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Quantifying the performance impairment associated with fatigue

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SUMMARY The present study systematically compared the effects of fatigue and alcohol intoxication on a range of neurobehavioural tasks. By doing so, it was possible to quantify the performance impairment associated with fatigue and express it as a blood alcohol impairment equivalent. Twenty-two healthy subjects aged 19–26 years participated in three counterbalanced conditions. In the sustained wakefulness condition, subjects were kept awake for 28 h. In the alcohol and placebo conditions, subjects consumed either an alcoholic or non-alcoholic beverage at 30 min intervals, until their blood alcohol concentration reached 0.10%. In each session, performance was measured at hourly intervals using four tasks from a standardised computer-based test battery. Analysis indicated that the placebo beverage did not significantly effect mean relative performance. In contrast, as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. Similarly, as hours of wakefulness increased performance levels for four of the six parameters significantly decreased. More importantly, equating the performance impairment in the two conditions indicated that, depending on the task measured, approximately 20–25 h of wakefulness produced performance decrements equivalent to those observed at a blood alcohol concentration (BAC) of 0.10%. Overall, these results suggest that moderate levels of fatigue produce performance equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment.

KEYWORDS alcohol intoxication, performance impairment, sustained wakefulness

INTRODUCTION

The negative impact of sleep loss and fatigue on neurobehavioural performance is well documented (Gillberg *et al*. 1994; Mullaney *et al*. 1983; Tilley and Wilkinson 1984). Studies have clearly shown that sustained wakefulness significantly impairs several components of performance, including response latency and variability, speed and accuracy, hand-eye coordination, and decision-making and memory (Babkoff *et al*. 1988; Fiorica *et al*. 1968; Linde and Bergstrom 1992). Nevertheless, understanding of the relative performance decrements produced by sleep loss and fatigue among policy-makers, and within the community, is poor.

By contrast, the impairing effects of alcohol intoxication are generally well accepted by the community and policy makers, resulting in strong enforcement of laws mandating that individuals whose blood alcohol concentration exceeds a certain level be restricted from driving, working and/or operating dangerous equipment. Consequently, several studies have used alcohol as a standard by which to compare impairment in psychomotor performance caused by other substances (Dick *et al*. 1984; Heishman *et al*. 1989; Thapar *et al*. 1995). By using alcohol as a reference point, such studies have provided more easily grasped results regarding the performance impairment associated with such substances.

In an attempt to provide policy makers and the community with an easily understood index of the relative risks associated with sleep loss and fatigue, Dawson and Reid (1997) equated the performance impairment of fatigue and alcohol intoxication using a computer-based unpredictable tracking task. By doing so, the authors demonstrated that one night of sleep deprivation

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produces performance impairment greater than is currently acceptable for alcohol intoxication.

While this initial study clearly established that fatigue and alcohol intoxication have quantitatively similar effects, it should be noted that performance on only one task was investigated. Thus, it is unclear at present whether these results are restricted to hand-eye coordination, or characteristic of the general cognitive effects of fatigue. While it is generally accepted that sleep loss and fatigue are associated with impaired neurobehavioural performance, recent research suggests that tasks may differ substantially in their sensitivity to sleep loss. Studies addressing this issue have suggested that tasks which are complex, high in workload, relatively monotonous and which require continuous attention are most vulnerable to sleep deprivation (Johnson 1982; Wilkinson 1964).

As conditions that cause deterioration in one particular function of performance may leave others unaffected, it is unreasonable to assume that one could predict all the effects of sleep loss from a single performance test. Thus, the current study sought to replicate and extend the initial findings of Dawson and Reid (1997) by systematically comparing the effects of fatigue and alcohol intoxication on a range of performance tasks.

METHOD

Subjects

Twenty-two participants aged 19–26 years were recruited for the study using advertisements placed around local universities. Volunteers were required to complete a general health questionnaire and sleep/wake diary prior to the study. Subjects who had a current health problem, and/or a history of psychiatric or sleep disorders were excluded. Subjects who smoked cigarettes or who were taking medication known to interact with alcohol were also excluded. Participants were social drinkers who did not regularly consume more than six standard drinks per week.

