance reached a plateau.

Sustained Wakefulness Condition

Subjects arrived at the sleep laboratory at 8:00 p.m. on the night prior to commencement of the study. Prior to retiring at approximately 11:00 p.m., subjects completed a re-training session to reacquaint themselves with the performance tasks. During this session, they completed practice tests for each of the performance tasks in the study. Subjects were woken at 7:00 a.m. the following morning and a baseline testing session was completed at 8:00 a.m. Subjects then completed a testing session every hour, until 11:00 p.m. the following day.

Alcohol Condition

Subjects arrived at the sleep laboratory at 8:00 p.m. on the night prior to commencement of the experimental period. Before retiring for the night, at approximately 11:00 p.m., subjects completed a practice session as outlined above. Subjects were woken at 7:00 a.m. the following morning and completed a baseline testing session at 8:00 a.m. From 9:00 a.m. subjects completed a testing session every hour. As in study one, subjects underwent a breath test and consumed an alcoholic beverage at half hourly intervals.

Equipment

Cognitive psychomotor performance

Cognitive psychomotor performance was measured using a standardised computer based test battery (Worksafe Integrated Test Battery). The apparatus for the battery consists of an IBM compatible computer, microprocessor unit, response boxes and computer monitor. The test battery is based on a standard information processing model (Wickens, 1984). According to this model there are seven key information processing functions (see Figure 2).

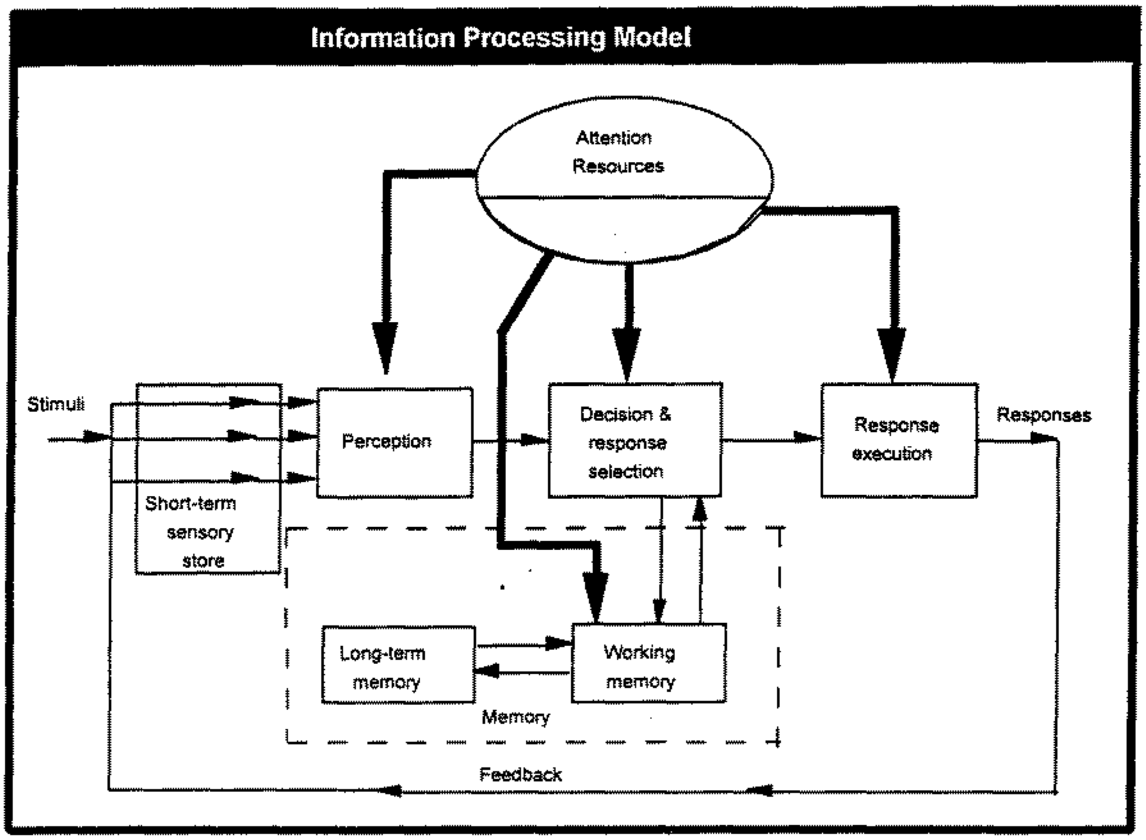

Figure 2. Synthesised information processing model indicating seven key information processing functions. Adapted from Wickens (1984).

The test battery software permits any combination of 12 visual and/or auditory tasks. The four tasks used in this study were (in order of complexity),

1. Simple Reaction Time (SRT)

2. Predictable Tracking (PT)

3. Vigilance (VIG)

4. Grammatical Reasoning (GR)

Each of these tasks was used to measure specific components of cognitive psychomotor performance according to the combinations outlined in Table 1.

	Simple Reaction Time	Predictable Tracking	Vigilance	Grammatical Reasoning
Short-term sensory store				
Perception	P	P	P	
Decision and Response selection			P	P
Working memory				P
Long-term memory				P
Attention resources		P	P	P
Response execution	P	P	P	

Table 1. Components of cognitive functioning required for performance of each test.
P: Primary information processing component skill(s) assessed by the task.

Performance Tasks

Simple Reaction Time

Simple reaction time is an unpredictable task that measures both reaction time and response time. Subjects were instructed to depress the home button on a tri-button unit. Then, using the same finger, they were required to depress the left hand response button when a stimulus was observed, returning to, and depressing, the home button afterwards.

Predictable Tracking

In the predictable tracking task , subjects were required, with the use of a joystick, to keep a cursor on, or as close as possible to, a target box. In this task, the whole track the target box is going to make was revealed to the subject in the set-up lap.

Vigilance

Vigilance is an unpredictable task that measures both accuracy and response time. To begin this task, subjects were instructed to have their hand hovering over the display area, ready to press any of the six black buttons or the single red button. Subjects were instructed to press the black button corresponding to the illuminated light, if only one light was illuminated, and to press the red button if two lights were illuminated simultaneously.

Grammatical Reasoning

Grammatical reasoning, the most complex of the tasks, measures accuracy, response time and reaction time. Using the same tri-box as SRT, the task began after the subject depressed the home button. Subjects were instructed to keep their finger on the home button, until a decision as to the truth/falsity of a specific statement (displayed on the monitor) had been made, and then to press the left (true) or right (false) button accordingly, using the same finger. After responding, subjects were required to return to and depress the home button, to initiate the next statement. Subjects were instructed to concentrate on accuracy rather than speed.

ANALYSIS OF RESULTS

Cognitive psychomotor performance data was analysed using relative performance. That is, each individual's performance was expressed relative to their personal baseline. In study one, the baseline measure was calculated by averaging the scores of each individuals nine practice trials carried prior to the first 8:00 a.m. performance test on the first of the two counterbalanced experimental conditions. In the second study the scores of each individuals 8:00 a.m. test session were used as the baseline measure.

