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The effects of cigarette smoking on overnight performance

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Abstract Fifteen healthy smokers and 15 non-smokers were enrolled into this study investigating the effects of smoking on overnight performance. Subjects arrived at the test centre at 1930 hours and were assessed at baseline (2000 hours) and at 2200, 0000, 0200, 0400, 0600, and 0800 hours on a battery of tests (including Critical Flicker Fusion, CFF; Choice Reaction Time, CRT; Compensatory Tracking Task, CTT; Short Term Memory Task, STM; and the Line Analogue Rating Scale, LARS). Results showed that the performance of the smokers was more consistent with baseline measures than that of the non-smokers, which became more impaired throughout the night on a number of tasks [CFF ($P < 0.005$), Total Reaction Time (TRT, $P < 0.05$), CTT ($P < 0.05$) and the Reaction Time (RT) aspect of the CTT task ($P < 0.0005$)]. The Recognition Reaction Time (RRT) aspect of the CRT task showed that the performance of the non-smokers became more impaired from baseline ($P < 0.005$), while that of the smokers remained at baseline levels until 0400 hours, when it deteriorated to become comparable to that of the non-smoking controls. Subjective sedation ratings (LARS) resulted in comparable levels of impairment for both study groups ($P < 0.00005$). Findings from the STM task failed to reach significance. These data suggest that when performance is being measured overnight, smokers show little or no impairment, whilst the performance of non-smokers showed performance decrements.

Key words Cigarette smoking · Overnight psychometric performance

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Introduction

Sleep is one of the most powerful and vital biological needs (Borland et al. 1986). The detrimental effects of insufficient or disturbed sleep, chronic sleep deprivation and prolonged wakefulness can, among other things, increase the risk of errors of performance and accidents (Åkerstedt 1991).

Studies conducted on sleep-deprived subjects show that performance impairment increases as the duration of the period of wakefulness (i.e. deprivation) increases (Williams et al. 1959; Dinges et al. 1987). Furthermore, daytime performance is impaired following sleep deprivation (Wilkinson et al. 1966) and the severity of the impairment is dependent upon the duration of the task (Wilkinson 1968). Fatigued subjects show impairment on a variety of tasks, e.g. reaction time tasks, mental arithmetic, logical reasoning and tracking (Dinges and Barone-Kribbs 1991). In some instances, sleep-deprived subjects "trade-off" speed for accuracy and although the performance is error free, the speed of reaction is greatly increased. On the other hand, when the reaction time component is not impaired there is a rise in errors and responses are omitted (Williams and Lubin 1967).

In order to combat fatigue-related performance decrements, coping strategies are used, such as the1-h nap (Rogers et al. 1989) and the use of caffeine in the form of tea and coffee, which is often self administered, leading to subjective ratings of increased alertness and efficiency (Buyesse 1991) and to improve objective measures of alertness as shown by the CFF task (Kerr et al. 1991). However, intake of high doses of caffeine (500 mg Frewer and Lader 1991; 3 and 6 mg/kg Loke et al. 1985) can reduce the performance improving properties noted both subjectively and objectively with lower doses.

Smoking could be defined as a coping strategy in habitual smokers (Pomerleau and Pomerleau 1984). Smokers generally report improvements in concentration directly after smoking a cigarette (Gilbert 1995). Subjective reports have been substantiated by objective measures (Hindmarch et al. 1990) showing that nicotine can also improve aspects of psychomotor performance. Sherwood et al. (1990a) demonstrated that the psychomotor performance of heavy, light and non-smokers was improved following doses of nicotine gum. Wesnes and Warburton (1983) found that the performance of tobacco smokers improved on a Rapid Visual Information Processing (RVIP) task in a dose-related manner, whilst Warburton et al. (1992) found that nicotine improves not only attention but also memory facilitation and Koelega (1993) found that nicotine can improve performance on any tasks involving sustained attention. Heimstra et al. (1967) found that during a 6-h simulated driving task, performance on tracking error and brake reaction time (BRT) was comparable among smokers smoking freely and non-smokers; however, deprived smokers demonstrated impaired performance on all aspects of the task. These findings were substantiated by Frankenhauser et al. (1971). Contradicting these findings were those of Sherwood (1995), who found that the tracking performance of non-deprived smokers improved following smoking 0.6 and 1.0 mg nicotine cigarettes; however, subjects showed no performance improvement following the 0.1 (placebo) and the 2.1 mg nicotine cigarette. This finding suggests that an optimum level of nicotine was required for the facilitation of a simulated car driving task. Brake response speeds were reduced following each of the active treatments.