Performance battery

Neurobehavioural performance was measured using a standardised computer based test battery (developed by WORKSAFE Australia). The apparatus for the battery consisted of an IBM compatible computer, microprocessor unit, response boxes and computer monitor. Based on a standard information processing model (Wickens 1984), the battery sought to provide a broad sampling of various components of neurobehavioural performance. Four of twelve possible performance tests were used, such that the level of cognitive complexity ranged from simple to more complex (as listed below). Since speed and accuracy scores can be effected differently by sleep deprivation (Angus and Heslegrave 1985; Webb and Levy 1982), tasks that assessed both were investigated.

The simple sensory comparison task required participants to focus on an attention fixing spot displayed on the monitor for 750 ms. Following this, a line of stimulus characters, divided into three blocks of either numbers, letters or a mixture was displayed. Participants were then required to respond to a visual cue, which appeared in the position of one of the stimulus blocks, by naming the block which had been there. Verbal responses were scored as correct, partially correct or incorrect.

The unpredictable tracking task (3-min trials) was performed using a joystick to control the position of a tracking cursor by centring it on a constantly moving target. Performance was measured as a percentage of time on target.

The vigilance task (3.5-min trials) required subjects to press one of six black buttons or a single red button, depending on which light was illuminated. If a single light was illuminated subjects were required to press the corresponding black button underneath it. If, however, two lights were illuminated simultaneously subjects were required to press the red button. Each light went off when a response was made, or after 2500 ms. For this report, two vigilance measures were evaluated: (i) the number of correct responses (accuracy), and (ii) increases in the duration of responses (response latency).

The grammatical reasoning task was based on a similar task by Baddeley (1968). This task required subjects to decide and indicate whether a logical statement, which referred to a pair of letters, was true or false (e.g. The statement ‘A precedes B’ is true for the letter pair AB). For each trial, subjects were presented individually with 32 statements, beneath which were a pair of letters (either AB or BA). To respond, subjects were required to hold down a home button on the response box until they were ready to press one of two other buttons, designated either true or false. Subjects were instructed to concentrate on accuracy, rather than speed. In this report, both accuracy (percentage of correct responses) and response latency were evaluated.

During test sessions, subjects were seated in front of the workstation in an isolated room, free of distraction, and were instructed to complete each task once (tasks were presented in a random order to prevent order effects). Each test session lasted approximately 15 min. Subjects received no feedback during the study, in order to avoid knowledge of results affecting performance levels.

Procedure

Subjects participated in a randomised cross-over design involving three experimental conditions: (i) an alcohol intoxication condition (ii) a placebo condition, and (iii) a sustained wakefulness condition. During the week before commencement of the experimental conditions, all participants were individually trained on the performance battery to familiarise themselves with the tasks and to minimise improvements in performance resulting from learning. Subjects were required to repeat each test until their performance reached a plateau.

The subjects reported to the laboratory at 20.00 h on the night before each condition. Prior to retiring at 23.00 h, subjects were required to complete additional practice trials on each

Table 1 Summary of ANOVA results for neurobehavioural performance variables

	Baseline		*Placebo*		*Alcohol intoxication*		*Sustained wakefulness*	
Performance variable	$F_{2,63}$	*P*	$F_{7,147}$	*P**	$F_{5,105}$	*P**	$F_{13,273}$	*P**
GRG response latency	0.24	NS	0.82	NS	4.96	0.0021	13.77	0.0001
GRG accuracy	2.81	NS	0.63	NS	6.88	0.0001	2.20	NS
VIG response latency	0.24	NS	2.19	NS	43.09	0.0001	33.74	0.0001
VIG accuracy	1.53	NS	2.02	NS	7.99	0.0008	11.04	0.0001
Unpredictable tracking	0.24	NS	2.63†	NS	5.32	0.0008	10.09	0.0001
Simple sensory comparison	0.26	NS	0.78	NS	1.88	NS	1.47	NS

GRG, grammatical reasoning; VIG, vigilance.
* Corrected by Greenhouse–Geisser epsilon; † Based on data from 20 subjects.

task. For each condition subjects were woken at 07.00 h, following a night of sleep, and allowed to breakfast and shower before a baseline testing session, which started at 08.00 h. During each condition subjects had free access to zeitgeibers such as television, radio and clocks.