Figure 3 indicates that subjects in the first study rapidly mastered the performance test during the practice session. There was little variation in mean relative performance after completing 5 tests and by 25 tests subjects had reached a clear performance plateau. Similar findings were observed in the second study.

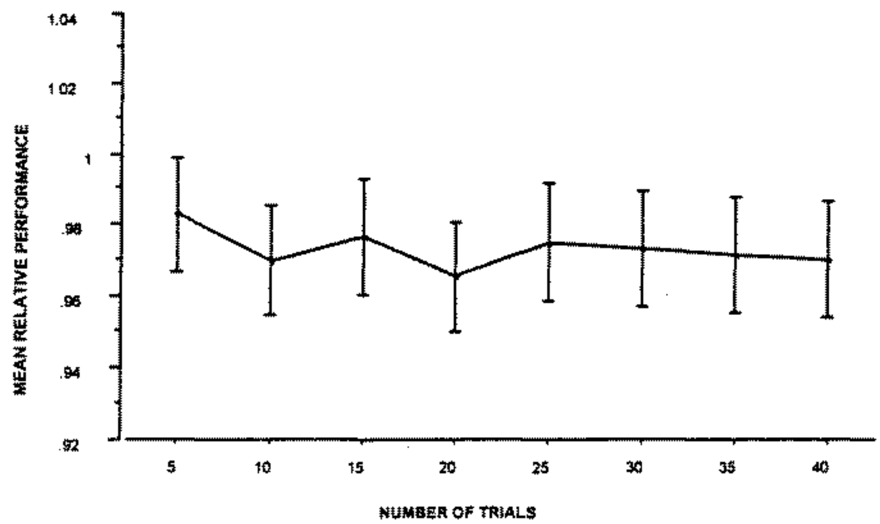

Figure 3. Mean relative performance for training session trials in the night prior to the first experimental condition (Study one). Error bars indicate ± s.e.m.

Alcohol Intoxication

To determine the relative effect of alcohol on performance, mean relative performance scores for all subjects were collapsed into 0.005% BAC intervals to determine the average performance decrement per unit increase of BAC. The linear relationship between increasing BAC and performance impairment was analysed by regressing mean relative performance against BAC for each 0.005% interval. Figure 4, shows the regression line between estimated BAC and mean relative performance in the alcohol condition.

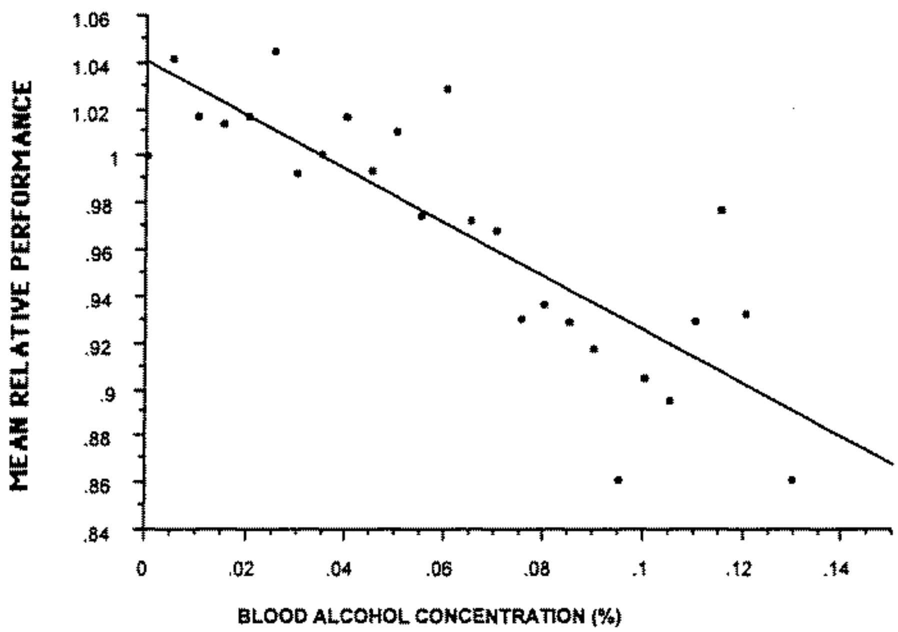

Figure 4. Scatter plot and linear regression of mean relative performance levels against blood alcohol concentrations between 0.00-0.13%.

The regression analysis indicated a significant linear correlation between subject's mean BAC and mean relative performance (Table 2). It was found that for each 0.01% increase in BAC, performance decreased by 1.16%. Thus, at a mean BAC of 0.10% mean performance decreased, on average, by 11.6%.

PERFORMANCE TEST	DF	F	P	R^2
Study One				
Ospat	1,24	54.4	< 0.05	0.69
Study Two				
Simple Reaction Time	1,7	13.41	<0.05	0.66
Predictable Tracking	1,7	9.61	<0.05	0.58
Vigilance				
Response Time	1,8	5.14	N.S.	0.39
Response Variability	1,6	1.63	N.S.	0.17
Grammatical Reasoning				
Response Time	1,6	7.33	<0.05	0.45
Accuracy	1,6	7,27	<0.05	0.39

Table 2. Regression analyses between mean relative performance and mean BAC.

Sustained Wakefulness

Performance in the SW condition was analysed by averaging performance data into two-hourly bins across the 28 hours of the study. Since there is a strong non-linear (circadian) component to the performance data and shiftworkers do not typically spend less than 10 or more than 26 hours awake (Australian Bureau of Statistics, 1993), the linear performance decrement per hour of wakefulness, was calculated using a linear regression between the tenth and twenty-sixth hour of wakefulness. This was methodologically appropriate since analysis of the performance data across this period shows a significant linear component ($p<.05$) and a non-significant non-linear component. Figure 5. illustrates this relationship plotting mean relative performance (from study one) against hours of wakefulness between the tenth and twenty-sixth hours.

