Sleep, Performance and Mood After the Energy-Expenditure Equivalent of 40 Hours of Sleep Deprivation

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ABSTRACT

Twelve Marine subjects marched approximately 20 miles to expend as much energy in one 16-hr day as is expended during 40 hrs of relatively inactive sleep deprivation. At the end of the march, performance on addition, vigilance, choice reaction time, tapping, short-term memory, symbol substitution, and three mood scales was decremented significantly. Those decrements closely approximated decrements reported in the literature following 40 hrs of sleep deprivation. However, recovery sleep stages and arousal thresholds were essentially unchanged as compared to baseline and were significantly different from those predicted after 40 hrs of sleep loss. It was concluded that while changes in performance were probably linked to total energy consumption, the commonly measured sleep variables were not.

DESCRIPTORS: Work, Performance, Exercise, Sleep, Sleep deprivation.

Work by Webb and Agnew (1971) has shown that the amount of stage 4 sleep in a given sleep period increases as a function of increasing prior wakefulness. Many studies involving sleep deprivation have shown an increase of stage 4 sleep over baseline. This increase in stage 4 is present after periods of as little as 40 hrs of wakefulness (Webb & Agnew, 1971; Berger, Walker, Scott, Magnuson, & Pollack, 1971; Moses, Lubin, Naitoh, & Johnson, 1977; Nakazawa, Kotorii, Ohshima, Kotorii, & Hasuzawa, 1978; Kapen, Boyar, Hellman, & Weitzman, 1975). Data from the above studies indicate that, in young adults, all-night stage 4 sleep will increase from about 6 to 11 percent and that total slow wave sleep, stage 3 and 4, will increase from about 20 to 27 percent after 40 hrs of sleep deprivation. No consistent explanation for this increase in slow wave sleep (SWS) following sleep deprivation has been presented.

Restorative theories of sleep (Oswald, 1970) posit that the changes in sleep found after deprivation are due to a build-up of some as yet unspecified substance which is related to energy consumption. Champions of this theory link increased SWS in childhood with the high metabolism of rapid growth (Oswald, 1970), link SWS with the production of thyroid hormone (Oswald, 1970), note SWS changes in starvation (MacFadyen, Oswald, & Lewis, 1973), and note the increases in SWS with the successful treatment of anorexia nervosa (Crisp, Stonehill, & Fenton, 1971).

Because modern restorative theory links sleep to energy consumption and resulting protein synthesis, it also predicts changes in sleep with differing amounts of daily activity. A large number of activity studies have been done (Adamson, Hunter, Ogunremi, Oswald, & Percy-Robb, 1974; Baeke-land & Lasky, 1966; Griffin & Trinder, 1978; Hauri, 1968; Hobraj, 1968; Horne & Porter, 1976; Matsumoto, Nishikawa, Suto, Sadahiro, & Miyoshi, 1974).
1968; Shapiro, Griesel, Bartel, & Jooste, 1975; Walker, Floyd, Fein Cavness, Lualhati, & Feinberg, 1978; Zir, Smith, & Parker, 1971; Zloty, Burdick, & Adamson, 1973) with various results. In addition to differing experimental conditions, results may have been inconsistent because experimenters have not been able to predict precisely how much exercise should result in a specific change in sleep pattern. This problem can be minimized by use of standard sources which allow one to calculate energy expenditure (Altman & Dittmer, 1968; Pace, 1974). Using these sources, it is possible to predict that during a 40-hr period of light activity (reading, office work, sitting, watching TV, eating) approximately 4500–5000 Kcal will be burned by a young adult male. And it is known that 40 hrs of sleep deprivation should result in only about a 20-min increase in total nightly stage 4 sleep.

Of the human exercise studies which have not disrupted sleep by placing the exercise directly prior to sleep, three of eight (Baekeland & Lasky, 1966; Shapiro et al., 1975; Zloty et al., 1973) have found consistent (not necessarily significant) increases in stage 4 sleep following periods of exercise. The five studies reporting very small or no increase in stage 4 (Adamson et al., 1974; Horne & Porter, 1976; Walker et al., 1978; Zir et al., 1971; Griffin & Trinder, 1978) usually involved very low levels of energy expenditure in subjects with a medium level of physical conditioning. Of the studies reporting increases in SWS, the level of activity cannot be determined in two but probably resulted in about a 3700 Kcal 16-hr day in the third.