Alcohol intoxication condition

Subjects completed a performance testing session hourly. Following the 09.00 h testing session, each subject was required to consume an alcoholic beverage, consisting of 40% vodka and a non-caffeinated soft drink mixer, at half hourly intervals. Twenty minutes after the consumption of each drink, BAC were estimated using a standard calibrated breathalyser (Lion Alcolmeter S-D2, Wales) accurate to 0.005% BAC. When a BAC of 0.10% was reached no further alcohol was given. Subjects were not informed of their BAC at anytime during the experimental period.

Placebo condition

The procedure for the placebo condition was essentially identical to the alcohol condition. Subjects in the placebo condition had the rim of their glass dipped in ethanol to give the impression that it contained alcohol. To ensure that subjects remained blind to the treatment condition to which they had been allocated, approximately equal numbers of subjects received alcohol or placebo in any given laboratory session.

Sustained wakefulness condition

In order to produce substantial levels of fatigue, subjects were deprived of sleep for one night and performance was measured at the low point of the circadian cycle. Following the 08.00 h baseline session, subjects completed a performance testing session every hour. In between their testing sessions, subjects could read, write, watch television or converse with other subjects, but were not allowed to exercise, shower or bath. Food and drinks containing caffeine were prohibited the night before and during the experimental conditions.

Statistical analysis

To control for interindividual variability on neurobehavioural performance, test scores for each subject under each condition were expressed relative to the test score they obtained in the baseline (08.00 h) testing session of that condition. Relative scores within each interval (hour of wakefulness or 0.01% BAC intervals) were then averaged to obtain the mean relative performance across subjects. Neurobehavioural performance data in the sustained wakefulness and alcohol intoxication conditions were then collapsed into 2-h bins and 0.02% BAC intervals, respectively.

Evaluation of systematic changes in each performance parameter across time (hours of wakefulness) or blood alcohol concentration were assessed separately by repeated-measures analysis of variance (ANOVA), with significance levels corrected for sphericity by Greenhouse–Geisser epsilon.

Linear regression analysis based on the means over all subjects was used to determine the line of best fit for the performance effects across hours of wakefulness and alcohol intoxication. The relationship between neurobehavioural performance and both hours of wakefulness and BAC was expressed as a percentage drop in performance for each hour of wakefulness or each percentage increase in BAC, respectively. For each performance parameter, the percentage drop in test performance in each of the two conditions was also equated, and the effects of sustained wakefulness on performance expressed as a BAC equivalent.

RESULTS

Baseline scores

To evaluate possible differences between the baseline (08.00 h) measure obtained in each condition, separate ANOVAs for each performance parameter were used. As is evident in Table 1, the baseline measures for each performance variable did not significantly differ as a function of condition.

Table 2 Summary of linear regression analysis of neurobehavioural performance variables

Performance parameter	*DF*	*F*	*P*	*R2*	*% decrease*
SW condition					(per hour)
GRG response latency	1,4	70.61	0.0011	0.95	2.69
GRG accuracy	1,4	3.64	NS	—	—
VIG response latency	1,4	98.54	0.0006	0.96	1.98
VIG accuracy	1,4	81.79	0.0008	0.95	0.61
Unpredictable tracking	1,4	70.93	0.011	0.95	3.36
Simple sensory	1,4	4.71	NS	—	—
Alcohol condition					(per 0.01% BAC)
GRG response latency†	1,2	74.30	0.0132	0.97	2.37
GRG accuracy	1,4	31.07	0.0051	0.89	0.68
VIG response latency	1,4	12.65	0.0002	0.98	2.05
VIG accuracy*	1,3	212.37	0.0007	0.99	0.29
Unpredictable tracking*	1,3	238.52	0.0006	0.99	2.68
Simple sensory	1,4	5.37	NS	—	—

* Based on data from 0.02%–0.10% BAC; † Based on data from 0.04%–0.10% BAC.

