Sustained operations and military performance

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A militarily realistic schedule is one that demands several days with only very limited opportunities for sleep, followed by several days without any opportunity for sleep. A trial was carried out to study the effects of total sleep deprivation following partial sleep deprivation. Twelve infantry soldiers, divided into two groups of six, took part in a 6-day trial in which the experimental group was scheduled for 1.5 h of sleep every 24 h for 3 days followed by 3 days in which no sleep was scheduled. The control group was scheduled to have 4 h of sleep every 24 h for 6 days. Following the sleep-deprivation period, unlimited sleep was permitted for both groups in a 40.25-h (1.7-day) rest period. Three of the six subjects in the experimental group completed the 152-h (6.3-day) trial; all six subjects in the control group completed the trial. On the last sleep-deprivation day, cognitive performance was 37% of the baseline value for the experimental group and 94% for the control group.

In both military and civilian life, occasions may arise in which, after several days of almost continuous activity, with only limited opportunities for sleep, there are no opportunities for sleep at all. Such situations may arise in armed combat or in emergencies, the latter handled, for example, by the police force and medical workers, and are likely to involve a combination of both mental and physical work.

Numerous experiments have been carried out to determine the effects of both partial and total sleep loss upon performance, but no one has studied these schedules sequentially. Examples of the longer *partial*-sleep-loss experiments are Hamilton, Wilkinson, and Edwards (1972) and Webb and Agnew (1965, 1974); see also the review by Johnson and Naitoh (1974). Examples of the longer *total*-sleep-loss experiments are Murray and Lubin (1958), Wilkinson (1962, 1964), Williams and Lubin (1967), and Williams, Lubin, and Goodnow (1959); see also the Johnson and Naitoh (1974) review. Moses, Johnson, Naitoh, and Lubin (1975) examined the effects on performance of 3 nights of sleep-stage deprivation followed by 1 night of total sleep loss; but during the stage-deprivation nights, the amount of sleep lost was small, ranging from 0.30 to 1.56 h. Accordingly, as part of a much larger study, one aspect of which has been published elsewhere (Legg & Haslam, 1984), it was decided to remedy this omission and assess the effects of total sleep deprivation following partial sleep deprivation over a 6-day period.

In an earlier experiment (Haslam, 1982b), the effects of partial sleep deprivation following total deprivation were examined, and it was found that 4 h of sleep in every 24 h had a markedly beneficial effect after 90 h without sleep. Next, it would have been appropriate to

assess the effects of a 3-day period with 4 h of sleep in every 24 h followed by 3 days of no sleep; but it was thought that the sleep debt would not have been sufficiently great in order to examine the subsequent effects of total sleep loss (Haslam, 1982a). Accordingly, it was decided that a schedule of 1.5 h of sleep in every 24 h should precede 3 days in which no sleep was scheduled (Haslam, 1981). The control group was scheduled 4 h of sleep a night for 6 nights, because results from an earlier experiment had indicated that this amount of sleep was sufficient to maintain performance over the experimental period (Haslam, 1982a). By reducing the control group's sleep to the minimum, the activity levels of the two groups were more nearly matched. However, as Meddis (1982) pointed out, proper control in sleep-deprivation experiments may always prove elusive. In the absence of a third group of subjects, we used the results from earlier experiments in which subjects were scheduled no sleep for 3 nights following 3 nights with "normal" (6 to 7 h per night) amounts of sleep.

In addition, because it is important to determine the minimum time needed for "recovery" (Haslam, 1981), it was decided to examine the effect of 2 nights of rest following the sleep-deprivation period. This amount was chosen because 2 nights of recovery sleep following a period of sleep loss are usually sufficient to restore performance to baseline levels (Johnson & Naitoh, 1974). In the experiment reported here, it was not known how many hours of sleep deprivation the experimental group would complete, and therefore it was decided that the recovery period should comprise 2 nights as well as the remaining hours of the day on which the experiment ended.

METHOD

Subjects

Twelve trained infantrymen, members of the Army Personnel Research Establishment (APRE) Trials Section,

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were divided randomly into two groups of six, with one noncommissioned officer and five privates in each group. The experimental group (Group A) was scheduled 1.5 h of sleep from midnight in every 24 h for 3 days, and then no sleep for 3 days. The control group (Group B) was scheduled 4 h of sleep from midnight in every 24 h for 6 days. The average age of Group A was 24.0 years (range = 20 to 33), and that of Group B was 26.2 years (range = 19 to 36).

Initially, the sleep schedules and length of the trial were unknown to the subjects; immediately before each sleep period, they were told their allocation for that night.