Parkin et al. (1997a) attempted to investigate the effects of smoking on late night performance by keeping subjects awake until 0230 hours. Differences between the smoking and non-smoking groups were apparent on certain psychometric measures (CFF, TRT and RRT). The performance of the smokers was more consistent than that of the non-smokers. The bed time of 0230 hours, however, may not have been late enough to detect maximum performance decrements, as most fatigue-related accidents occur between the hours of 0000 and 0600 hours (Åkerstedt et al. 1994).

The present study was designed to increase fatigue in subjects by not allowing them to sleep overnight. The subjects were tested every 2 h. This design was employed in order to examine the effects of fatigue in a population of smokers allowed to smoke freely and in a group of non-smokers.

Materials and methods

Subjects

Thirty male and female volunteers (mean age 32; range 24–40 years) participated in this study. Fifteen were smokers and 15 non-smokers. The two groups were matched for age and sex. The smokers had been smoking at least ten cigarettes per day (mean 22 cigarettes per day; ≥ 9 mg tar/0.9 mg nicotine) for a minimum of 5 years prior to the start of the study. All subjects fulfilled the inclusion/exclusion criteria in that they were in good physical and mental health on entering the study, with no family history of major psychiatric illness, and all were free from concomitant medication (excluding the oral contraceptive pill). Subjects were naive with respect to the experimental hypothesis. Ethical approval was gained from the University of Surrey Ethics Committee.

Design

This study employed a parallel group design. The results were analysed blind in order to control for experimenter bias.

Procedure

Prior to enrolment onto the study, all subjects gave their written, informed consent, and were familiarised with all procedures and fully trained on the psychomotor test battery until their results reached a plateau (McClelland 1987; Parkin et al. 1997b).

The trial consisted of 1 test night only. After a normal working day, subjects arrived at the test centre at 1930 hours and were screened for alcohol. The psychometric test battery was completed at 2000, 2200, 0000, 0200, 0400, 0600 and 0800 hours. The subjects were not allowed to sleep for the duration of the trial and smokers were allowed to smoke freely. All food was standardised and caffeine was prohibited for the duration of the study. Food and decaffeinated drinks were provided by the investigators. Subjects were allowed to occupy themselves for the duration of the night by watching television and playing games. Smokers were only ever tested with other smokers.

Assessments

Each of the tasks used in this study has been used as a psychometric assessment extensively over the past 25 years (Hindmarch 1980) and has been shown to be reliable, valid and pharmacosensitive (Sherwood and Kerr 1993).

Critical Flicker Fusion Test (CFF)

The CFF is a means of measuring the ability to distinguish discrete sensory data (Hindmarch 1982; Parrott 1982), and is taken as an index of overall CNS activity (Hindmarch and Subhan 1983). The subjects were required to discriminate flicker from fusion (and vice versa) in a set of four light emitting diodes held in foveal fixation at 1 m. Individual thresholds were determined by the psychophysical method of limits on three ascending and three descending scales. The average of the six values was used as an overall response. The validity and reliability of this test have been shown by many researchers (Bobon et al. 1982; Levander 1982; Parrott 1982). CFF thresholds are frequently used in psychopharmacology to indicate arousal or sedation following drug ingestion, and the task has shown to be pharmacosensitive in that CFF can distinguish not only between different drugs belonging to the same class (Hindmarch et al. 1991) but also between different doses of the same drug, e.g. oxazepam (Kerr et al. 1992).

Choice Reaction Time (CRT)

Subjects were required to extinguish one of six red lights, all equidistant from the start position. All stimuli were illuminated at random and extinguished by touching the appropriate response button. This test enables three measures, recognition reaction time (RRT), motor reaction time (MRT), and the sum of the two, the total reaction time (TRT) according to the additional theory of Donders (1969). The response measure was the mean reaction time for 20 stimulus presentations. The CRT is used as a measure of sensorimotor reaction to a critical stimulus (Frewer and Hindmarch, 1988).