Alcohol intoxication condition

Table 1 displays the results of the ANOVAS run on each performance variable as a function of BAC. Five of the six performance parameters significantly ($P = 0.0008$–0.0001) decreased as BAC increased, with poorest performance resulting at a BAC of 0.10% or greater.

The linear relationship between increasing BAC and performance impairment was analysed by regressing mean relative performance against BAC for each 0.02% interval. As is evident in Table 2, there was a significant ($P = 0.0132$–0.0002) linear correlation between BAC and mean relative performance for all of the variables except one. It was found that for each 0.01% increase in BAC, the decrease in performance relative to baseline ranged from 0.29 to 2.68%.

Placebo condition

To ensure that differences in performance reflected only the effects of actual alcohol intoxication a placebo condition was incorporated into the study. As indicated in Table 1, mean relative performance in the placebo condition did not significantly vary.

Sustained wakefulness condition

Table 1 displays the results of the ANOVAS for each performance variable as a function of hours of wakefulness. Four of the six performance parameters showed statistically significant ($P = 0.0001$) variation by hours of wakefulness. In general, the hours-of-wakefulness effect on each performance parameter was associated with poorest performance resulting after 25–27 h of wakefulness.

Since there is a strong non-linear component to the performance data, which remained at a fairly stable level throughout the period which coincides with their normal waking day, the performance decrement per hour of wakefulness was calculated using a linear regression between the 17th (equivalent to 23.00 h) and 27th hour of wakefulness.

As indicated in Table 2, regression analyses revealed a significant linear correlation ($P = 0.0011$–0.0001) between mean relative performance and hours of wakefulness for four of the six performance variables. Between the 17th and 27th hours of wakefulness the decrease in performance relative to baseline ranged from 0.61 to 3.35% per hour (Table 2).

Fatigue and alcohol intoxication

The primary aim of the present study was to express the effects of fatigue on a range of neurobehavioural performance tasks as a blood alcohol equivalent. Figures 1–6 illustrate the comparative effects of alcohol intoxication and fatigue on the six performance parameters. When compared to the impairment of performance caused by alcohol at a BAC of 0.10%, the same degree of impairment was produced after 20.3 (grammatical reasoning response latency), 22.3 (vigilance accuracy), 24.9 (vigilance response latency) or 25.1 (tracking accuracy) hours. Even after 28 h of sustained wakefulness, neither of the remaining two performance variables (grammatical reasoning accuracy and simple sensory comparison) decreased to a level equivalent to the impairment observed at a BAC of 0.10%.

DISCUSSION

In the present study moderate levels of alcohol intoxication had a clearly measurable effect on neurobehavioural performance. We observed that as blood alcohol concentration increased performance on all the tasks, except for one, significantly decreased. A similar effect was observed in the sustained wakefulness condition. As hours of wakefulness increased performance levels for four of the six parameters significantly decreased. Comparison of the two effects indicated

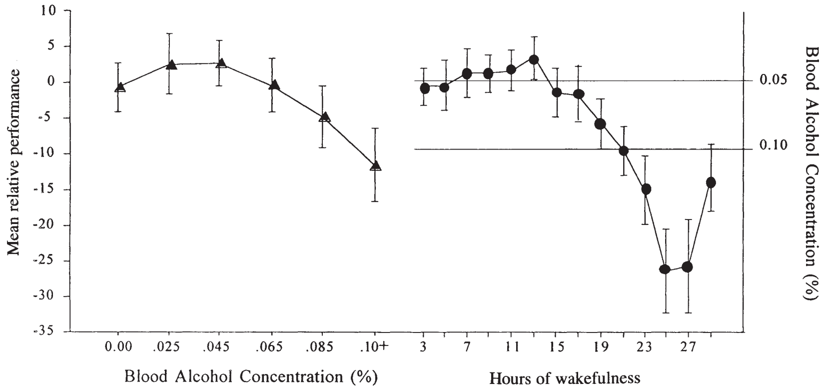

Figure 1. Mean relative performance levels for the response latency component of the grammatical reasoning task in the alcohol intoxication (left) and substained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

