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SUSTAINED AIR OPERATIONS: PROLONGED DUTY OVERNIGHT

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Sustained air operations imply round-the-clock scenarios and, inevitably, prolonged duty overnight. The ability of crews to cope with such work-rest patterns depends to a large extent on obtaining sufficient sleep during critical rest periods. Hypnotics may be essential to ensure sleep as the rest periods themselves are limited in number and duration, and occur at all times of the day and night. However, even if good sleep is attained during all the available rest periods, there may still be much difficulty in sustaining alertness during duty overnight, particularly if the duty periods themselves are prolonged. This paper deals with the use of various potential interventions to sustain alertness during intensive air operations.

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IRREGULARITY OF WORK AND REST

During the late 1970s the RAF Institute of Aviation Medicine was concerned with the capability of aircrew operating in the interdictor role, and laboratory studies were directed toward defining the issues involved in coping with the inevitable irregularity of rest (Nicholson et al, 1984). Such information was essential to ensure that means could be developed to assist squadrons in maintaining round-the-clock operations in which the high workload would be shared between all aircrew, and in which crews could be deployed in a flexible manner between night and day operations. The work and rest of such projected scenarios were simulated over periods of 9 days, which was the period over which aircrew would have been expected to operate at maximum output.

The simulated 9 day schedule of work and rest involved 24, 6-h periods of work and 12, 6-h periods of rest (Fig.1). The schedule was preceded and followed by 2 days of normal daytime duty and nocturnal rest, and these periods provided control data. It was the primary intention of the study to ensure that sleep deprivation was minimised, and so the schedule provided an average of 8 h rest each 24h - though in unequal parts from the 6h periods of rest. The rest periods were arranged over the 9 days so that the number of night and daytime sleeps were equal and runs of consecutive night or daytime sleeps avoided. The synchronising effect of sleep was also minimised by avoiding, as far as possible, consecutive periods of rest around the usual nocturnal time of sleep.

Over the period of 9 days, rest periods began at each of four times (0300, 0900, 1500 or 2100 h). There were three single work periods of 6 h, six double work periods of 12 h and three triple work periods of 18 h duration. The complete findings of the simulation have been published elsewhere (Nicholson et al 1984), and for the purpose of the present paper the information obtained relevant to prolonged duty overnight is reported.