Short Term Memory Task (STM)

The STM task (based on the theories of Sternberg 1966, 1975) is a means by which high speed scanning and retrieval from short term memory can be assessed. Subjects were required to judge whether a test digit was contained in a set of stimuli digits held in short term memory, and indicate "yes" or "no" by pressing the corresponding mouse button. Accuracy and response times were measured. Short term memory tasks have been used previously in nicotine research. Findings showed improvements in performance following nicotine (Warburton et al. 1992). Sherwood et al. (1990b), however, suggested that improved attentional and information processing skills may account for the improvement on this task, rather than an increase in the function of storage and retrieval per se.

Compensatory Tracking Test (CTT)

This interactive test of psychomotor function entailed tracking a moving arrow across a VDU screen using a mouse. The response measure (RMS) was the mean deviation from the track program over the 2-min trial, with a lower response score depicting more accurate tracking. A peripheral awareness task (PRT) was included, in which the subject responded to a stimulus presented in the periphery of vision, while simultaneously attending to the tracking test. The mean reaction time to ten of these stimuli over the trial period was taken as the response measure for this component of the divided attention task.

Line Analogue Rating Scale (LARS, subjective sedation ratings)

Subjective ratings of drug effects were obtained from a series of 10 cm line analogue rating scales. The mean scores of ratings of "tiredness", "drowsiness", and "alertness" (which were included amongst a number of distracter scales) are taken as a measurement of perceived sedation (Hindmarch and Gudgeon 1980). For this task, the higher the score (in mm), the more tired, drowsy and less alert the subject is feeling. Parrott (1982) showed that there was a highly significant positive Spearman's rank correlation between levels of subjective sedation shown by the LARS and CFF thresholds.

Statistical analysis

To control for inter-subject variability in baseline scores, all data were transformed to differences from baseline by simple subtraction. The data for the psychometric variables (CFF, CRT, STM, CTT and subjective ratings of sedation) were then analysed using analysis of variance tests (ANOVA). These were repeated measures analyses with two factors: smoker (or non-smoker) and time (at seven levels: 2000, 2200, 0000, 0200, 0400, 0600 and 0800 hours). Initial results were reported as being changes from baseline. Post hoc analyses using the Newman-Keuls test were conducted on all significant findings, thus enabling comparisons between the two treatment groups for each time point.

Results

The results from the CFF task show an overall effect of time which was significant [$F(5,140) = 4.634$; $P < 0.005$] for both the smokers and the non-smokers. The performance of the non-smokers decreased from baseline and this pattern continued throughout the night (Fig. 1). CFF thresholds for the smokers were more constant at the beginning of the test period, even rising at the 2200 hours test point; however, thresholds decreased back to baseline levels at 0000 hours, then declined further subsequent to the 0200 hour test point. The thresholds of the non-smokers were significantly lower than those of the smokers at 2200, 0400 and 0800 hours ($P < 0.05$).

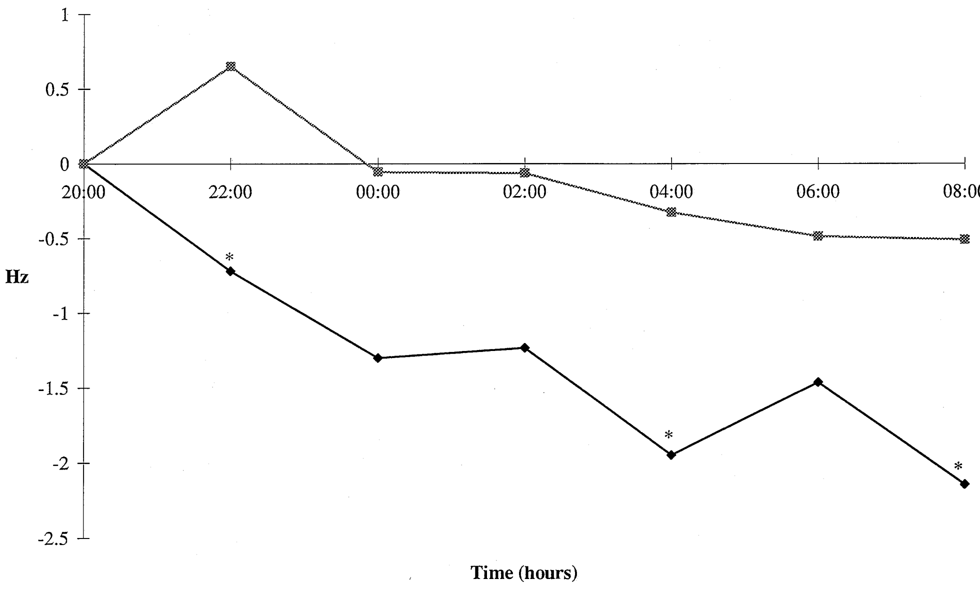

Fig. 1 CFF results. Differences from baseline. * $P < 0.05$ between groups; overall effect of time $P < 0.006$. –◆– Non-smokers, –▩– smokers