The possible causal relationship between energy expenditure and sleep deprivation effects can be extended to two other areas. Both performance and arousal threshold have been found to change as a function of sleep deprivation. If energy expenditure is the mediating factor in the effects of sleep deprivation, then one must expect both performance to be worse and arousal thresholds to be higher after an appropriate period of caloric expenditure.

Some question may exist concerning the feasibility of projecting energy consumption estimates based on normal, waking subjects to subjects at night (circadian effects on energy consumption) or during sleep deprivation (a “stress” condition). For this reason, a pilot study was done. Four young, male subjects underwent 40 hrs of sleep deprivation and had caloric expenditure tested every 6 hrs at two work loads. No significant difference or consistent pattern of effects was found over the 7 trials. The lack of circadian effects has also recently been reported by Hagan and Horvath (1978).

The present experiment was undertaken to test the hypothesis that a long lasting, medium level energy expenditure exercise march performed by Marine subjects, such that approximately 5000 Kcal would be expended during a normal 16-hr wake period, would have the same effects on sleep, arousal threshold (Williams, Hammack, Daly, Demet, & Lubin, 1964), performance and mood as a 40-hr period of sleep deprivation as predicted by the restorative theory of sleep.

Method

Twelve Marines, aged 18–25, volunteered to participate. All subjects had finished basic training, were presently assigned to infantry divisions, ran 50 miles a month or more, and had previously undertaken fairly lengthy (15–30 mile) marches or runs at least once but not in recent weeks.

One subject reported to the laboratory each Monday morning and remained until Friday morning. Subjects practiced a series of performance tasks on Monday and had an EKG and Stress EKG (bike test) done. Both oxygen consumption and heart rate were measured during the bike test. The ride was at standard work loads, and the oxygen-consumption readings were to assure that oxygen consumption per load was at the expected values each week. Heart rate was measured as an index of overall physical condition. Following the bike test, the subject was allowed to march on the treadmill for a few minutes to adjust to the march planned for Wednesday. Tuesday and Thursday served as baseline and recovery days respectively. Testing times were the same on all days. On Wednesday (see Table 1 for schedule), the subject marched on the treadmill in an air-conditioned room (temperature between 72 and 75°F) for 6.5 hrs between 0745 and 1600. Subjects wore standard Marine fatigues and carried their own pack. The march rate and angle of march varied from individual to individual and at different times. The experimenter attempted to keep each subject’s oxygen consumption the same (between 1.90 and 2.30 l/min) throughout the march so that the total caloric consumption for the day would be approximately 5000 Kcal. This total energy expenditure level is similar to that of 8 hrs of work in lumbering or steel work. Subjects were given a 15-min break after each hour of march to take performance and mood scales. They were also allowed to watch TV or listen to the radio throughout the march.

During his stay in the laboratory, each subject was constantly monitored by the laboratory staff. Three meals

| 0615 | Subject awakened
| 0625 | Morning 4-choice
| 0745 | March/Rest
| 0830 | Tests (1)
| 0845 | March/Rest
| 1106 | Tests (2)
| 1121 | March/Rest
| 1224 | (Lunch)
| 1254 | March/Rest
| 1357 | Tests (3)

| 1412 | March/Rest
| 1515 | Williams Word Memory
| 1530 | March/Rest
| 1600 | Tests (4)
| 1800 | Tests (5)
| 2000 | Wilkinson Addition
| 2100 | Wilkinson Auditory
| | Vigilance
| 2200 | Tests (6)
| 2215 | Bedtime

**TABLE 1**

*Daily schedule*
a day were taken in a nearby mess. Alcoholic beverages were not allowed. Subjects were permitted to drink coffee before 1800 and to smoke cigarettes to the extent they normally did. During free time, subjects watched TV, read, played games or sat in the courtyard. Performance batteries were given 7–8 times during each day.