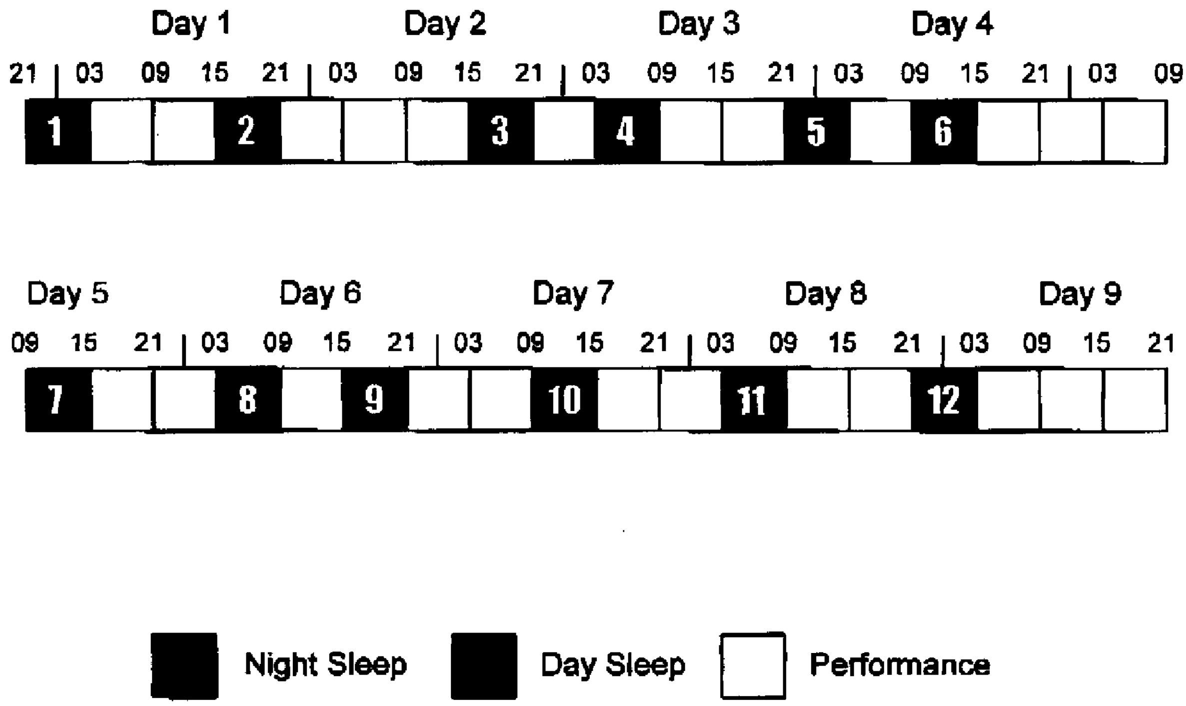

Fig 1. Schedule of work and rest

The quality of sleep during each rest period was measured by electroencephalography. Total sleep times (min) for each rest period are given in Figure 2. In the rest periods before and after the schedule the total sleep time almost accounted for the 6h period, but during the schedule total sleep time varied considerably. Sleep at 2100h and 0300h was always restful, but sleep during the day, ie at 0900h and particularly 1500h, was short unless it followed an interval of significant sleep deprivation. Further analyses were related to the time of day as well as to the preceding pattern of work and rest. These indicated that the greatest difficulty in falling asleep would occur around 2000h, whereas the longest sleep would have been most likely when the sleep began around 0100h. Duration of sleep during the day would be particularly short except when preceded by periods of wakefulness approaching 20 h. The most restful sleep would be obtained when it commenced between 2100h and 0300h and the quality would be improved at any time by a reasonable period of preceding wakefulness.

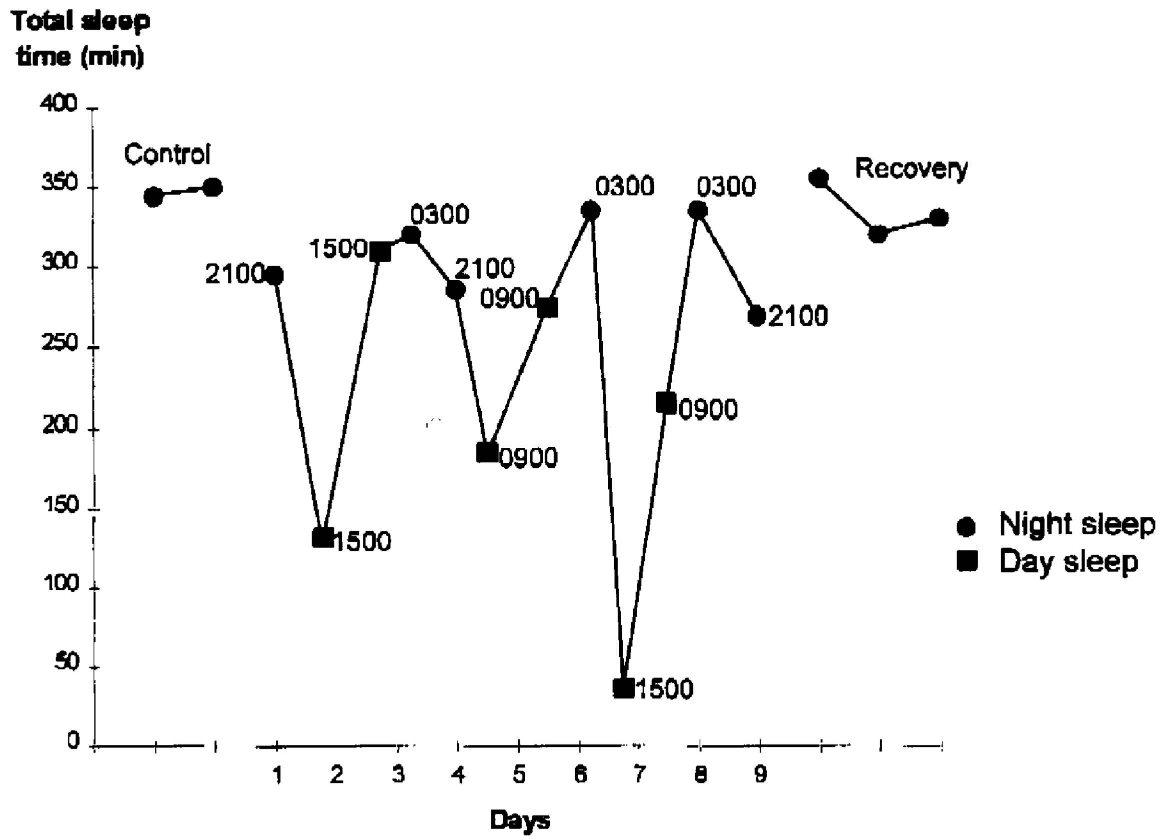

Fig 2. Total sleep time determined electroencephalographically for each rest period