For purposes of motivation, the subjects were told that those who finished the trial and maintained a certain standard in key tasks would be granted a long weekend leave.

Trial Design

The experimental period started at 0715 h. The 6-day period was preceded and followed by 2-day periods, the first for acquiring baseline measurements, and the second for acquiring recovery measurements. During the baseline measurement phase, 7.25 h of uninterrupted sleep were allowed from midnight, and during the recovery phase, 8.25 h of sleep were allowed from 2300 h. Following the sleep-deprivation phase, 1.7 days (40.25 h) were allowed for rest and sleep (Table 1).

To prevent unscheduled sleep, subjects were monitored continuously, and a medical safety officer was on duty throughout the sleep-deprivation period. Subjects slept (when permitted) on camp beds in unheated huts.

Pattern of Activities

A program of tests and activities was devised to keep the subjects occupied for most of the day, and also the night when necessary. The mornings were taken up with laboratory tests, not all of which are reported here; a full account is given in Haslam (1983a). The afternoons consisted of physical activity, with 1.5 h on the rifle-shooting ranges, and 2 h spent grenade throwing, interspersed with some running. Other tests, mostly sedentary, were carried out for 3 h in the early evening (see Haslam, 1983a). Trenches were dug for 3 h prior to midnight, and a 2-h simulated casualty evacuation exercise was carried out from 0530 to 0730 h. When Group B was asleep, Group A undertook the sedentary task of weapon cleaning.

Sleep Logs

In order to find out the approximate amount of scheduled sleep taken, and also the amount of recovery sleep, personal sleep logs were completed by the subjects. The amount of self-reported sleep matches very closely the amount of EEG-recorded sleep (Haslam, Allnutt, Worsley, Dunn, Abraham, Few, Labuc, & Lawrence, 1977). A military observer also recorded the length of the first recovery sleep.

Recovery Period

On the recovery day, subjects remained under supervision, and could take naps as desired. For relaxation, they could read books, play card games, and look at video films or television.

Objective Tests

Vigilance rifle shooting. The "Vigilance Shooting" test, an experimenter-paced task, is a 20-min test in which subjects are in the prone position. A total of nine silhouette human targets appear for 5 sec each at random time intervals (10 sec to 7 min) at ranges of 100, 200, and 300 m. The subject fires one round at each target. In order that subjects do not learn the sequence of time intervals and ranges, three versions of the test are used. The score recorded for each subject is the number of hits; subjects are told their scores.

Grouping capacity. Grouping capacity is the ability to fire five rounds so that the shots fall in a very small area. A group of five rounds is fired at an aiming point on a board at a distance of 100 m; measurements are made to the nearest .25 in. (approximately 6 mm). Subjects are told their shot group sizes. These rifle-firing tests were carried out daily at 1230 h.

Cognitive tests. The cognitive tests were carried out in an unheated laboratory. Three paper-and-pencil tests were used: a 10-min map grid reference encoding/decoding test using a military cipher, an adaptation of the Williams Word Memory Test (Williams, Gieseeking, & Lubin, 1966), and a 15-min addition test based on Wilkinson (1962). During the week preceding the testing, subjects underwent training sessions on the cognitive tests in order to minimize practice effects over the experimental period.

The encoding/decoding test consisted of 30 six-figure grid references and 30 five-letter codes (eg. BVJQA) that had to be encoded and decoded, respectively, using a code strip printed across the top of the page.

Table 1
Trial Design

Days 1 and 2	Days 3 to 5	Days 6 to 8	Day 9	Days 10 and 11
B1, B2	E1 to E3	E4 to E6		R1, R2
Baseline measurements: 7.25/24 h of sleep	Experimental: Group A—1.5/24 h of sleep; Group B—4/24 h of sleep	Experimental: Group A—no scheduled sleep; Group B—4/24 h of sleep	Rest/sleep for 40.25 h	Recovery measurements: 8.25/24 h of sleep

In the memory test, a written list of 15 words was presented and the subjects were allowed 4 min to copy and to memorize the material. Five minutes were allowed for the subjects to record as many of the words as they could recall. For the test material, an almost equal number of words was selected from the AA and A categories in the Thorndike and Lorge (1944) word list; AA words occur 1,000 or more times and A words, 500 or more times, in the Lorge-Thorndike semantic count. All words were monosyllabic and could be used as nouns. Twenty-four lists of 15 randomly selected words were used, one for each experimental and one for each training session. Care was taken to eliminate obvious paired associates (e.g., hand-glove).