**Tests**

During each testing session, each subject completed the NPRU Mood Scale (Johnson & Naitoh, 1974), Profile of Mood States (McNair, Loom, & Droppleman, 1971), Stanford Sleepiness Scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1975) and soreness ratings; and oral body temperature and heart rate were recorded. Performance tests included a 5- or 16-min segment of a 4-choice serial reaction time test (Wilkinson & Houghton, 1975), the Fiitts Reciprocal Tapping Task (Graeber, Lubanovic, Thompson, Halberg, Halberg, & Levine, in press), and the Digit Symbol Substitution Test (from the Wechsler Adult Intelligence Scale). Other tests given at the end of the march, or in the evening following the march included a modified version of the Williams Word Memory Test (Williams et al., 1966), 50 min of the Wilkinson Addition Test (Wilkinson, 1970), and the 50 min of the Wilkinson Auditory Vigilance Test (Wilkinson, 1970).

On each evening, electrodes were placed as specified by Rechtschaffen and Kales (1968) at about 1945. The subject was monitored and kept awake until lights out at approximately 2215. Heart rate was recorded throughout sleep on FM tape for later computer analysis. Smith delta and spindle detectors (Smith, Funke, Yeo, & Ambuehi, 1975) were used to record the occurrence of delta and spindle activity. Equipment problems precluded scoring of the spindle data. Data were written on paper on all nights and taped for the last 3 nights. Subjects were awakened in the morning at 0615 and remained awake throughout the day. The night technician identified each sleep record only as a 5-digit random number taken from a random number table in his possession. The night technician did not score any sleep records, and the code he used was broken by the experimenter after all the records were scored.

**Arousal**

Seven of the 12 subjects had their stage 2 arousal threshold tested 5 times on each laboratory night. The arousal stimulus was a 1 kHz pure tone produced by an amplifier and step attenuator system (range 35–118 dB SPL in 36–38 dB background noise) and delivered through a University Sound MLC 8 speaker approximately 48 cm above the subject's head. Because possible time course recovery efforts might exist, the 5 arousals were made within 5 approximate time windows—5 min after sleep onset, 75–100 min after sleep onset, 150–200 min after sleep onset, 270–320 min after sleep onset, and 370–430 min after sleep onset. Other criteria for all arousals except the first included: at least 5 min of well-defined stage 2 sleep, 10 min since any body movement or muscle artifact greater than 8 sec, 30 min since any natural or experimental arousal. Threshold when awake was obtained each evening before bedtime.

**Statistical Analyses**

All data collected on Monday were considered practice and were discarded without analysis.

For all variables, data from the baseline day (Tuesday) were compared with the recovery day (Thursday) and averaged if there were no significant decrements on the recovery day compared to the baseline day. This step controlled for learning effects on the tests and permitted a direct comparison with the march day effects.

Paired t-tests were used to compare values of the averaged baseline recovery days and the march day on the tests which were administered only once each day and for sleep parameters. On tests which were administered 6 times per day, the analysis was an ANOVA with main effect terms for subject (11 df), exercise or not (1 df), and time of day (5 df). Pairwise comparisons were made using the Duncan Multiple Range Test at the .05 level.

**Results**

All subjects completed the 6.5-hr march as scheduled. The overall average oxygen consumption level was 2.06 l/min. To attain this expenditure, subjects carried a pack which weighed an average of 31.5 pounds (SD 8.6). To keep energy consumption constant, the average grade of march remained about the same from the beginning to the end of the march (5.33 to 5.46 degrees of grade), but the rate of march was slowed from an average of 3.20 mph (SD .24) to 2.91 mph (SD .25). March heart rate ranged between 130 and 150 bpm with first hour and last hour means of 136.8 (SD 7.9) and 147.9 (SD 4.0) bpm respectively. Resting heart rate, which was taken during each of the 6 daily testing sessions, was significantly higher (F for the time by condition interaction was 13.90 and significance means p < .05) throughout the entire march day as compared to the mean of baseline and recovery days (see Fig. 1). Significant heart rate elevation continued throughout the march night as compared to both the baseline and the recovery night. While heart rate during the recovery day did not differ from baseline, significant heart rate elevation was found during the first 3 hrs of the recovery night as compared to the baseline night.