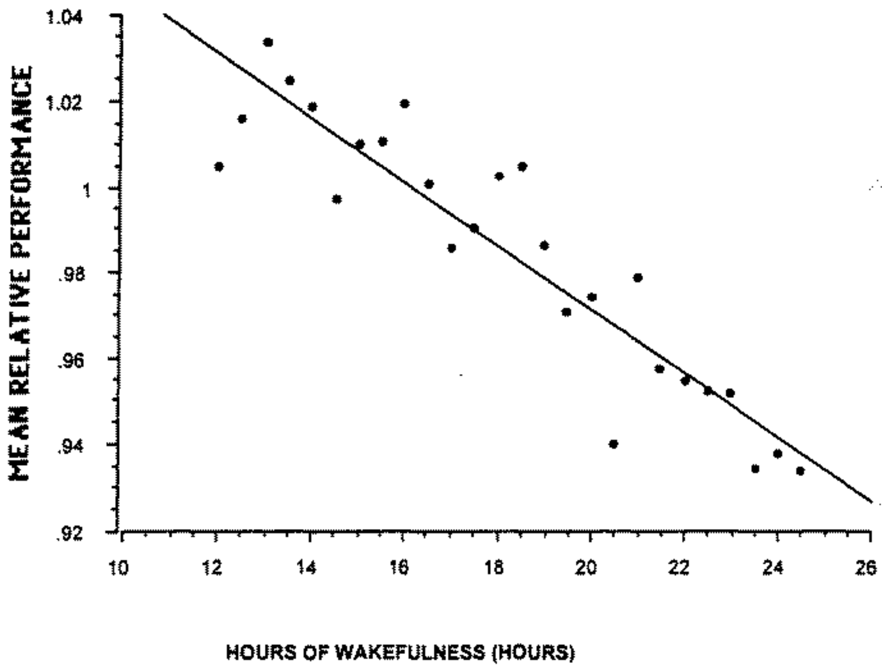

Figure 5. Scatterplot and linear regression of mean relative performance levels against prior wakefulness between the 10th and 26th hour of sustained wakefulness.

Regression analysis revealed a significant linear correlation between mean relative performance and hours of wakefulness (Table 3). Between the tenth and twenty-sixth hours of wakefulness, performance relative to baseline decreased by 0.74%/h.

PERFORMANCE TEST	DF	F	P	R^2
Study One				
Ospat	1,24	132.9	< 0.05	0.92
Study Two				
Simple Reaction Time	1,6	14.1	<0.05	0.70
Predictable Tracking	1,6	6.0	<0.05	0.5
Vigilance				
Response Time	1,6	22.53	<0.05	0.79
Response Variability	1,6	16.91	<0.05	0.74
Grammatical Reasoning				
Response Time	1,6	44.24	<0.05	0.88
Accuracy	1,6	14.42	<0.05	0.71

Table 3. Regression analyses between mean relative performance and hours of wakefulness.

The results discussed above illustrate the effects of SW and alcohol intoxication on cognitive psychomotor performance. However, the aim of the present study was to express the effects of fatigue as a blood alcohol equivalent. Figures 6 to 9 illustrate the comparative effects of SW and alcohol consumption on performance by plotting mean relative performance and BAC against hours of wakefulness.

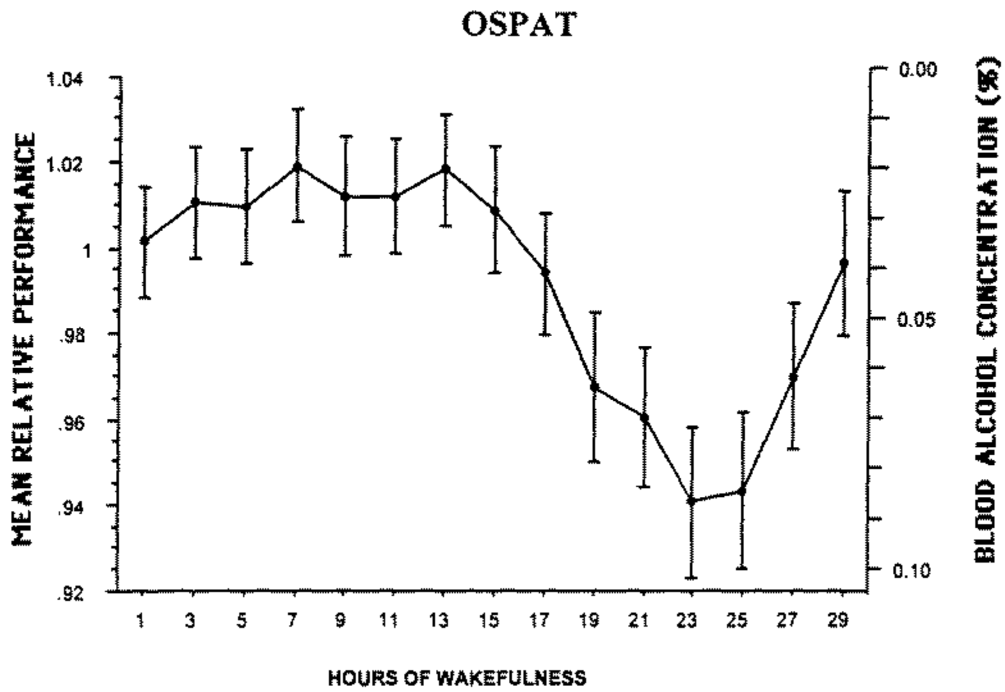

Figure 6. Performance (OSPAT) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate ± one s.e.m.

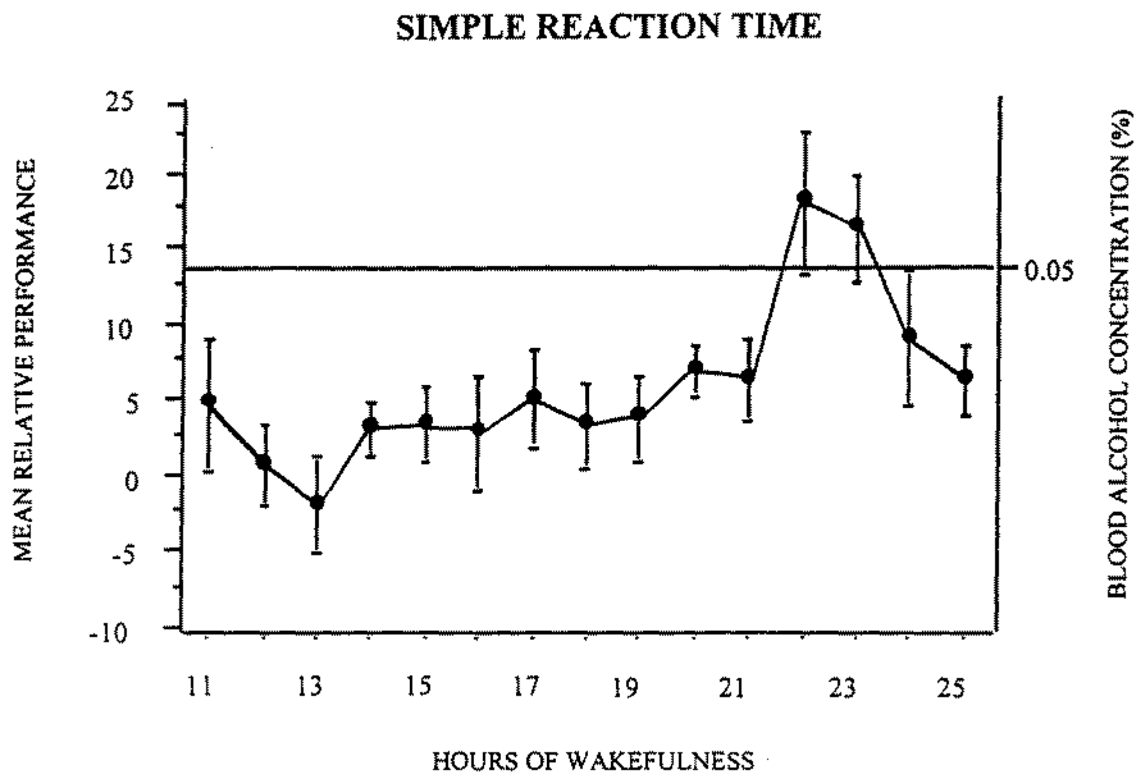

Figure 7. Performance (SRT) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate ± one s.e.m.