As far as performance during the work periods was concerned, the usual circadian pattern with lowest scores in the early morning, was maintained throughout the schedule. Performance decreased with increasing time awake and for some tasks there was a trend towards impaired performance as the 9 day period proceeded. However, there was evidence of improvement in some tasks over the schedule, though caution must be exercised in the interpretation of this finding. The intensity of testing during the schedule clearly led to continued learning on some tasks, and so the effect of cumulative sleep loss was probably masked. Overall, the analysis established that impaired performance was related to circadian rhythmicity, duration on task, and cumulative sleep loss, and these three factors are fundamental to understanding how performance during duty against a background of irregularity of work and rest can be predicted.

Adaptation of the individual to irregularity of rest and activity was the primary concern of the study. It suggested that during a lengthy period of irregular work and rest the efficiency of individuals is likely to be increasingly impaired, and that their performance will be influenced by their circadian rhythmicity and by the length of time on task, as well as by any cumulative loss of sleep. Above all, it was clear that, in complex schedules, a significant difficulty in maintaining capability would occur during prolonged periods of work extending to the latter part of the night. It must also be borne in mind that behavioural changes such as impaired interpersonal relations, which are difficult to measure, may be equally, if not more, important than decrements indicated by tests of performance.

The 9-day study confirmed the overriding importance of avoiding cumulative sleep loss and of poor performance during long periods of work overnight to sustaining intensive rates of work. In this context it must be appreciated that in sustaining such operations it is highly unlikely that any significant change to the work-rest patterns themselves will be possible. The schedule is determined by a host of, often immutable, operational constraints. Nevertheless, the study indicated that crews were likely to be able to cope with 12 x 6-h missions over a 9 day period, and that using the longer periods of wakefulness for double missions, 15 missions may be possible. Ensuring sleep is essential and this can be assisted by hypnotics, but overnight duty is the vulnerable component in operations designed to provide sustained capability.

PERFORMANCE OVER 24 HOURS

Our studies on irregularity of work and rest also provided data necessary to quantify the characteristics of periods of work which determine performance.(Minors et al 1986, Spencer, 1987) Several factors were shown to influence performance during a particular duty period; these were : the interval between the end of the previous sleep and the commencement of duty (time since sleep); duration of duty (time on task); and the clock time of duty (time of day). It was evident that the adverse juxtaposition of a long duty period and the timing of duty during the 24 hour period prejudiced the ability to sustain vigilance.

Further analysis of these data showed that as far as "time on task" is concerned, performance rises during the first few hours, falls to its initial value after around 5 hours, and then levels off around 12 to 16 hours after commencement of duty (Fig 3). As far as "time of day" is concerned performance rises during the day and falls during the late evening and overnight reaching its nadir around 0500 h in the morning (Fig 3). Hence, very low levels of performance are reached if the latter part of a prolonged duty period coincides with the circadian trough in performance. For example, if a 16 hour duty period commences around 0200 h it is likely that performance will be maintained as the fall during the latter half of the work period coincides with the rising phase during the day. On the other hand, if duty commences around 1400 h the drop in performance during the latter part of the duty period would coincide with the circadian fall during the night, and so low levels may be reached (Fig 4).

This knowledge is crucial to the management of aircrew involved in high workload, round-the-clock operations. Assuming sleep loss is avoided it can be assumed that long periods of duty during the day lead to only limited deteriorations in performance, whereas similar periods overnight lead to serious decrements which may be accompanied by microsleeps. Further, it is possible to determine the duration of night and day periods of duty which would equate to the same degree of impairment. It is, therefore, evident that if prolonged duty overnight is essential to maintain a sustained operation, then some means must be developed to avoid the lowest levels of impairment. Various approaches have been studied including sleep prior to duty overnight, naps, during the period of duty itself if feasible , breaks during the duty period, and stimulants.