The addition test consisted of two pages of 100 sums arranged in 10 rows of 10 sums. Each sum consisted of three two-digit numbers to be added. On the experimental days, cognitive test sessions were at 0430 and 0930 h; during baseline and recovery days, there was only one session, at 0930 h daily, because of the subjects' sleep schedule.

Subjective Tests

For the assessment of mood, the Profile of Mood States (POMS) (McNair, Lorr, & Droppleman, 1971) was used. This is a self-rated questionnaire in which the factors of tension, depression, anger, confusion, fatigue, and vigor are assessed. These can be summed, with vigor weighted negatively, to give a Total Mood Disturbance score. The questionnaire was completed at the end of each cognitive test session.

Statistical Analysis

To compare the performance levels of both groups over all test sessions, each measurement was analyzed separately as a two-factor experiment with repeated measures on one factor (Winer, 1971). Degrees of freedom were adjusted to account for departures of the covariance matrix from compound symmetry, using the procedure outlined by Greenhouse & Geisser (1959). A priori selected contrasts were used to analyze changes over experiment phases within each group. For these contrasts, the error terms from the single group two-factor ANOVA tables were used (subjects $\times$ sessions), with adjusted degrees of freedom. When values were missing because subjects had been withdrawn from the experiment, estimated values, derived from a regression technique, were inserted.

The sleep-deprivation days are referred to as Days E1 to E6, baseline days, as Days B1 and B2, and the recovery measurement days, as Days R1 and R2.

RESULTS AND DISCUSSION

Three subjects in Group A completed the 152-h (6.3-day) trial; all six in Group B completed the trial. By the end of the total-sleep-deprivation phase, the survivors in Group A had had no scheduled sleep for 85 h and a total of only 4.5 h over the previous 67 h. No subject with-

drew from the trial voluntarily. Because of excessive sleepiness, the first subject was withdrawn from the trial at 0500 h on the 5th sleep-deprivation day, and the second and third at 0930 and 1230 h, respectively, on the 6th deprivation day. The numbers of hours that these three subjects had been without scheduled sleep following the partial-sleep-loss phase were 51.5, 80, and 83, respectively. Group B had had a total of 24 h of scheduled sleep over the 152-h period. With regard to unscheduled sleep, no subject in Group A had had more than a few minutes of sleep at a time throughout the trial, and the total amount taken was small, less than 30 min. Group B subjects apparently did not require unscheduled sleep, although they felt tired.

Recovery Sleep

Group A. The average amount of recovery sleep (which started for the survivors at 1500 h on Day E6) was 16.75 h (range = 12.5 to 20.0). The subject who was withdrawn from the trial first had had the least sleep, and the subject who was withdrawn last had had the most.

Group B. The average amount of sleep taken by Group B subjects was 12.83 h (range = 9.0 to 17.0).

Difference between Groups A and B. The difference in the amount of recovery sleep taken by the two groups was not statistically significant.

The usual amount of sleep taken by both Group A and Group B subjects (outside the experiment) is about 7 h. Therefore, Group B subjects were deprived of about 3 h of sleep a night for 6 nights; their "sleep debt" was thus 18 h. The Group A subjects' sleep debt was 37.5 h, that is, over twice that of Group B, and yet their recovery sleep was approximately only 4 h longer. It is interesting to note that 16.75 h is only about 3 h greater than the figure of 12 to 14 h that represents the usual amount of recovery sleep following 2 to 4 days without sleep; yet, in the present experiment, Group A subjects were scheduled 3 days without sleep following 3 days with a total of 4.5 h of sleep. This is further evidence that the amount of recovery sleep needed after sleep deprivation is small relative to the amount lost. Friedman, Bergmann, and Rechtschaffen (1979) suggested that, following sleep deprivation, sleep may be more intense, thus serving its function (whatever that may be) in less time than usual. One aspect of the intensity described by Friedman et al. is increased sleep-stage continuity. In an earlier experiment (Haslam, 1982b), there was more continuity of Stage 4 sleep following sleep deprivation than there was on baseline days.

Objective Tests

Vigilance rifle shooting. The difference in performance between Group A and Group B was not statistically significant; one reason for this could be the large variation in performance between subjects within groups, especially as sleep deprivation increased. However, the groups $\times$ days interaction was significant [$F(9,90) = 4.13$, $p < .001$].

For Group A, selected contrasts indicated that performance on Days E4 to E6 was significantly worse than it

was on baseline days [$F(1,19) = 9.04, p < .01$], recovery days [$F(1,19) = 13.78, p < .01$], and Days E1 to E3 [$F(1,19) = 7.46, p < .05$].