**Performance**

**Tests Given Once per Day.** Results of the performance tests are summarized in Table 2. Signifi-

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1All main effects reported were calculated using their own error term, not a pooled error term. All tests were performed at the .05 level (two tailed) unless otherwise noted. Degrees of freedom reported are those normally allowed by the analysis. By strict Geisser-Greenhouse criterion, 1 and 11 df would be allowed for each F-test and a .05 F-value of 4.84 would be necessary for significance. Where time by condition means are presented by interaction F-values of less than 4.84, the main effect value for the exercise condition always exceeded 4.84.
significant decrements were found on the Williams Word Memory Test and the Wilkinson Auditory Vigilance Test on the march day as compared to the combined baseline and recovery days. On the Wilkinson Addition Test the subject was asked to make a mark on his test booklet at the end of each 10 min of the 50-min test. The data were analyzed to allow comparison with the sleep-deprivation data presented by Donnell (1969). During the first 10 min of the test, there was a significant decrease in the percent of problems completed correctly on the march day compared to baseline days. This difference remained significant throughout the 50-min test. The number of addition problems attempted was significantly fewer at the end of 50 min. On the march day, the number of correct additions was also significantly less after 10 min.

Tests Given More Than Once per Day. On the Fitts Tapping Task, the interaction of time of day with condition was not significant \((F = 0.217)\), but the main effect for exercise was significant \((F = 6.92)\). The overall tapping score on baseline days was 1.124 vs 1.037 on the march day.

On Digit Symbol Substitution, the time of day by condition interaction was significant \((F = 4.02)\). When individual time means across the exercise and baseline days were examined, performance was significantly poorer at 1400, 1600, and 1800 on the march day compared to the combined baseline days. Only 4 (of 5) min data was available from 11 of 12 subjects on the 4-choice reaction time test. Neither the interaction \((F = 1.84)\) nor the main effect \((F = 1.32)\) \(F\)-values for the march days compared to baseline and recovery were significant for the total number of reaction time button presses attempted.

**Mood and Subjective Report**

The Profile of Mood States, NPRU Mood Scale, Stanford Sleepiness Scale, and three soreness rating scales were administered 6 times daily (during each testing session). They were analyzed by ANOVA and are summarized in Table 3. On the Profile of

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**TABLE 2**

*Baseline and exercise performance and baseline and 40 hrs of sleep-deprivation performance*

<table>
<thead>
<tr>
<th>Performance Measures</th>
<th>Baseline</th>
<th>March</th>
<th>Difference</th>
<th>(t)</th>
<th>Baseline</th>
<th>Deprivation</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Auditory Vigilance (d')</td>
<td>2.10</td>
<td>1.71</td>
<td>0.39</td>
<td>4.27*</td>
<td>2.81</td>
<td>2.57</td>
<td>0.24*</td>
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<tr>
<td>Addition:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% correct first 10 min</td>
<td>.864</td>
<td>.787</td>
<td>.077</td>
<td>4.39*</td>
<td>.856</td>
<td>.870</td>
<td>.014</td>
</tr>
<tr>
<td># correct first 10 min</td>
<td>26.3</td>
<td>23.2</td>
<td>3.1</td>
<td>2.97*</td>
<td>73.1</td>
<td>70.3</td>
<td>2.8</td>
</tr>
<tr>
<td>total adds first 10 min</td>
<td>33.4</td>
<td>33.4</td>
<td>0.0</td>
<td>0.00</td>
<td>86.6</td>
<td>81.8</td>
<td>4.8</td>
</tr>
<tr>
<td>Williams Word Memory</td>
<td>7.83</td>
<td>7.00</td>
<td>0.83</td>
<td>2.53*</td>
<td>8.42</td>
<td>7.60</td>
<td>0.82</td>
</tr>
<tr>
<td>Fitts Tapping</td>
<td>1.124</td>
<td>1.037</td>
<td>0.087</td>
<td>6.29**</td>
<td>1.109</td>
<td>1.075</td>
<td>0.034</td>
</tr>
<tr>
<td>Digit Symbol Substitution 4-choice:</td>
<td>68.6</td>
<td>66.2</td>
<td>2.4</td>
<td>8.65**</td>
<td>404</td>
<td>368</td>
<td>36</td>
</tr>
<tr>
<td>1400</td>
<td>442</td>
<td>406</td>
<td>36</td>
<td>1.32e</td>
<td>404</td>
<td>368</td>
<td>36</td>
</tr>
<tr>
<td>1600</td>
<td>403</td>
<td>404</td>
<td>-1</td>
<td></td>
<td>404</td>
<td>381</td>
<td>23</td>
</tr>
</tbody>
</table>