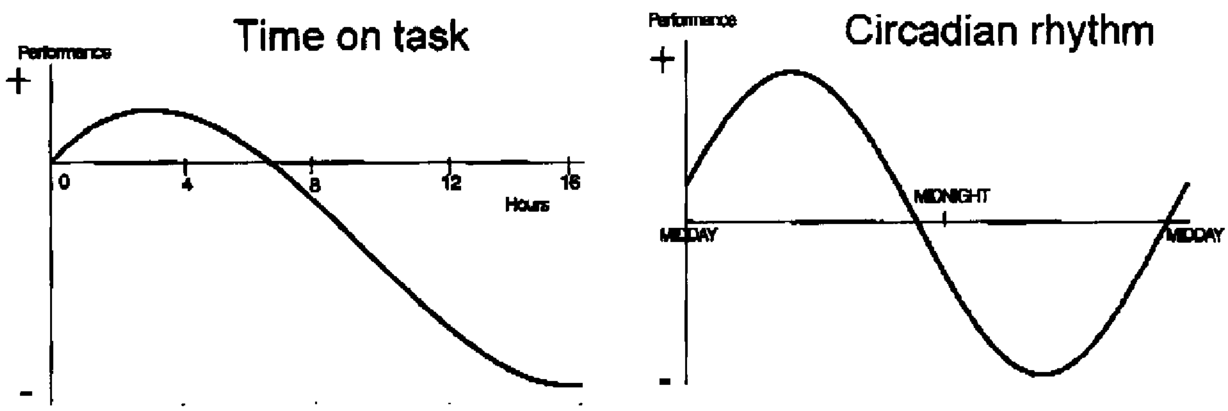

Fig 3. A model of change in performance with time on task (left) and time of day(right).

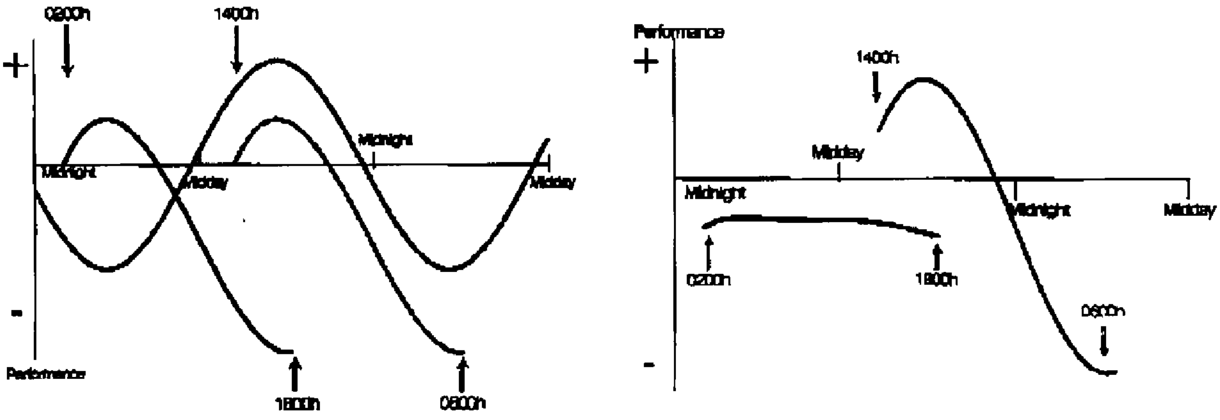

Fig 4. Time on task and time of day related to duty commencing at 0200 and 1400 h (left) and resultant of the time on task and time of day related to duty commencing at 0200 and 1400 h. (right). If a 16 h duty period commenced around 0200 h it is likely that performance would be maintained as the fall in performance during the latter half of the work period would coincide with the rising phase during the day. On the other hand if the duty period commences around 1400 h the fall in performance during the latter part of the duty period would coincide with the lowest level during the night related to the circadian rhythmicity of the individual, and so very low levels of performance may be reached. Such adverse juxtapositions of time on task and time of day should be avoided if crews are expected to remain continuously on their task. For this reason careful attention must be given to the length of duty periods in such operations, and the length should be determined in relation to the time of day. These considerations assume that the aircrew are fully rested at the commencement of their duty.