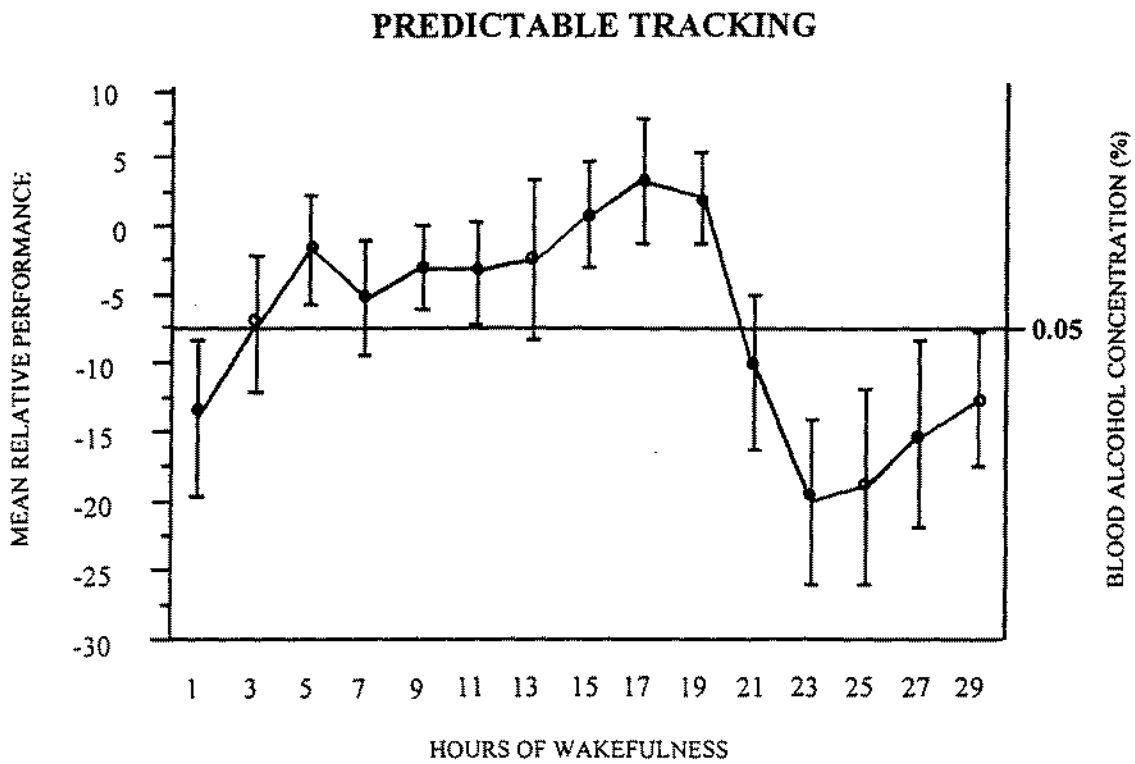

Figure 8. Performance (PT) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate ± one s.e.m.

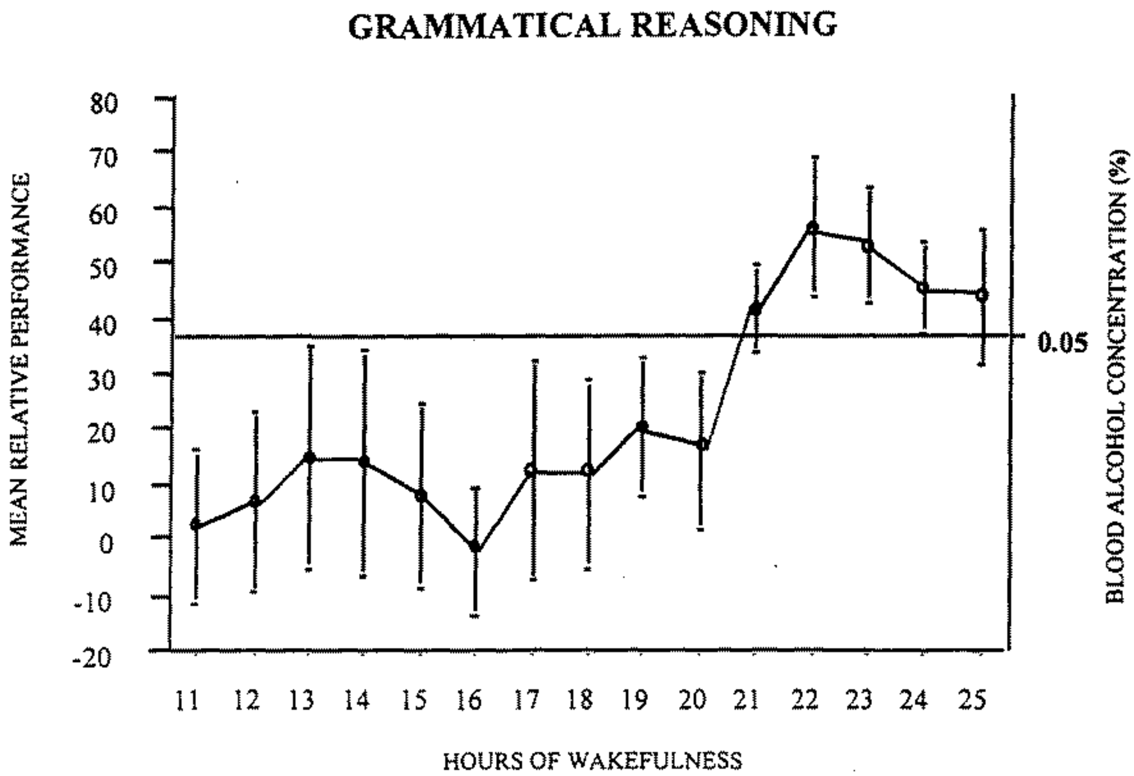

Figure 9. Performance (GR accuracy) in the SW condition expressed as mean relative performance on the left hand axis and the %BAC equivalent on the right hand axis. Error bars indicate ± one s.e.m.