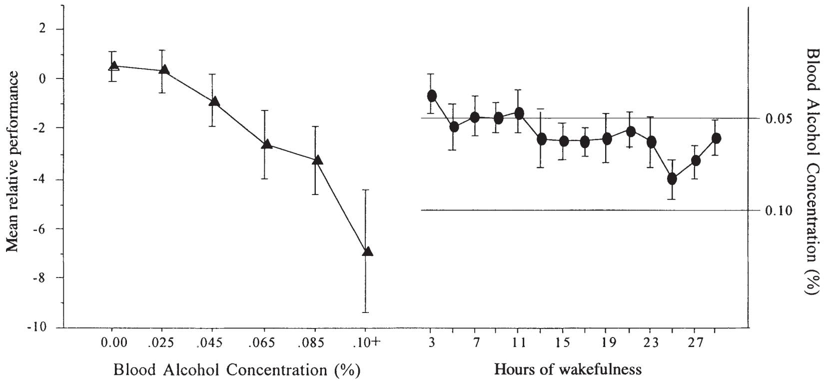

Figure 2. Mean relative performance levels for the accuracy component of the grammatical reasoning task in the alcohol intoxiction (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

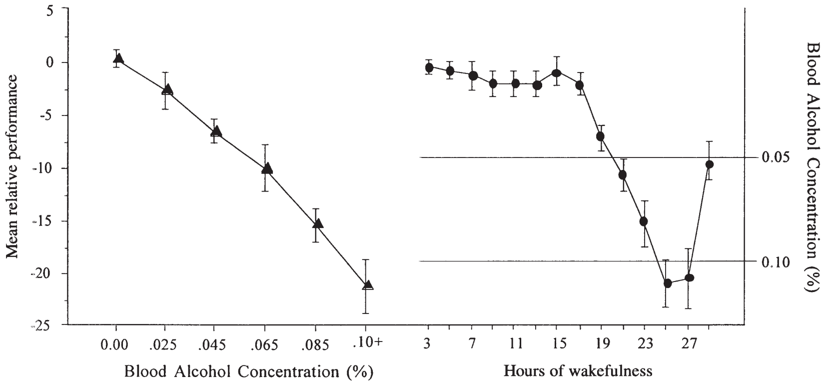

Figure 3. Mean relative performance levels for the response latency component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

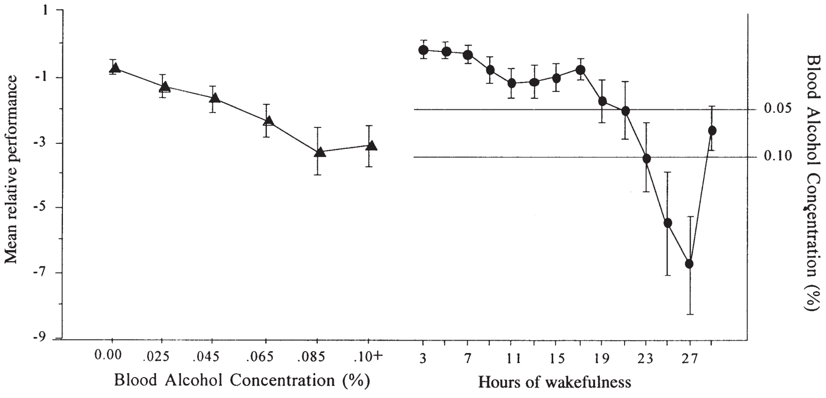

Figure 4. Mean relative performance levels for the accuracy component of the vigilance task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% ad 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