There were no significant differences between non-smokers and smokers on any aspect of CRT. However time effects were evident in that performance in the non-smokers declined over the night, whereas that of the smokers remained more constant. Specifically, TRT (Fig. 2a) showed the performance of the non-smokers deteriorating from midnight until the end of the trial [$F(5,140) = 3.234$; $P < 0.05$], while the responses of the smokers remained at baseline level until around 0500 hours. RRT (Fig. 2b) showed the performance of the non-smokers deteriorating from the outset of the trial [$F(5,140) = 3.552$; $P < 0.005$], while those of the smokers remained at baseline level until around 0400 hours. MRT showed the performance of the smokers remaining slightly faster than those of the non-smokers for the duration of the trial (Fig. 2c).

The tracking error of the smokers was superior to baseline performance at all time points excepting midnight [$F(1, 28) = 7.120$; $P < 0.05$; Table 1], and was notably more accurate than that of the non-smokers. The Reaction Time component (Table 1) of the CTT task showed a significant effect of time [$F(5, 145) = 5.453$; $P < 0.0005$], with the response times for the two groups increasing as the night progressed.

The results from the STM task (Table 1) show that there was an improvement as response times decreased from baseline [$F(6, 174) = 5.504$; $P < 0.00005$] for both study groups. After an initial decrease in response time, the scores for the non-smokers remained almost constant, whilst those of the smokers varied more.

The data from the subjective sedation rating scales (LARS) show a significant effect of time [$F(5, 140) = 15.947$; $P < 0.00005$], as the subjects from both groups felt progressively more tired as the night wore on. The scores for the smokers were marginally lower than those of the non-smokers; however, there were no significant differences between the two groups (Fig. 3).

Discussion

These data show that for the psychometric performance measures CFF, TRT, RRT, CTT, CTT-RT and subjective sedation ratings, there were significant effects of tiredness, with subjects performing more poorly as the night progressed. For the performance measures CFF, TRT, RRT and CTT the results obtained from the smoking group were more consistent with (or improved from) baseline scores than the non-smokers. In the instances of CTT-RT and the subjective ratings of sedation (LARS), there were no notable differences between the two groups. The results from the STM task improved over the night.

These data could have implications for shiftworkers, people who have to occasionally work through the night or those whom embark upon a long journey, as smokers allowed to smoke freely are able to maintain more consistent performance levels on most of the variables measured. Records for the number of cigarettes smoked showed that following an initial heavy smoking phase on first arrival, the number of cigarettes slowed down to a relatively consistent level for the duration of the night. Smokers generally self regulate their nicotine levels, smoking a cigarette only when the need for nicotine is felt (Gilbert 1995). Nicotine increases the acetylcholine release from the cerebral cortex, which has been associated with cortical arousal. Thus the maintenance of performance levels shown by the smokers may be due to their self regulation of nicotine and therefore their increased levels of acetylcholine in the central nervous system (CNS). Cigarette smoking could therefore be determined to be a coping strategy in habitual smokers, and may thus explain why the smokers performed more consistently than the non-smokers throughout this trial.

Cotten et al. (1971) found that performance on a simple reaction time task was improved by smoking 40 and 55 min following a cigarette; however, if the task was conducted immediately or 5 min following the cigarette, performance was impaired. Tests conducted at 15 and 25 min post-cigarette showed no differences from the control condition in which there was no smoking. The aim of this study was not to judge how long following a cigarette performance was improved, merely whether the free smoking of cigarettes affected performance under adverse performance conditions such as this overnight study regime.

There is conflicting evidence on the effect of nicotine withdrawal on smokers. Parrott et al. (1996) gave evidence that sensory, motor, information processing and attentional skills all deteriorated when smokers were required to abstain from cigarette smoking, substantiating evidence from Koelega (1993), who reported impaired performance with acute withdrawal from nicotine. Contradicting these findings is a report by Warburton and Arnall (1994) showing that there are no differences in performance on a RVIP task between a group of smokers deprived for up to 12 h and a group of non-smokers; however, following cigarette smoking, the performance of the smokers was improved. As there was no effect of withdrawal, Warburton and Arnall (1994) suggested that the improvements in performance were a direct result of smoking the nicotine cigarette. Lyon et al. (1975) reported similar findings which showed that the effects of alcohol were comparable between non-smokers and deprived smokers, but following two cigarettes, smokers showed shorter response times. In this study, the smoking subjects were allowed to smoke freely on study days both prior to arrival and whilst at the test centre.