By equating the two rates at which performance declines, (i.e. % decline / hour of wakefulness and % decline / ?BAC) it was calculated that the performance decrement for each hour of wakefulness was equivalent to the performance decrement observed with a 0.04% rise in BAC (study one data). Therefore, after 24 hours of SW cognitive psychomotor performance in study one decreased to a level equivalent to the performance observed at a BAC of 0.096%. While in the second study, after 24, 21, 21 and 13 hours of SW, performance on tasks of simple reaction time, predictable tracking and grammatical reasoning (accuracy and response time), respectively, decreased to a level equivalent to the performance observed at a BAC of 0.05%.

DISCUSSION

Cognitive psychomotor performance levels for all tests except for vigilance decreased significantly in the alcohol condition. Similarly, cognitive psychomotor performance levels decreased significantly for all performance tests in the SW conditions. Comparison of the two effects indicated that moderate levels of sustained wakefulness produce performance decrements comparable to those observed at moderate levels of alcohol intoxication in social drinkers.

In the alcohol condition increasing blood alcohol concentrations were associated with a significant linear decline in cognitive psychomotor performance. For example, in study one mean relative performance in the alcohol condition was impaired by approximately 5.8% at a BAC of 0.05% and by 11.6% at a BAC of 0.10. Overall, mean relative performance declined by approximately 1.16% per 0.01% BAC. These results are consistent with previous findings that suggest that cognitive psychomotor performance declines linearly with increasing intoxication between 0.0-0.075% BAC (Billings et al, 1991).

It is important to note that there was no decrease in mean relative performance up until a BAC of 0.03%. This is similar to the findings of Wilkinson and Colquhoun (1968) who also reported an increase in performance on a choice serial reaction test up until a BAC of 0.032%. This result is thought to reflect the fact that alcohol acts as a stimulant at low blood alcohol concentrations.

In contrast, cognitive psychomotor performance in the SW condition showed a more complex relationship. Mean relative performance showed three distinct phases. In the first phase (0-10 hours) performance remained relatively stable at a plateau. In the second phase (10-26 hours) performance declined linearly. During the third interval (26-28 hours) mean relative performance increased again presumably reflecting the well reported circadian variation in cognitive psychomotor performance (Folkard et al, 1993).

Since few shiftworkers remain awake for less than 10 or more than 26 hours between shifts (Australian Bureau of Statistics, 1993), the comparative analysis focussed on the second phase. Between the 10th and 26th hours mean relative performance, showed a strong linear decline of approximately 0.74 % per hour. The performance decline observed between hours 10 and 26 is consistent with previous studies, documenting cognitive psychomotor performance decreases for periods of sustained wakefulness between 12 and 86 hours (Linde et al, 1992; Storer et al, 1989: Fiorica et al, 1968).

While the results in each of the individual experimental conditions have, in and of themselves been previously established (Linde et al, 1992; Storer et al, 1989; Wang et al, 1992; Gustafon, 1986; Roache et al, 1992) equating the effects is relatively novel.

The results of this comparison indicate that the effects of 10-26 hours of SW from 1800-1000 hours, and moderate alcohol consumption have quantitatively similar effects on cognitive psychomotor performance. Although there are previous anecdotal reports indicating qualitative similarities between fatigue and alcohol intoxication (Klein et al, 1970; Kleitman, 1939), these studies establish the quantitative similarities of the two forms of impairment. In study one, equating the performance impairment between the 10th and 26th hour indicated a mean BAC equivalent of approximately 0.05% after 18 hours and 0.096% after 24 hours. If the results of this study were generalised to an applied setting they suggest that between 0300h and 0800h on the first night shift a shiftworker would show a cognitive psychomotor performance decrement similar to or greater than the legally proscribed BAC for many industrialised countries.

The second study further expanded on these findings. The results of the comparisons indicate that sleep deprivation effects specific components of performance differently, dependent on their relative degree of complexity. That is to say, sustained wakefulness effects more complex cognitive psychomotor abilities before simpler abilities. In accordance with the Information Processing Model earlier referred to, the simplest measure of performance incorporated in this study, simple reaction time, required only perception and response excecution functions. It was found that 24 hours of sleep deprivation were necessary to produce a performance decrement comparable to that associated with a BAC of 0.05%. Whereas for performance on the predictable tracking task, a slightly more complex task that also requires attention resource functions, a decrement equivalent to that of BAC of 0.05% was observed after 21 hours of sustained wakefulness.

Similarly, 21 hours of sleep deprivation produced a decrement in performance on the grammatical reasoning task equivalent to that associated with a BAC of 0.05%. It is interesting to note, however, that a decrement in the speed component of grammatical reasoning, equivalent to that associated with a BAC of 0.05%, was observed after only 13 hours of sustained wakefulness (graph not shown). While this may at first contradict the suggestion that more complex abilities are affected sooner by sustained deprivation, it must be remembered that subjects were told to concentrate on accuracy in this task, rather than speed. Indeed, the apparent speed-accuracy trade-off observed in the grammatical reasoning task is similar to that found in previous studies (Craig and Condon, 1985).

The data from both studies supports the idea that sustained wakefulness may carry a risk comparable with moderate alcohol intoxication since approximately 50% of shiftworkers on 8 hour shift patterns typically spend at least 24 hours awake on the first night shift in a roster (Knauth et al, 1981). Furthermore, the highest level of impairment observed in this study (~0.096% BAC) would occur at the end of a typical night shift (i.e. 0600-0900h) and would frequently coincide with the trip home for many shiftworkers.

While the results of this study clearly illustrate the comparative risks associated with sustained wakefulness for the first night shift, these results may underestimate the effect of night work in many real world settings. Previous research suggests that the performance impairment associated with shiftwork may be even greater on subsequent night shifts because of the reduced recuperative value of poor daytime sleep (Akerstedt, 1995b). Several studies have reported that the performance decrements, reduced alertness and fatigue reported by night shift workers is greater on the second and third night shift (Tilley et al, 1981). If this is the case, then it may be reasonable to assume that the alcohol impairment equivalent on these nights may be even greater than reported here for the first night.

However, it is not a simple process of calculating the performance decrement for hours of wakefulness, since shiftworkers may be sleeping at different times of the day and night. In addition they may have accumulated sleep loss from night one to three of their work schedule. Therefore, it may be useful to use longer experimental protocols to model actual shift schedules and establish the BAC equivalence for the performance decrement associated with the fatigue that can accumulate over a sequence of night shifts.

Taken together, the results from this study support the idea that the performance impairment and, by inference, the risk associated with sustained wakefulness across the night are not insubstantial and are quantitatively similar to those observed for moderate alcohol intoxication in social drinkers.