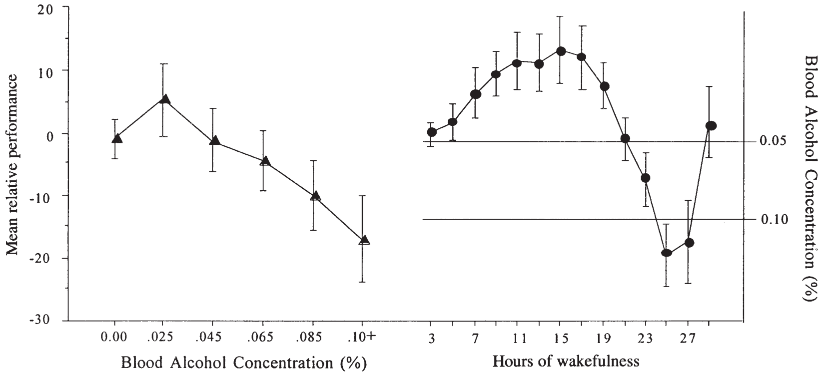

Figure 5. Mean relative performance levels for the unpredictable tracking task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

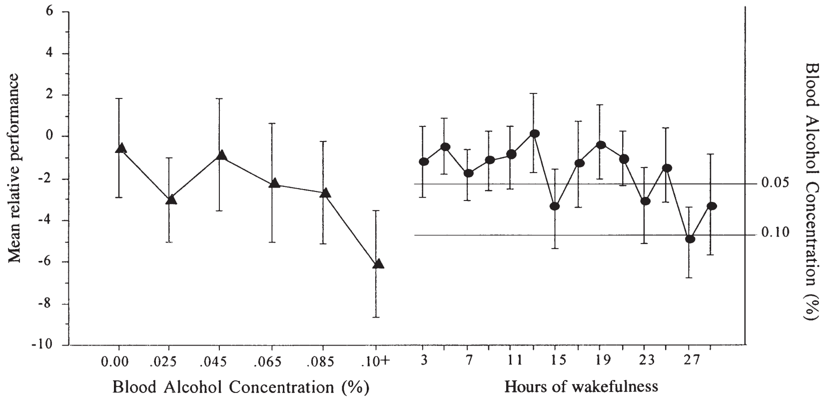

Figure 6. Mean relative performance levels for the simple sensory comparison task in the alcohol intoxication (left) and sustained wakefulness condition. The equivalent performance decrement at a BAC of 0.05% and 0.10% are indicated on the right hand axis. Error bars indicate ±1 SEM.

that moderate levels of fatigue produce performance decrements comparable to those observed at moderate levels of alcohol intoxication in social drinkers.

As previous research has found that some individuals tend to perform in a manner that is consistent with the expectation that they are intoxicated due to alcohol consumption (Brechenridge and Dodd 1991), a placebo condition was included in this study. We found that the placebo beverage did not significantly effect mean relative performance. Thus, it was assumed that performance decrements observed during the alcohol condition were caused solely by increasing blood alcohol concentration. Moreover, it is worth noting that the placebo condition in this study generally did not create the perception of alcohol consumption. Furthermore, when participants had already experienced the alcohol condition, and thus the effects of alcohol on their subsequent behaviour and performance, placebo beverages were even less convincing, suggesting that inclusion of a placebo condition is not necessary in future studies of a similar nature.

In general, increasing BAC were associated with a significant linear decrease in neurobehavioural performance. At a BAC of 0.10% mean relative performance was impaired by approximately 6.8% and 14.2% (grammatical reasoning accuracy and response latency, respectively), 2.3% and 20.5% (vigilance accuracy and response latency, respectively) or 21.4% (tracking). Overall, the decline in mean relative performance ranged from approximately 0.29% to 2.68% per 0.01% BAC. These results are consistent with previous findings that suggest that alcohol produces a dose-dependent decrease in neurobehavioural performance (Billings *et al.* 1991).