As there was no withdrawal from cigarettes involved in the present study, maintenance of performance among the smokers may be a result of the nicotine obtained from the cigarettes. No improvement in

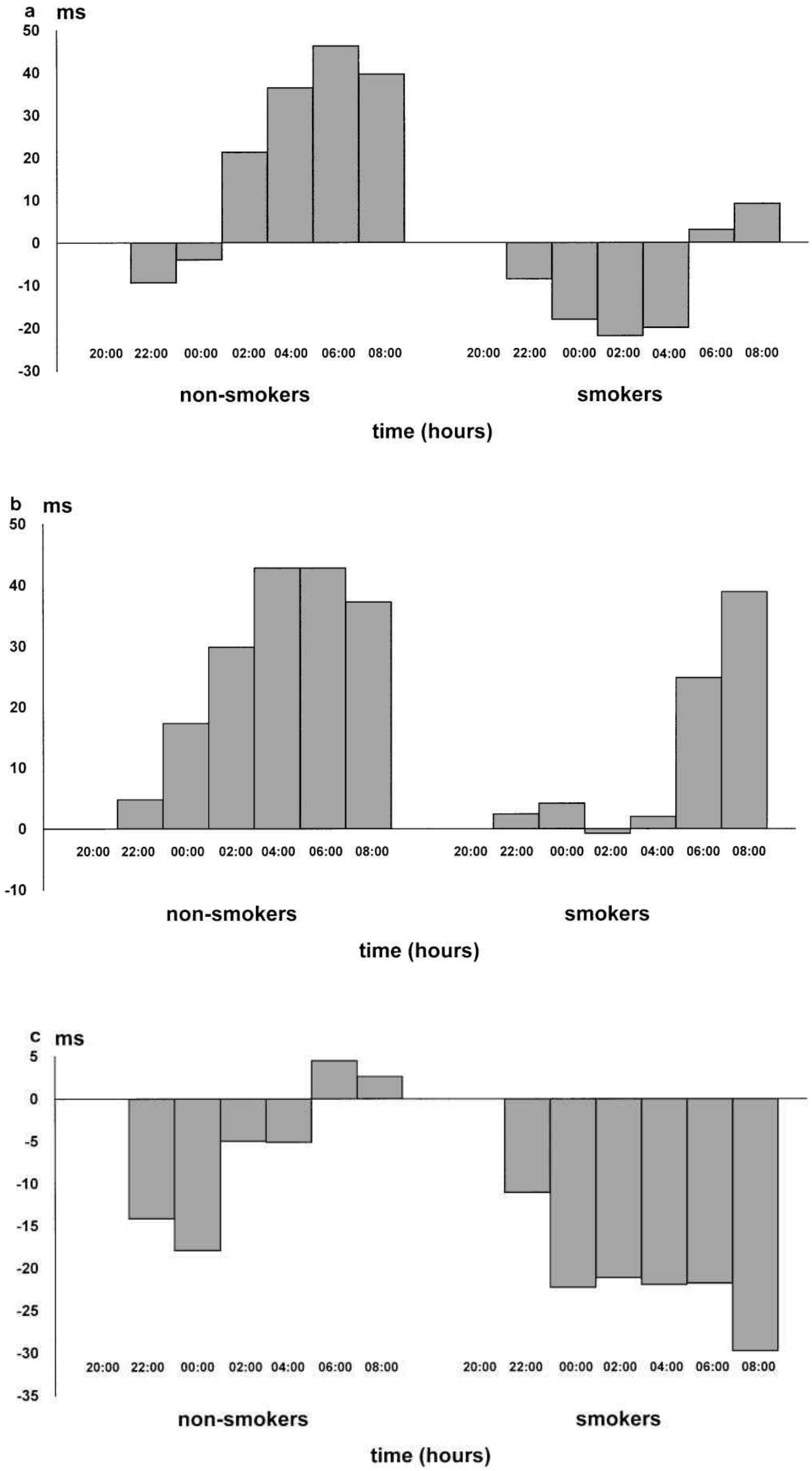

Fig. 2 a Cumulative TRT data for the smokers and non-smokers throughout the night. **b** Cumulative RRT data for the smokers and non-smokers throughout the night. **c** Cumulative MRT data for the smokers and non-smokers throughout the night