*\(a\) Wilkinson (1968).
*c Naitoh (Note 1).
*d Williams, Gieseking, and Lubin (1966).
*Main effect \(F\)-value.
*\(p < .05)\.
### TABLE 3
Mood during and after the march

<table>
<thead>
<tr>
<th>Mood Measures</th>
<th>F&lt;sup&gt;a&lt;/sup&gt;</th>
<th>0800</th>
<th>1100</th>
<th>1400</th>
<th>1600</th>
<th>1800</th>
<th>2200</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>B</td>
<td>E</td>
<td>B</td>
<td>E</td>
<td>B</td>
<td>E</td>
</tr>
<tr>
<td>Profile of Mood States</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fatigue</td>
<td>9.48*</td>
<td>3.5</td>
<td>3.0</td>
<td>2.6</td>
<td>6.2*</td>
<td>2.9</td>
<td>10.6*</td>
</tr>
<tr>
<td>Vigor</td>
<td>4.67*</td>
<td>15.1</td>
<td>17.1</td>
<td>17.2</td>
<td>10.9*</td>
<td>15.2</td>
<td>8.0*</td>
</tr>
<tr>
<td>Confusion</td>
<td>1.21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depression</td>
<td>1.56</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anger</td>
<td>1.51</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension</td>
<td>1.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NPRU Mood Scale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive</td>
<td>4.98*</td>
<td>31.0</td>
<td>29.8</td>
<td>24.4</td>
<td>33.1*</td>
<td>17.8</td>
<td>31.4*</td>
</tr>
<tr>
<td>Negative</td>
<td>2.65*</td>
<td>3.5</td>
<td>3.5</td>
<td>2.8</td>
<td>6.2</td>
<td>3.0</td>
<td>9.7*</td>
</tr>
<tr>
<td>Stanford Sleepiness Scale</td>
<td>4.16*</td>
<td>2.2</td>
<td>1.8</td>
<td>1.9</td>
<td>2.8*</td>
<td>2.0</td>
<td>3.6*</td>
</tr>
</tbody>
</table>

<sup>a</sup>For the time by condition interaction.

<sup>b</sup>E = Baseline, E = Exercise.

*Signifies either a significant F-value or a significant difference with the Duncan Multiple Range Test both at the .05 level.

Mood States, significant effects on the march day compared to the combined baseline days were found on the fatigue, vigor and confusion scales but not on the depression, anger or tension scales. The condition by time of day interaction terms were significant for the fatigue and vigor scales. Fatigue was highest and vigor lowest compared to baseline in the middle of the afternoon with some recovery seen in the evening. Subjects reported being more confused throughout the march day.

Significant condition by time of day interaction effects were found on both the positive and negative scales of the NPRU Mood Scale. Again, effects were greatest toward the end of the march and there was some recovery in the evening (see Table 3). Similar results were found with the Stanford Sleepiness Scale.

### Sleep

The sleep stage data (expressed in percents except for latency and delta count) from the 5 subjects who were not aroused during the night were compared to the sleep stage data from the 7 subjects who were aroused. The subjects who were not aroused during the night differed significantly from those who were aroused only in having significantly less wakefulness ($X_{WA} = .000$, $X_A = .018$, $t = 2.570$) and more movement ($X_{NA} = .025$, $X_A = .015$, $t = 4.189$). The baseline-exercise comparisons for these variables were done separately but, because the conclusion reached for each analysis was the same, only the average data will be presented.

The sleep data for the average baseline and the march night can be found in Table 4. There was a significant reduction in REM and a significant increase in stage 4 on the march night as compared to the average of the baseline conditions. The significant stage 4 increase was not maintained when the t-tests were checked by nonparametric analog (Wilcoxon rank-sum test).

### Arousal Thresholds

The arousal threshold data from the baseline and recovery nights did not differ significantly. The average of the baseline and recovery nights was then compared to the exercise condition by an analysis of variance with terms for subject (6 df), exercise or baseline condition (1 df), time across the night (4 df) and interactions. Both the condition by time across the night interaction ($F = 1.17$) and the main effect for conditions ($F = 0.06$) were nonsignificant. The overall exercise and baseline mean thresholds were 77.6 and 78.8 dB respectively.