SLEEPS TO MINIMISE PERFORMANCE DECREMENTS

Short evening sleeps

Prolonged duty overnight is the sine qua non of sustained and intensive air operations, and that such duty periods have very low levels of performance due to the adverse juxtaposition of prolonged duty and the nadir of circadian activity. However, it is possible that an evening sleep period before a period of overnight duty may ameliorate the deterioration to some extent. It is in this context that the possible beneficial effect of an early evening sleep prior to overnight duty was studied (Nicholson et al 1985)

The subjects were six healthy male volunteers aged between 20 and 21 years. In the study subjects completed nine different schedules of work and rest, each separated by a week, though in this account we deal only with those schedules concerned with the effect of an evening sleep on overnight performance. Schedules were of 48 hours duration and began with an overnight sleep from 2300h to 0700h. During the day after the initial overnight sleep performance was measured over three hour periods from 0900h, 1400h, 1900h, and then through the night at 0000h and 0400h, and similarly through the next day. In the schedule with an evening sleep the period of sleep was from 0800h to 2200h, and so replaced one of the performance periods preceding the overnight period of duty (Fig.5).

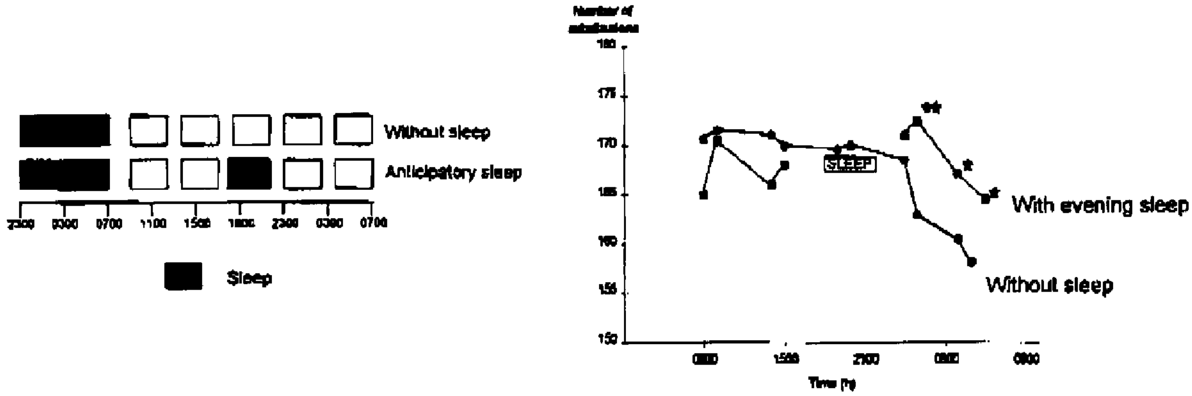

Fig.5 Schedule of work and rest related to anticipatory sleep (left) with performance on Digit Symbol Substitution with and without sleep (right)

Performance overnight (0000 - 0300h and 0400 - 0700h) with early evening sleep (1800 - 2200h) showed improved digit symbol substitution , symbol copying, mental arithmetic and cancellation in all subjects. There was also some evidence that visuo-motor coordination, critical flicker fusion, reaction times, tracking and auditory vigilance were improved. It, therefore, appeared that relatively short periods of sleep had a beneficial effect on subsequent performance even in the absence of a preceding sleep debt, and that sleep in the early evening could attenuate the circadian fall in performance overnight.

Naps during duty

Although impaired efficiency overnight may be ameliorated by an evening sleep of about 4h duration (Nicholson et al 1985), shorter sleeps within the period of duty may be beneficial in certain circumstances. However, any advantage that may be gained from short sleeps depends on several factors, including the length of the preceding period of sleep loss, the duration of the sleep, the phase of the circadian rhythm when the sleep was taken, and the relatively poor ability of individuals to perform soon after awakening, otherwise known as "sleep inertia". The circadian time of performance testing and the nature of the performance tests must also be taken into consideration. It was to establish the effectiveness of a short period of sleep in reducing the progressive impairment of performance specific to overnight duty that the effect of a 1h nap taken at 0200h was investigated (Rogers et al. 1989).