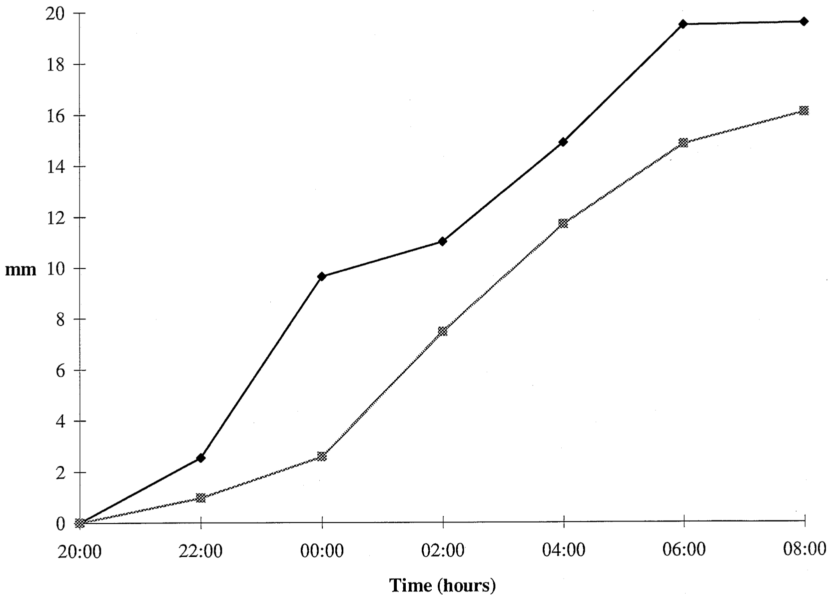

Fig. 3 LARS subjective sedation differences from baseline. Overall effect of time $P < 0.00005$. –◆– Non-smokers, –▩– smokers

Table 1 Showing mean scores for the tracking task (RMS) for the reaction time aspect of the CTT (MS) and for the STM task (MS)

Time (hours)	2000	2200	0000	0200	0400	0600	0800
CTT							
Smoker	63.479	36.84	47.23	42.75	28.59	29.31	34.55
Non-smokers	28.349	33.20	29.26	56.55	40.06	48.57	34.57
CTT-RT							
Smoker	520.674	503.84	538.13	564.33	536.93	547.88	513.72
Non-smokers	507.0867	496.78	542.16	537.07	559.88	553.57	547.75
STM							
Smoker	808.94	760.58	714.65	764.56	724.01	745.24	676.98
Non-smokers	777.38	731.14	722.38	709.91	677.09	646.15	713.39

performance was noted, and as there was no relief from withdrawal, this was expected.

These results therefore give an indication of the effects of nicotine in smokers on psychomotor performance over a prolonged period of wakefulness. Although natural fatigue is noted in both study groups, four of the objective measures used in this study show that fatigue-related impairment occurs to a lesser extent in the smoking population than in the non-smoking group, even though the same levels of sedation are reported in subjective ratings.

The high correlation between CFF and the LARS subjective sedation ratings shown by Parrott (1982) is not in evidence on this occasion for the smoking group. Although the Sedation ratings showed both groups becoming significantly more fatigued as the night progressed, CFF thresholds remained constant for the smoking group. This would suggest that although the smokers felt more tired as the night progressed, they were actually able to maintain performance levels.

One criticism of this study could be that no measures were taken for long duration vigilance. Previous research has shown that performance becomes more impaired in longer duration tasks among sleep-deprived subjects (Lee and Kleitman 1923; Bjerner 1949; Wilkinson 1968). The present research, however, shows that it is possible to detect performance impairment from only the short duration tasks used in this study, supporting evidence from Lisper and Kjellberg (1972), who reported that short duration reaction time task performance deteriorated among subjects suffering sleep loss.

Results from this study showed profound performance impairment among non-smokers on short duration tasks, which previous research suggests (Lee and Kleitman 1923; Bjerner 1949; Wilkinson 1968) could be greatly exaggerated in any person performing long laborious tasks overnight.

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