### Discussion

#### Effects of Exercise

Decrements in performance over an extended period of mental work (Hockey & Colquhoun, 1972; Bonnet & Webb, 1978) or physical work (Soule & Goldman, 1973; Davey, 1973) are not completely unexpected even when accompanied by physiological arousal. The present experiment serves once again to document such effects. Even with fairly frequent breaks, clear subjective shifts in fatigue and vigor were seen after 3 hrs of marching, and objective performance decrements after 5. By the end of the march, decrements were found on
TABLE 4
Percent of sleep stages on averaged baseline, after march, and as predicted from 40-hr sleep-deprivation studies

<table>
<thead>
<tr>
<th>Sleep Variables</th>
<th>Averaged Baseline Percent</th>
<th>Exercise Percent</th>
<th>t</th>
<th>Deprivation Predicted Percent</th>
<th>t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latency</td>
<td>18.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.2&lt;sup&gt;a&lt;/sup&gt;</td>
<td>NS</td>
<td>14.7</td>
<td>NS</td>
</tr>
<tr>
<td>Wakefulness</td>
<td>1.4</td>
<td>1.5</td>
<td>.420</td>
<td>1.2</td>
<td>NS</td>
</tr>
<tr>
<td>Stage 1</td>
<td>5.6</td>
<td>5.4</td>
<td>2.450*</td>
<td>3.1</td>
<td>4.399*</td>
</tr>
<tr>
<td>REM</td>
<td>28.4</td>
<td>25.4</td>
<td>-.641</td>
<td>10.2</td>
<td>3.664*</td>
</tr>
<tr>
<td>Stage 2</td>
<td>48.5</td>
<td>49.8</td>
<td>.752</td>
<td>47.4</td>
<td>1.440</td>
</tr>
<tr>
<td>Stage 3</td>
<td>7.7</td>
<td>7.3</td>
<td>2.406*</td>
<td>11.7</td>
<td>3.430*</td>
</tr>
<tr>
<td>Stage 4</td>
<td>6.4</td>
<td>7.9</td>
<td>1.102</td>
<td>19.4</td>
<td>5.542*</td>
</tr>
<tr>
<td>SWS</td>
<td>14.1</td>
<td>14.9</td>
<td>-.637</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Movement</td>
<td>1.5</td>
<td>2.0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Delta count</td>
<td>8208&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8885&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1.390</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

<sup>a</sup> min.  
<sup>b</sup> counts.  
*These t-values were significant at the .05 level. The stage 4 baseline-exercise comparison did not remain significant when checked by nonparametric analog.

The magnitude of mood and performance changes as a result of the march in this study and 40 hrs of sleep deprivation in several other studies is summarized in Table 2 (performance) and Table 5 (mood). Wilkinson (1968) reported a fall in d' (d' is thought to be an unbiased estimator of sensitivity/performance) of .24 on his auditory vigilance task following one night without sleep. The decrease in d' in the present study was .39. Donnell (1969) reported significantly fewer attempted problems on the Wilkinson Addition Test after 10 min of testing and significantly lower percent correct after 50 min of testing after one night of sleep deprivation as compared to baseline. In the present experiment, percent correct was significantly less after 10 min and the number of additions attempted was significantly less after 50 min. If number attempted and percent correct are combined to get number correct, Donnell (1969) reported a decrease of 2.8 problems in number correct at the end of 10 min while that decrease is 3.1 problems in the present experiment. Williams et al. (1966) reported 1.58 fewer words per list remembered in their short-term memory task after one night of sleep deprivation. In a current study of fragmented sleep (Naitoh, Note 1) in the San Diego laboratory, a decrease of .82 words per list after one night of sleep deprivation was found. In the present experiment, the decrement was .83 words per list after the march when compared to baseline. In the same fragmented sleep study, there

TABLE 5
Comparison of mood scale data from exercise with mood data from 40 hrs of sleep deprivation