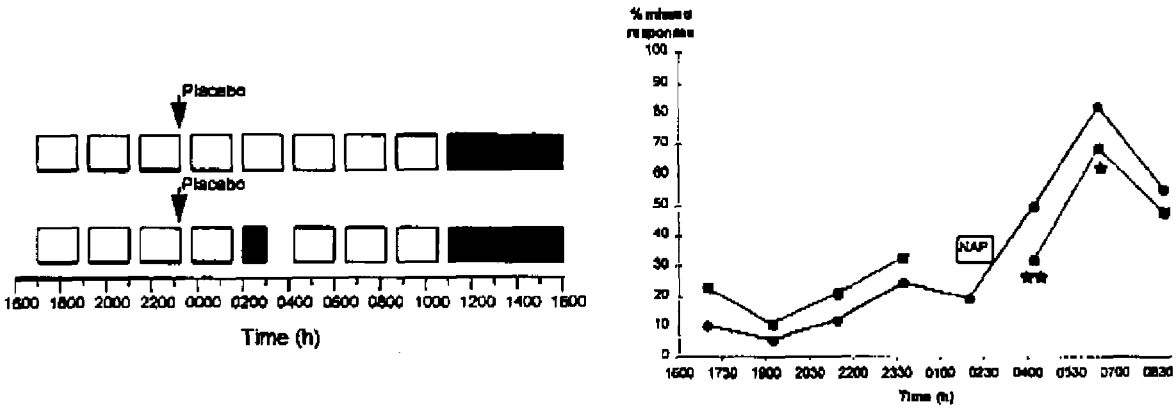

Fig.6 Schedule of work and rest related to naps during a duty period (left) and performance on a visual vigilance task with and without a nap (right).

The subjects were six healthy females, aged between 20 and 32 years (mean 25 years). Each schedule was of 17.5h duration and was preceded by a 4h rest period during which the subjects were awake but restricted to passive activities (reading, watching television etc.). Performance was measured during eight sessions, each lasting 1.75h, which began at 1700h, 1915h, 2130h, 2345h, 0200h, 0415h, 0630h and 0845h, with a 30 min break between sessions when the subjects were supervised to ensure that they remained awake. In the schedule which included a nap the subjects retired to bed at 0200h (Fig 6). Sleep was measured by electroencephalography. Subjects were awoken 1h after sleep onset, (indicated by latency to the first unbroken 5 min of stage 2), and performance testing was resumed at 0415h.

Overnight, in the absence of the nap, performance on all tasks except short-term memory deteriorated. Sustained attention, digit symbol substitution, auditory and visual vigilance were impaired around midnight compared with the levels attained during the early evening, and the lowest scores appeared around 0630h, though decrements in complex vigilance, two-letter cancellation, and logic, did not appear until 0415h or 0630h. Within-run deteriorations in visual and auditory vigilance were evident around midnight, and were present within 12 min of commencing each task.

The nap was characterised by short latencies to slow wave sleep. As expected, the long period of prior wakefulness influenced the propensity for slow wave sleep in the nap, which occupied around half the sleep time. However, this was insufficient to influence the requirement for slow wave sleep during the recovery sleep, unlike other studies of post nap sleep at night where a 2h nap in the late afternoon reduced slow wave activity from 10% to 5% of the total sleep time. The 1h nap taken at 0200h had only a limited effect on the usual decrements in performance observed overnight. An improvement was discerned on auditory vigilance at 0415h and 0630h and on digit symbol substitution at 0630h, but impairments remained on all other tasks.

Previous studies have shown that a 1h or 2h nap taken around the nadir of the circadian cycle during a single overnight period of work may attenuate the expected decrements in performance, but it would appear that a sleep of much longer duration than 1h, which is unlikely to be practical is needed to have a persistent effect when testing sessions are particularly demanding. There is also the possibility that sleep inertia may have persisted beyond the nap and counteracted any possible improvement in subsequent performance.

Breaks in duty

In some circumstances it may be possible to break up periods of continuous work with short breaks, and this has been studied in work periods of 12 hours (Rogers, 1997). Eight performance sessions which lasted seventy five minutes were separated by 15 minute breaks. Within each session there were six runs of the tracking component of the task studied (Multi-attribute task battery). Performance overnight after an evening sleep, and during the day was measured under two workload conditions. The decrements associated with time on task and with working at night were more severe under conditions of high workload. Tracking performance deteriorated over the six runs within a session , particularly at night when significant decrements occurred by the third run compared with the fifth run during the day. Following a 15 minute break there was a general improvement in tracking performance at the beginning of a session compared with the last run of the previous session, particularly overnight (Fig. 7). As well as stopping work during these breaks, subjects were also able to eat, drink, walk around and interact with others. It is not yet clear what aspect of the break was responsible for the recuperative effects.