In contrast, mean relative performance in the sustained wakefulness condition showed three distinct phases. Neurobehavioural performance remained at a relatively stable level during the period which coincided with the normal waking day (0–17 h). In the second phase, performance decreased linearly, with poorest performance generally occurring between 08.00 and 10.00 h, after 25–27 h of wakefulness. It was observed that mean relative performance increased again after 26–28 h of wakefulness presumably reflecting either the well reported circadian variation in neurobehavioural performance (Folkard *et al.* 1993) or, as subjects were aware of the time, an end of testing session effect.

The decrease in performance observed for four of the measures in this study is consistent with previous studies documenting neurobehavioural performance decreases for periods of sustained wakefulness between 12 and 86 h (Linde and Bergstrom 1992; Storer *et al.* 1989; Fiorica *et al.* 1968). Between the 17th and 27th hours of wakefulness, mean relative performance significantly decreased at a rate of approximately 2.61% (grammatical reasoning response latency), 0.61 and 1.98% (vigilance accuracy and response latency, respectively) or 3.36% (tracking) per hour.

While the results in each of the experimental conditions are interesting in themselves, and have previously been established, the primary aim of the present study was to compare the effects of alcohol intoxication and sustained wakefulness. Given that the experimental design meant that a greater number of testing sessions occurred in the sustained wakefulness condition, it was considered possible that boredom related to excessive testing may have contributed to the performance decrement observed. However, given that in the alcohol condition an equivalent, if not greater, effect was observed for four of the six performance variables, we believe it unlikely.

Equating the effects of the two conditions indicated that 17–27 h of sustained wakefulness (from 23.00 to 10.00 h) and moderate alcohol consumption have quantitatively similar effects on neurobehavioural performance. Indeed, the findings of this study suggest that after only 20 h of sustained wakefulness, in the early hours of the morning, performance impairment may be equivalent to that observed at a BAC of 0.10%.

This study has confirmed the suggestion made by Dawson and Reid (1997) that moderate levels of fatigue produce performance decrements equivalent to or greater than those observed at levels of alcohol intoxication deemed unacceptable when driving, working and/or operating dangerous equipment. More importantly, however, this study was designed to determine whether the results of Dawson and Reid (1997) were an isolated finding, or characteristic of the general cognitive effects of fatigue. Using the degree of impairment caused by alcohol that produced a BAC of 0.10% as a standard, this study systematically compared the effects of fatigue on a range of neurobehavioural tasks. Results indicate that while, in general, fatigue had a detrimental effect on psychomotor performance, the specific components of performance differed in their degree of sensitivity to sleep deprivation.

The observed differences between the performance tasks with respect to their vulnerability to fatigue can be explained by their relative degrees of complexity. That is to say, the more complex neurobehavioural parameters measured in the present study were more sensitive than were the simpler performance parameters. While only 20.3 h of sustained wakefulness (at 03.00 h) was necessary to produce a performance decrement on the most complex task (grammatical reasoning) equivalent to the impairment observed at a BAC of 0.10%, it was after 22.3 (at 05.00 h) and 24.9 h (at 08.00 h) of sustained wakefulness that a similar result was seen in a less complex task (vigilance accuracy and response latency, respectively). Furthermore, on the unpredictable tracking task, a slightly less complex task than vigilance, a decrement in performance equivalent to that observed at a BAC of 0.10% was produced after 25.1 h of wakefulness (at 08.00 h).

It was observed that despite a slight downward trend performance on the simplest of the four tasks did not significantly decrease, even following 28 h of sustained wakefulness. In contrast, performance on this task was significantly impaired after a dose of alcohol that produced a BAC of 0.10% (or greater). These results are in line with the suggestion that simple tasks are less sensitive to sleep deprivation (Johnson 1982). Indeed, we believe it likely that impairment of performance on this task may have occurred if we had extended the period of sustained wakefulness. It is interesting to note that several studies (e.g. Dinges *et al.* 1988) have reported that tasks similarly lacking in complexity, such as simple reaction time tasks, are affected early and profoundly by sleep loss, thus strongly suggesting that monotony may increase sensitivity to sustained wakefulness. Indeed, the fact that this task was not vulnerable to fatigue may possibly be explained by the interesting and challenging properties of the task.