Scores on Days E1 to E3 were not significantly different from those on baseline and recovery days, when 62% of the targets were hit. On day E6, however, Group A hit only 25.6% of the targets. With regard to Group B, there was no significant variation in performance over the trial period.

Grouping capacity. The performance of Group A was not significantly different from that of Group B (again, presumably because of the large variation in performance between subjects within groups), but the groups $\times$ days interaction was significant [$F(4,37) = 2.65, p < .05$].

Selected contrasts indicated for Group A that performance on Days E4 to E6 was significantly worse than on baseline days [$F(1,13) = 9.18, p < .01$], recovery days [$F(1,13) = 14.40, p < .01$], and Days E1 to E3 [$F(1,13) = 12.65, p < .01$]. Scores on Days E1 to E3 were not significantly different from those on baseline and recovery days, when the dispersal of rounds was about 90 mm. For Group A, the percentage deterioration in performance on Day E6 compared with performance on baseline and recovery days was 125.9%. For Group B, there was no statistically significant variation in performance over the trial period.

Encoding/Decoding Tests

Number correct. The only statistically significant factors were the groups $\times$ days interactions [encode: $F(5,53) = 3.94, p < .01$; decode: $F(4,45) = 4.78, p < .01$].

Selected contrasts indicated that there was a significant deterioration in performance in Group A over the sleep-deprivation days, but not in Group B.

In Group A, performance on Day E6 at 0430 and at 0930 h was 34.7% and 38.8% of baseline values for encoding, and 27.7% and 24.8% for decoding.

Number of errors. With regard to the number of errors, neither the difference in performance between the groups nor the groups $\times$ days interactions were significant. For both groups of subjects, the numbers of errors increased over the deprivation period, but they were also high on the recovery days. This suggests a sacrifice of accuracy for speed, a finding much like that of Thorne, Genser, Sing, and Hegge (1983).

Correlation Between Encoding and Decoding

Number correct. A correlation of $r = +0.86$ ($p < .001$) was found between encoding and decoding.

Addition Test

Number correct. Only the groups $\times$ days interaction was significant [$F(2,25) = 4.73, p < .05$].

Selected contrasts indicated that there was a significant deterioration in performance in Group A over the sleep-deprivation days, but not in Group B.

For Group A, performance on Day E6 at 0430 and 0930 h was 57.8% and 24.5% of baseline values.

Number of errors. Group A made significantly more

errors than Group B [$F(1,10) = 7.44, p < .05$], but the groups $\times$ days interaction was not significant.

Memory Test

Number correct. Significantly fewer items were recalled by Group A than by Group B [$F(1,10) = 5.24, p < .05$], and the groups $\times$ days interaction was also significant [$F(5,55) = 2.98, p < .05$].

Selected contrasts indicated that performance deteriorated significantly for both groups, but that the deterioration was greater for Group A. Toward the end of the deprivation phase, the performance of Group B recovered to some extent.

For Group A, performance on Day E6 at 0430 and 0930 h was 43.6% and 45.1% of baseline values.

Number of errors. The error rate was low, but it increased for Group A over the deprivation phase. No statistical analysis was carried out because of the low error scores.

Correlation Between Cognitive Tests

The correlations between scores on encoding/decoding, addition, and memory tests were all positive, and were all significant at the $p < .001$ level of confidence.

Time-of-Day Effects in Relation to Cognitive Test Performance

Group A. Comparisons were made by means of selected contrasts between performance at 0430 h and performance at 0930 h over Days E1 to E3 combined and Days E4 to E6 combined. Results indicated that performance was significantly better at 0430 h than at 0930 h over Days E1 to E3 in the decoding and memory tests ($p < .05$ and $p < .01$, respectively), and over Days E4 to E6 in the arithmetic and memory tests ($p < .01$ and $p < .05$, respectively). This is an unexpected finding.

Group B. Results for Group B indicated that performance was significantly better at 0930 h than at 0430 h over Days E4 to E6 in the encoding and memory tests ($p < .01$ and $p < .05$, respectively). This difference is in the expected direction.

For normal people, the early hours of the morning is the time of day when performance is usually at its worst (Colquhoun, Blake, & Edwards, 1968); this is the so-called "circadian lull" when people feel at their lowest ebb. There is also said to be maximum interaction between sleep loss and circadian effects at this time (Kleitman, 1972). The majority of subjects in Group B found this time to be the most difficult, that is, just after they had been awakened from sleep, at 0400 h. However, the majority of Group A subjects found the cognitive test session at 0930 h to be the most exacting time. It is not known why Group A found the later test session to be the more difficult time. Due to the presence of time cues and the speed with which the effect occurred, it is unlikely that there was a phase shift.