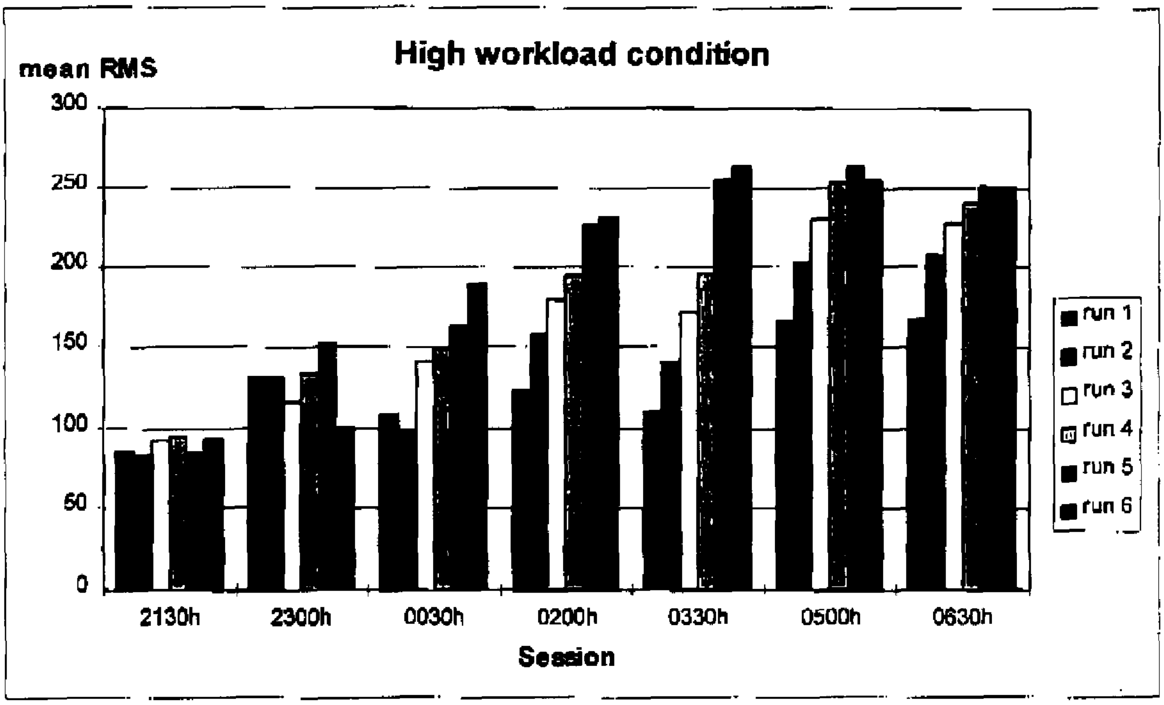

Fig. 7 Mean RMS for the tracking component of the MAT battery during the high workload condition overnight.

These and studies from elsewhere on the use of sleep preceding and a nap during duty show that the deterioration in performance overnight may be ameliorated under certain circumstances, but it must be borne in mind that in the management of intensive and sustained operations such techniques have practical difficulties, and they are unlikely to be appropriate unless they provide an overriding improvement in capability. During a sustained operation each overnight period of work will follow an irregular pattern of work and rest over several days and that good sleep preceding duty is an essential element to avoid cumulative sleep loss. It is unlikely to be possible to provide an extra sleep anticipating a duty period. Indeed, it is considered that impaired performance overnight against a background of intensive rates of work and irregularity of rest is unlikely to be ameliorated by such techniques. It is in this way that we have sought to establish whether stimulants would be more useful.

CONSIDERATIONS OF STIMULANTS

Our approach to this problem has been to identify a stimulant free of adverse effects on affective behaviour (Nicholson & Pascoe 1991, 1992, Nicholson et al 1989). In this context we do not support the use of amphetamines in military operations because of the well known euphoric effect. However, it is difficult to establish from experimental studies which stimulants would be free of such central effects. We have taken the approach that a stimulant free of effects on the noradrenergic and serotonergic systems, i.e. likely to be predominantly dopaminergic, is more likely to be acceptable. In the search for such a drug we have used the fact that noradrenergic and serotonergic drugs directly suppress REM sleep additionally to any decrease in REM activity which may be associated with increased wakefulness during sleep. We have observed that both caffeine and pemoline are free of such activity, and these observations are consistent with the drugs being free of adrenergic and serotinergic activity. It has been to pemoline that we have given most of our attention.