It is also noteworthy that while we observed a decrease in accuracy on the grammatical reasoning task, impairment of this performance parameter was not comparable to that produced by a BAC of 0.10%. While this may at first contradict the suggestion that in this study vulnerability to fatigue was, to a large degree, determined by task complexity, it should be noted that participants were instructed to concentrate on accuracy rather than speed when completing the grammatical reasoning task. Thus, our particular instructions to participants may explain, at least in part, this irregularity. Alternatively, this finding is in line with the suggestion of a natural speed-accuracy trade-off. Similar results have been observed in several studies, which report a decline in speed of performance, but not accuracy, when sleep-deprived subjects are required to perform a logical-reasoning task (Angus and Heslegrave 1985; Webb and Levy 1982).

Interestingly, this was not the case with the vigilance task. In this instance, despite instruction to concentrate primarily on accuracy, this component was slightly more vulnerable to fatigue than was response latency. The absence of a trade-off on this task may be explained by the different properties of the vigilance and grammatical reasoning tasks. In accordance with the distinction raised by Broadbent (1953), the latter of these tasks can be defined as an unpaced task in which the subject determines the rate of stimuli presentation. In contrast, the vigilance task can be defined as a paced task in which stimuli are presented at a speed controlled by the experimenter. In line with this distinction, our findings are consistent with those of Broadbent (1953) who observed that while a paced task rapidly deteriorated during the experimental period, in terms of speed, an unpaced version of the same task did not.

A further explanation for the differences observed between these two tasks may relate to the extremely monotonous nature of the vigilance task. Indeed, we believe it likely that subjects were more motivated to perform well on the grammatical reasoning task, which was generally considered more interesting and challenging. Hence degree of motivation may explain why measures of both speed and accuracy decreased on the vigilance task, while on the former task accuracy remained relatively stable. This suggestion is in line with previous studies which have found that motivation can, to a degree, counteract the effects of sleep loss (Horne and Pettitt 1985).

It is worth noting that while the effects of alcohol and fatigue were generally similar there were exceptions. As mentioned, it was observed that fatigue had a greater effect on the response time component of the grammatical reasoning task than on the accuracy component. In contrast, despite our instructions to concentrate on accuracy rather than response time the opposite was observed for the alcohol condition. This finding suggests that alcohol and fatigue may have a differential effect on the strategy we instructed individuals to adopt.

Taken together, the results from this study support the suggestion that even moderate levels of fatigue produce performance decrements greater than is currently acceptable for alcohol intoxication. Furthermore, our findings suggest that while fatigue has a generally detrimental effect on neurobehavioural performance, specific components of performance differ in their sensitivity to sustained wakefulness. It is important to note that these levels of fatigue were due to a combination of prior hours of wakefulness and circadian factors. As such, the same amount of prior wakefulness at a different time of day would not produce the same blood alcohol equivalent as that observed in the early hours of the morning.

Since approximately 50% of shift workers typically spend at least 24 h awake on the first night shift in a roster (Tepas *et al.* 1981), our findings have important implications within the shift work industry. Indeed, the results of this study if generalised to an applied setting, suggest that on the first night shift, on a number of tasks, a shift worker would show a neurobehavioural performance decrement similar to or greater than is acceptable for alcohol intoxication.

While the current study supports the idea that fatigue may carry a risk comparable with moderate alcohol intoxication, it is difficult to know to what degree these results can be generalised to real-life settings. Indeed, laboratory measures and environments usually bear little resemblance to actual tasks and settings. Furthermore, while our study used a battery of tests to evaluate the effects of fatigue on performance there is no guarantee that all the functions involved in real-life tasks, such as driving, were utilised and assessed. An alternative approach would be to simulate the actual task as accurately as possible. Given that, for practical and ethical reasons, it is difficult to experimentally study the relationship between fatigue and actual driving, simulators of varying realism have been used. Thus, protocols using simulators could be used to model real-life settings and establish a more accurate estimate of the BAC equivalence for the performance decrement associated with sleep loss and fatigue.

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