Deterioration in Test Performance

In view of the small amount of sleep scheduled for

Group A, and of the fact that subjects had to be continuously prevented from dozing on the last sleep-deprivation day, it is surprising that performance held up as well as it did. Taking an average of both test sessions on Day E6 in all three cognitive tests, performance was 37% of that on baseline days (compared with 94% for Group B). In earlier trials (Haslam 1981, 1983b), after subjects had gone 3 days without sleep, their performance on encoding/decoding tasks was approximately 50% to 55% of control values; considering that in the present experiment the 3 days without scheduled sleep followed 3 days with very limited sleep, 37% compares very favorably. With regard to Group B, results for an earlier experiment (Haslam, 1982a) were confirmed in that 4 h of sleep in every 24 h was sufficient to maintain a level of performance that was not significantly different from baseline values.

Subjective Measures

Profile of Mood States. Analysis of variance indicated that the groups were not significantly different from each other on any of the scales or on "Total Mood" (presumably because of the large variation between subjects within groups), and that the groups $\times$ days interactions were not significant. For both groups combined, the main finding was that during the sleep-deprivation days, "Total Mood" was significantly worse than it was during baseline days; also, it was significantly better on recovery days than on baseline days (p ranges from .05 to .001). This latter finding supports the observation that, before a trial of this nature, there is a certain amount of apprehension and tension. As stated earlier, the sleep schedules and length of the trial were unknown to the subjects; also unknown to most of them was their ability to withstand shortage of sleep, and the end of the sleep-deprivation period resulted in a relaxation of tension. In their sleep-deprivation studies, Gillberg and Akerstedt (1981) also found that ratings of "elated" and "high spirits" were significantly higher after the recovery night than after the baseline night (and also higher than during the last hours of a vigil).

Since the deterioration in mood in Group B was statistically significant and since there was no significant impairment in cognitive functioning, these results support the view of Johnson (1979) that the major changes during partial sleep loss are a deterioration in mood and subjective feelings of fatigue.

The Need for Sleep

Although total sleep deprivation apparently produces few, if any, physical ill effects, there is usually a deterioration in psychological functioning, with increased irritability, a decline in cognitive performance, occurrence of visual illusions, and paroxysmal EEG activity, which indicates impairment of the central nervous system. However, the deterioration in cognitive ability may be due more to a lessening of interest than to capacity to perform. This statement is reminiscent of the work of Whiting and English (1925), who believed that mental fatigue does not directly cause work decrement but raises the

threshold at which work motives are effective. They went on to say that "if such positive motives are adequate at all, then fatigue . . . has no effect upon work efficiency" (p. 49).

As stated earlier, in spite of severe sleep loss, when the subjects were kept awake in the present experiment, they performed fairly well relative to how they performed on baseline; also, in an earlier experiment (Haslam, 1983b), it was shown in subjects deprived of sleep for 90 h that an elevation in mood, attributed to the promise of sleep, improved cognitive performance so that it was not significantly different from baseline levels. This raises again the questions of the function of sleep. Sleep appears to be important, because after sleep loss the need to sleep seems to have the essential qualities of a physiological drive state (analogous to thirst and hunger) that increases in relation to sleep deprivation (Akerstedt & Gillberg, 1981; Dement, Seidel, & Carskadon, 1982). In the present experiment, for Group A subjects, especially those who did not complete the trial, the "drive" for sleep was very strong, and appeared to have the qualities of a physiological need.

In spite of this apparent need for sleep after sleep loss, there is little to support the view that sleep has body-restorative functions (Horne, 1978), and if sleep were for cerebral restitution, "then the extent of cerebral capacity to perform at near optimal levels during limited total sleep deprivation would be less than is found" (Horne, 1981, p. 97). [Horne, however, is of the opinion that sleep does have a restorative function (personal communication, 1983)]. In any event, the results from the present experiment indicate that, in spite of performance holding up relatively well in conditions of severe sleep deprivation, given a sleep debt of a certain size (which will vary between individuals), the physiological need to sleep will become increasingly dominant, eventually outweighing all motives.

SUMMARY

- (1) Three of 6 subjects completed the 152-h trial with a total of 4.5 h sleep.
- (2) For Group A, cognitive test performance on the last day was approximately 37% of baseline values; there was no significant deterioration for Group B.
- (3) For both groups, mood was significantly worse during sleep loss than on baseline and recovery days.
- (4) After sleep deprivation, the need to sleep eventually outweighed all other motives.

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