Pemoline is an indirect dopaminergic agent and is relatively free of sympathomimetic activity. It is known to increase alertness and improve performance during the day, and, for sleep deprived subjects, overnight. However, it is envisaged that a drug like pemoline would only be used overnight and, therefore, information is needed on the effects that such a drug would have on performance and alertness of duty periods which commence during the latter part of the day, and which are, indeed, likely to lead to very low levels of performance. There is no doubt that pemoline increases alertness, but there is uncertainty concerning the appropriate dose that should be used in a situation which may well prove to have critical time constraints. It was in this context that we have carried out studies on the effect of pemoline and on its potential use in a simulated overnight operation.

An initial study highlighted the persistent effect of pemoline. Indeed, 30, 60 and 90mg pemoline increased daytime alertness over periods of 8 hours, while 40mg pemoline prevented the deterioration of performance over 8 and 12 hour periods overnight, but also disturbed sleep which commenced up to 12 hours after ingestion. It was, therefore, decided that the studies pertinent to an operational scenario would be carried out with maximum dose of 40mg pemoline.

Two further studies (Turner and Mills, 1996, Nicholson and Turner, 1998) have shown that a 20mg dose would be appropriate for maintaining performance overnight without disturbing recovery sleep the next morning. In a high workload task all measures of performance were improved with 20mg pemoline as soon as performance was impaired when compared to control levels(Fig.).

CONCLUSION

Although modulation of the work-rest pattern can ameliorate impaired performance during prolonged duty overnight, it is unlikely that such an approach would be practical in intensive and sustained operations. It is in this context that stimulants may prove to be the most effective solution under operational conditions.

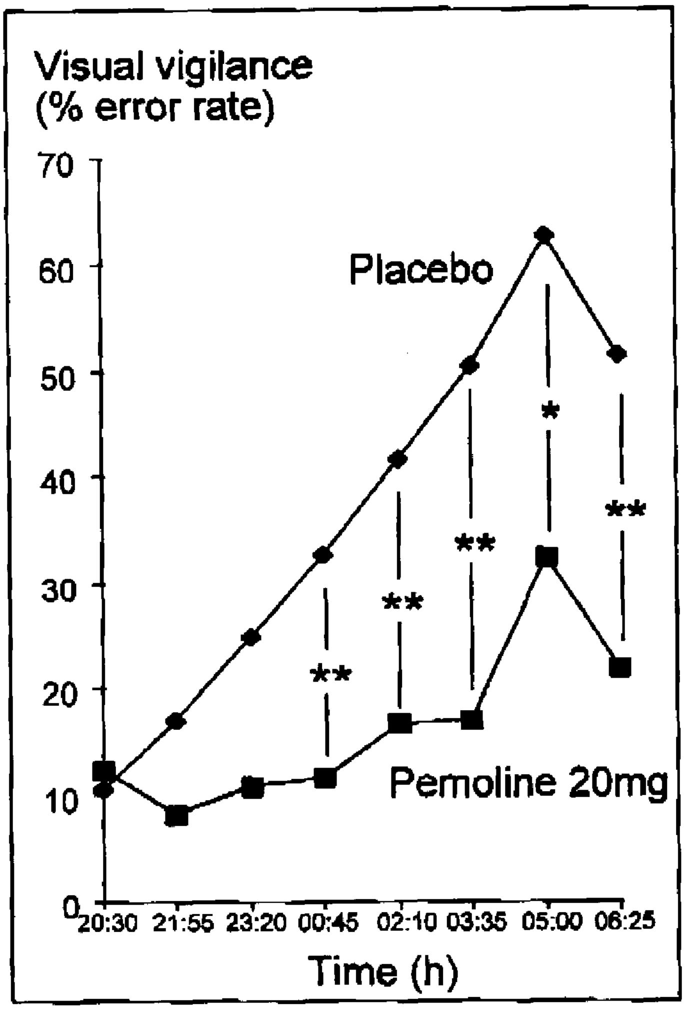

Fig. 8 Performance at a visual vigilance task showing improvements in performance with pemoline.

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