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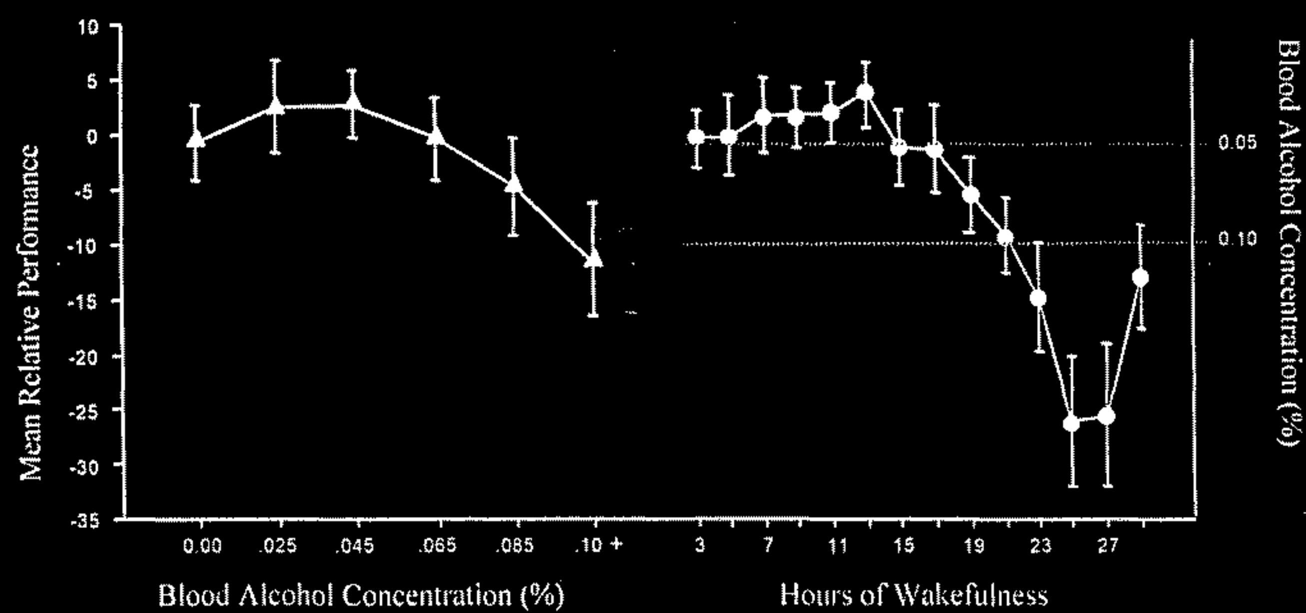
Components of Cognitive Processing measured by different tests of the Performance Battery

	Sensory Comparison	Unpredictable Tracking	Vigilance	Grammatical Reasoning
Short-term Memory				
Perception				
Attention Resources				
Decision & Response				
Working Memory				
Long-term memory				
Response Execution				