<table>
<thead>
<tr>
<th>Mood Measures</th>
<th>Present Study</th>
<th>40-hr Sleep Deprivation&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Baseline 1600</td>
<td>1800 2200</td>
<td>Exercise 1600 1800 2200</td>
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<tr>
<td>NPRU Mood Scale</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Positive</td>
<td>31.5</td>
<td>30.6</td>
<td>19.7</td>
</tr>
<tr>
<td>Negative</td>
<td>2.8</td>
<td>2.4</td>
<td>8.0</td>
</tr>
<tr>
<td>Stanford Sleepiness Scale</td>
<td>1.9</td>
<td>2.3</td>
<td>4.0</td>
</tr>
</tbody>
</table>

<sup>a</sup> Naitoh (Note 1).  
*<sup>p</sup> < .05 with Duncan Multiple Range Test after an overall significant F-value.
was a reduction on the Fitts Tapping Task from 1.109 to 1.075 after sleep deprivation while the average tapping score on the march day in the present experiment was 1.037 compared to a baseline of 1.124. In the Naitoh (Note 1) data the number of attempts on the 4-choice reaction time test in the first 4-min period was reduced by an average of 30 while in the present study attempts were reduced by about 18.

Mood scores in the present experiment on some variables could be directly compared to mood scores from the Naitoh (Note 1) study given at the same time of day after one night of sleep loss. These are reported in Table 5. As can be seen, mood shift after the march was slightly greater in all cases than after a night of sleep deprivation.

Data from five studies (Berger et al., 1971; Kapen et al., 1975; Moses et al., 1977; Nakazawa et al., 1978; Webb & Agnew, 1971) reporting recovery sleep after 40 hrs of sleep deprivation were examined and used in a ratio with the baseline data of the present study to predict the average sleep changes that should have occurred for each subject if the march condition were equivalent to 40 hrs of sleep deprivation. These average estimates also appear in Table 4 along with a t-value comparing actual sleep on the march night with that predicted by the deprivation studies. As can be seen from the table, there was significantly more stage 1 and significantly less stage 3, stage 4 and total SWS on the march night than that predicted from the sleep-deprivation studies.

The great similarity in performance and mood change on all of the tasks in the present study, when compared to a number of sleep-deprivation studies, points to total energy consumption as the most likely factor in determining the performance decrements characteristic of various sleep-deprivation periods. The role of other possible factors including deprivation of sleep, boredom, violation of normal circadian rhythms or the buildup of any substance not related to simple energy expenditure in the production of performance and mood effects characteristic of sleep deprivation can be viewed as less important based upon the results of this study.

One night of sleep was adequate for complete recovery on all performance and mood variables. This is also seen after short-term sleep deprivation (Morgan, Coates, Brown, & Alluisi, Note 2).

The data indicate essentially no effect of the 6.5-hr march on recovery sleep stage distribution or auditory arousal threshold. However, since the performance and mood effects were very similar in magnitude to those found after a night without sleep and the total energy expenditure amount was derived from standard metabolic tables (Altman & Dittmer, 1968; Pace, 1974) to approximate a normal day and night of laboratory sleep deprivation, it is difficult to conclude that the energy expenditure of these subjects was of an inappropriate magnitude for the predicted effects on sleep to occur. On the other hand, biorhythmic or adaptive theories of sleep (Webb, 1974) would predict that sleep and arousal threshold should not change as a function of activity.

It could be argued that the various SWS changes predicted by restorative theories did not appear because of elevated heart rate and body temperature at bedtime. However, poor sleepers have elevated body temperature and heart rate at bedtime but do not have less SWS (Monroe, 1967; Church & Johnson, 1979) than good sleepers. Further, in the present study, latency to sleep was decreased (though not significantly) after exercise, and this means that the beginning of sleep was not adversely affected by the march.

These performance, sleep and recovery findings indicate:

1) That the fatigue caused by the march was equivalent in terms of effect on mood and performance to that seen after one night of sleep deprivation.

2) That the sleep on the night after the march was restorative; that is, that performance recovered to baseline levels throughout the recovery day. This is also expected from one-night sleep-deprivation studies (Morgan et al., Note 2).

3) That the restorative nature of the sleep after the march was not reflected in the traditional EEG or auditory arousal variables, which in essence did not differ from baseline values. This allows the possibility that while the sleep stage distribution changes after sleep deprivation, such changes may have no relationship whatsoever to recovery of function.

4) That the consistent increase in SWS following sleep deprivation is not based on total energy consumption but, rather, upon some other factor such as time since previous sleep.

REFERENCES


REFERENCE NOTES


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