AB 12 C5

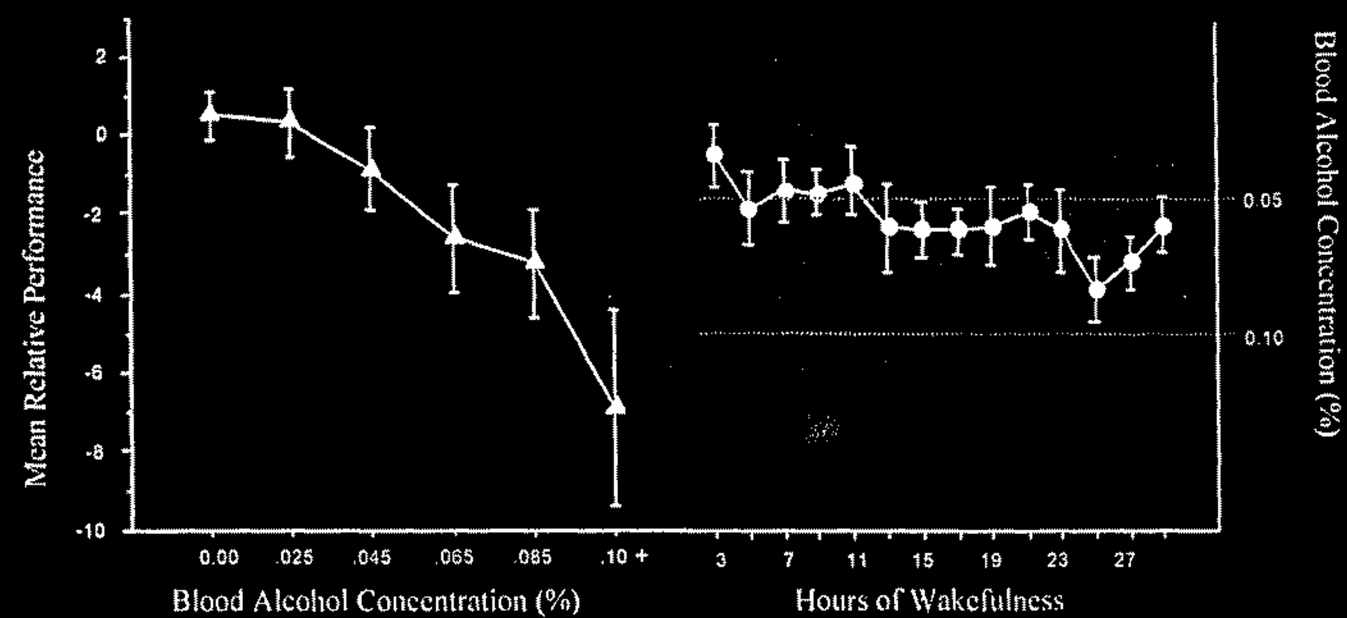
SIMPLE SENSORY COMPARISON

Grammatical Reasoning

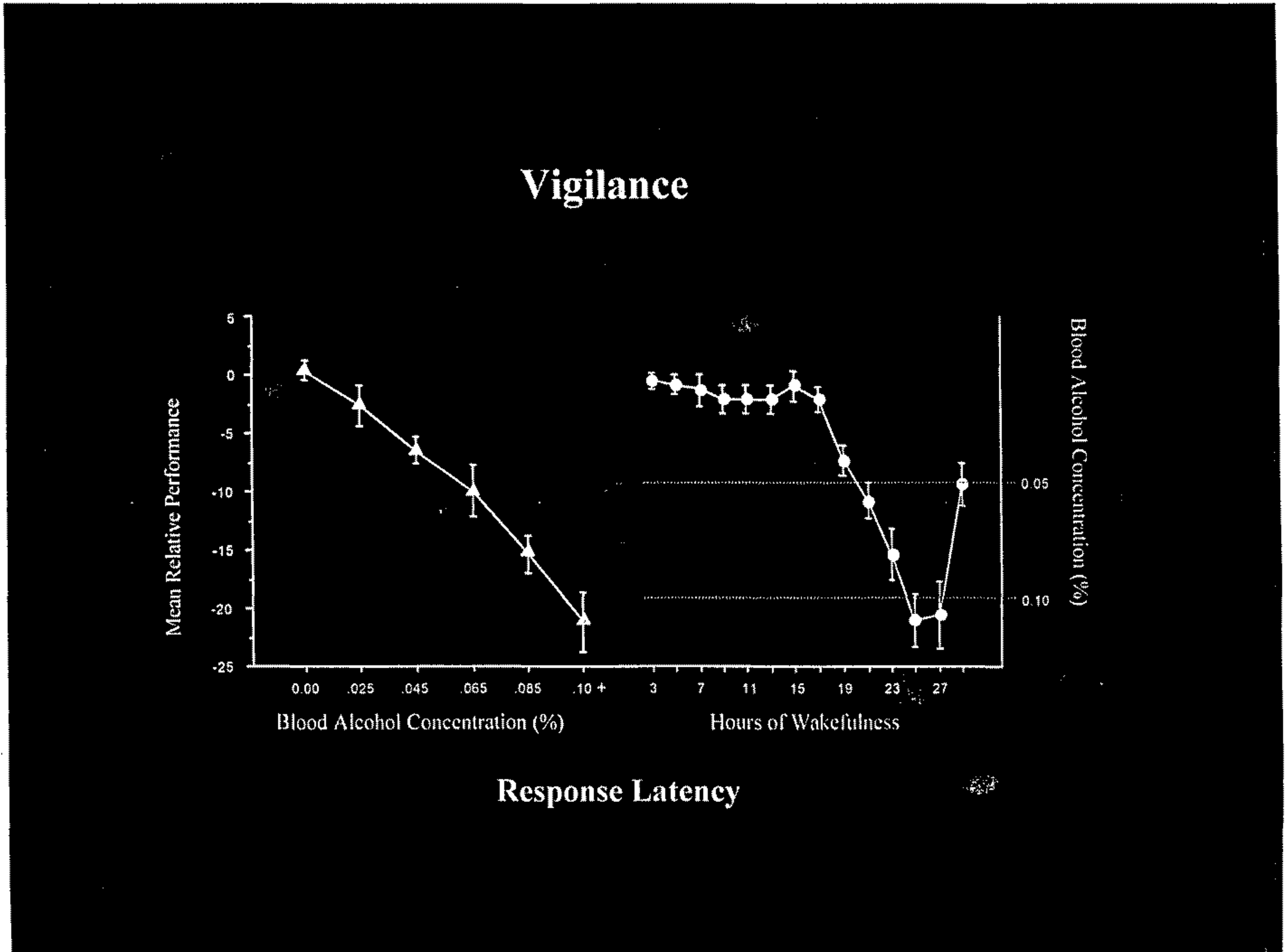


Response Latency

Grammatical Reasoning

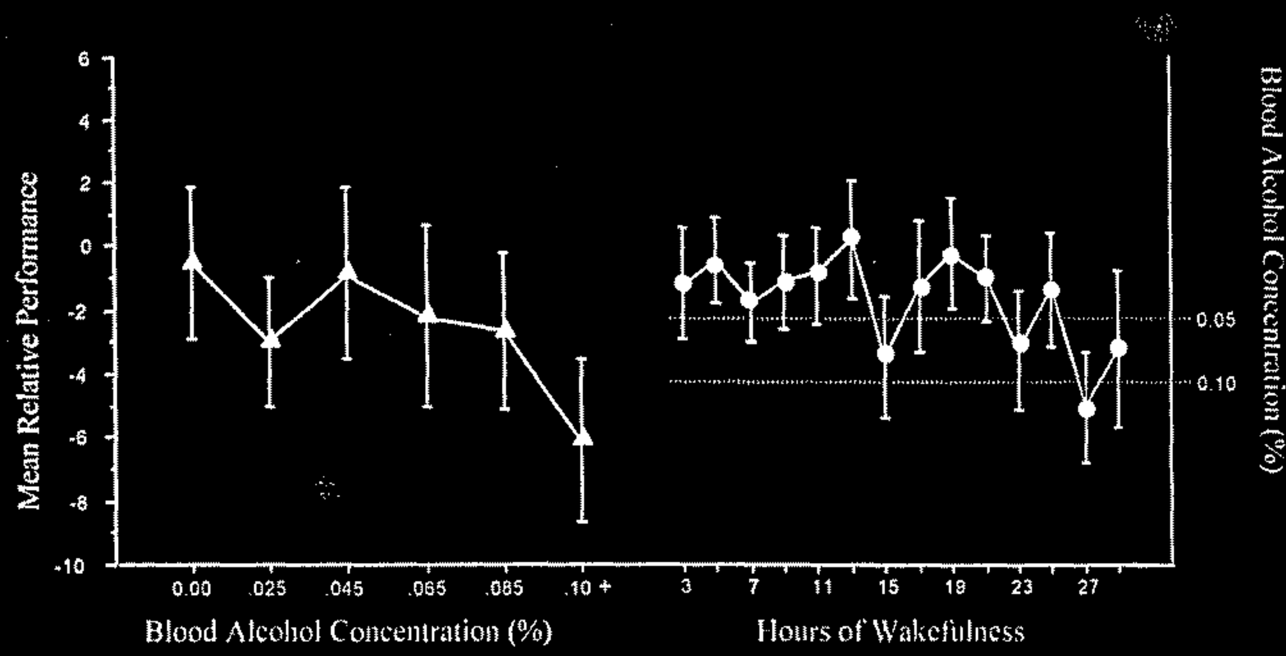


Accuracy

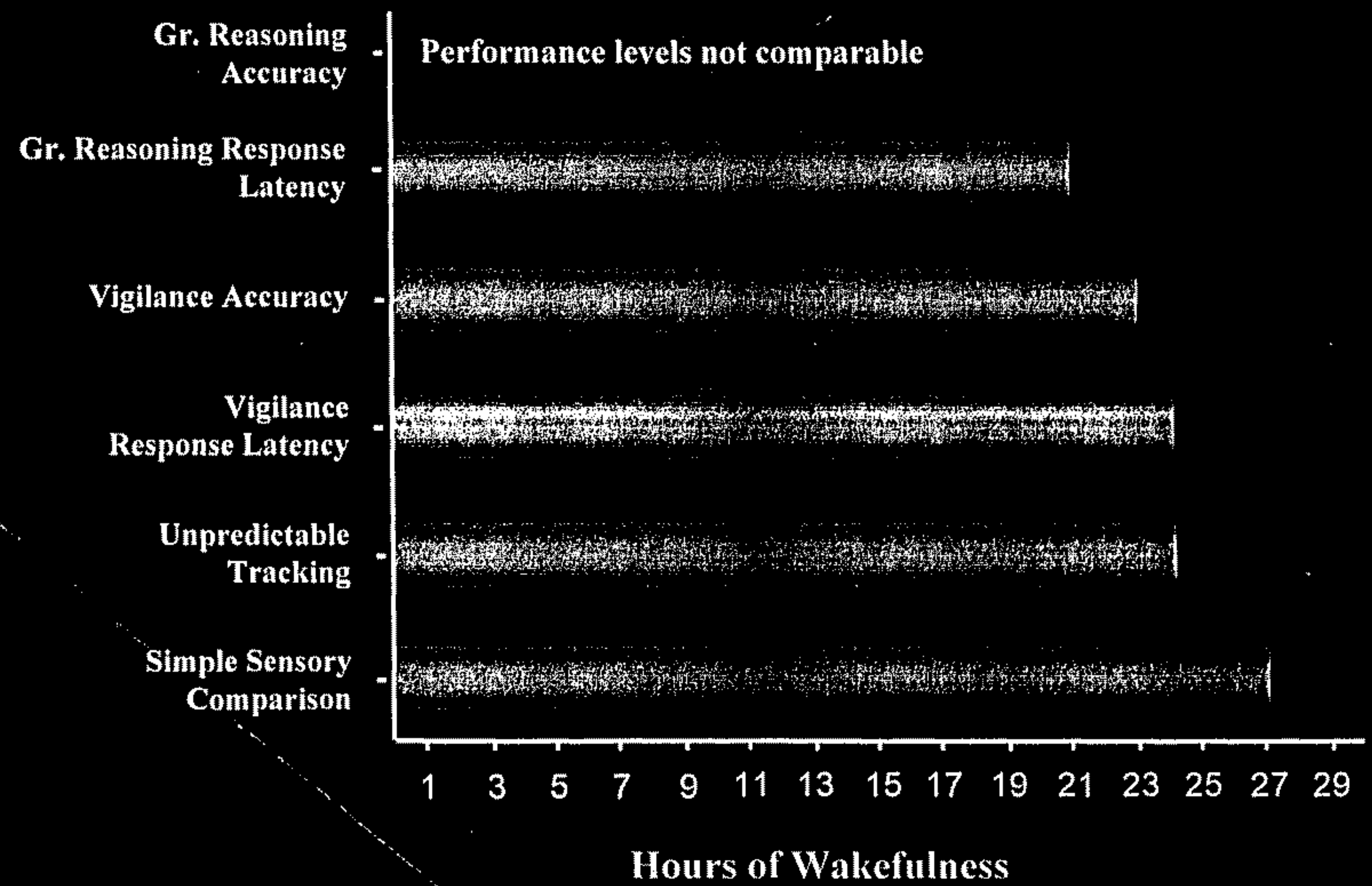


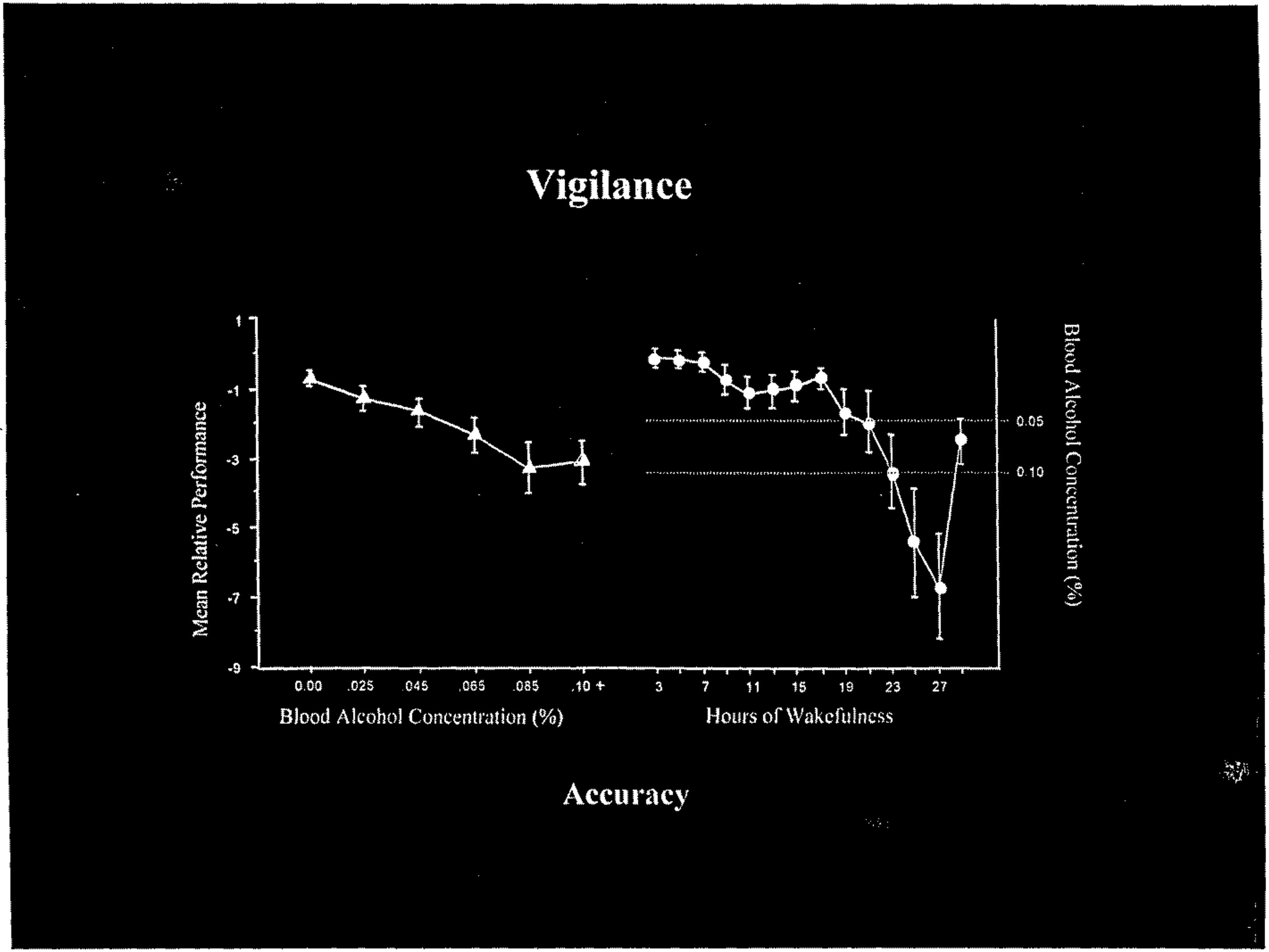
Vigilance
Mean Relative Performance
5
0
-5
-10
-15
-20
-25
0.00
.025
.045
.065
.085
.10 +
Blood Alcohol Concentration (%)
3
7
11
15
19
23
27
Hours of Wakefulness
0.05
0.10
Blood Alcohol Concentration (%)
Response Latency

Simple Sensory Comparison



The Relative Effects of Sustained Wakefulness on Performance (BAC 0.10%)




Vigilance
Mean Relative Performance
1
-1
-3
-5
-7
-9
0.00
.025
.045
.065
.085
.10 +
Blood Alcohol Concentration (%)
3
7
11
15
19
23
27
Hours of Wakefulness
0.05
0.10
Blood Alcohol Concentration (%)
Accuracy

Unpredictable Tracking