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Sleepiness and Sleep State on a 90-Min Schedule

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ABSTRACT

The effects of REM and slow wave sleep (SWS) on subjective sleepiness were studied in 10 subjects placed on a 90-min sleep-wakefulness schedule for either $5^1/_3$ or 6 (24-hr) days. Subjects were permitted to sleep for 30-min periods separated by 60 min of enforced wakefulness. Sleep recordings showed that sleep onset REM periods occurred frequently; REM and SWS appeared during the same sleep period only 27 times; and REM sleep tended to occur on sleep periods that alternated with SWS periods. Sleepiness was measured using the Stanford Sleepiness Scale (SSS) given 15 min before (pre-sleep) and 15 min after (post-sleep) each sleep period. Average SSS ratings showed a 24-hr fluctuation in sleepiness. In addition, negative and positive SSS changes tended to alternate with each 90-min period. Significant correlations were found with post-sleep SSS ratings and SWS and with pre-sleep SSS ratings and REM sleep. Differences between pre- and post-sleep SSS scores were also correlated with the sleep states: increased sleepiness was correlated with SWS and decreased sleepiness with REM sleep.

DESCRIPTORS: Sleepiness, Slow wave sleep, REM sleep.

The physiological properties of rapid eye movement (REM) sleep and non-rapid eye movement (NREM) slow wave sleep (stages 3+4) are strikingly different (e.g., activated EEG vs slow, high amplitude, synchronous EEG; bursts of rapid eye movements vs ocular quiescence; tonic motor inhibition vs tonic muscle activity). Nevertheless, equally striking functional differences between these two sleep states have not been shown. Several experiments attempting to demonstrate divergent behavioral consequences by selective deprivation of one state or the other have shown few distinctions. Agnew, Webb, and Williams (1967) reported no differences in performance by subjects deprived of either REM or stage 4 sleep for 7 nights. The "overall impression" of personality tests, however, revealed a "depressive or hypochondriacal reaction" to stage 4 sleep deprivation, while subjects deprived of REM sleep "became less well integrated and less interpersonally effective. They tended to show signs of confusion, suspicion, and withdrawal [Agnew et al., 1967, p. 856]."

In another study, Johnson (1973) showed no performance or psychological differences in subjects after 3 nights of stage 4 or REM sleep deprivation; nor were differences apparent when the selective deprivation was followed by total sleep deprivation for one night. In another attempt to differentiate the effects of stage 4 and REM sleep, Johnson, Naitoh, Lubin, and Moses (1972) assessed the recuperative effects of the sleep states following 2 nights of total sleep deprivation. Among groups of subjects permitted either uninterrupted sleep, no REM sleep, or no stage 4 sleep during recovery, "there was no significant difference in the amount of recovery [on tests of performance, memory, and mood] for the three kinds of recovery sleep [Johnson et al., 1972, p. 83]."

These authors and others (e.g., Dement, Ferguson, Cohen, & Barchas, 1969) have remarked on the difficulties of reliably achieving total selective deprivation of any stage of sleep. Given this difficulty and the fact, as Johnson has emphasized (Johnson, 1973), that we do not know if the amount of sleep represents a ratio scale—that is, if twice the amount of a sleep stage represents twice the recuperative (or other) value of that stage—or whether the total value may be achieved in only a fleeting time, it is even more difficult to evaluate the selective sleep deprivation studies.

The alternative method of studying the sleep states by assessing behavior after obtaining only a single state of sleep has been only partially feasible, since REM sleep normally occurs only after a prolonged period of NREM sleep. In one naturally occurring condition in which REM sleep frequently

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appears before NREM sleep—narcolepsy (e.g., Rechtschaffen, Wolpert, Dement, Mitchell, & Fisher, 1963; Takahashi & Jimbo, 1963; Dement, Rechtschaffen, & Gulevich, 1966)—other considerations (specifically, altered states of consciousness, see Guilleminault, Billiard, Montplaisir, & Dement, 1975) may interfere with direct testing of behavioral differences. In another naturally occurring circumstance where REM sleep may precede NREM sleep—napping (e.g., Maron, Rechtschaffen, & Wolpert, 1964; Webb, Agnew, & Sternthal, 1966; Karacan, Finley, Williams, & Hursch, 1970)—time of day effects and unreliability of the appearance of REM sleep may hamper experimental design.

In a previous report of 5 subjects placed on a 90-min schedule of sleep and wakefulness (Carskadon & Dement, 1975), several findings suggested that the 90-min day paradigm might appropriately supplement selective deprivation studies in assessing the behavioral consequences of the sleep states. These findings included 1) the reliable occurrence of REM sleep before slow wave sleep (SWS), 2) the separation of most REM and SWS periods by at least 60 min of wakefulness, and 3) the predictable appearance of REM sleep on alternate sleep periods.

The purpose of the present study was to replicate these findings in an additional 5 subjects and to determine (in all 10 subjects) whether changes in one behavioral measure—sleepiness—could be attributed to sleep stage differences.

Subjects and Methods

Ten normal, healthy, young adult (ages 17 to 21 yrs) volunteers received nominal monetary reimbursement for participating in the studies. Five subjects were evaluated in each study. All subjects had at least one adaptation night and two baseline all-night sleep recordings in the laboratory before beginning the 90-min sleep-wakefulness schedule. On these nights, the sleep period was limited to 8 hrs, from midnight to 0800. On the 90-min schedule, sleep was divided into 16 portions of 30 min during the 24-hr day. Sleep periods were separated by 60 min of enforced wakefulness.

In the first study (Carskadon & Dement, 1975), 3 men and 2 women began the 90-min schedule at midnight following 16 hrs of wakefulness. They lived on the schedule for 86 consecutive 90-min periods (5⅓ days). In the second group of 3 men and 2 women, the 90-min schedule was instituted at 0900 following the second baseline night and continued for 96 consecutive 90-min periods (6 days). In both studies, the 90-min schedule was terminated at 0800, and subjects were kept awake until midnight. Subjects then slept ad lib in the laboratory for at least 2 consecutive recovery nights.

All sleep periods were recorded in individual, darkened, sound-attenuated bedrooms. Sleep periods were continuously monitored with electroencephalogram (recorded from C_3 or C_4 placements referred to the opposite mastoid), electro-oculogram (recorded from the outer canthi), and electromyogram (recorded from chin surface electrodes). Sleep records were scored in 30-sec epochs by the criteria of Rechtschaffen and Kales (1968).

During the periods of enforced wakefulness, both on baseline and experimental days, subjects were given a series of tasks to complete at specified intervals (see Fig. 1). When no activities were scheduled, the subjects were given "free" time. Showers, replacement of electrodes, and meals generally took place at these times. Except during performance tests, subjects were continuously attended during all waking periods throughout the study to ensure that they did not sleep at unscheduled times. Caffeinated and alcoholic beverages were forbidden during the experiments.

To measure sleepiness, subjects completed the Stanford Sleepiness Scale (SSS), a 7-point self-administered

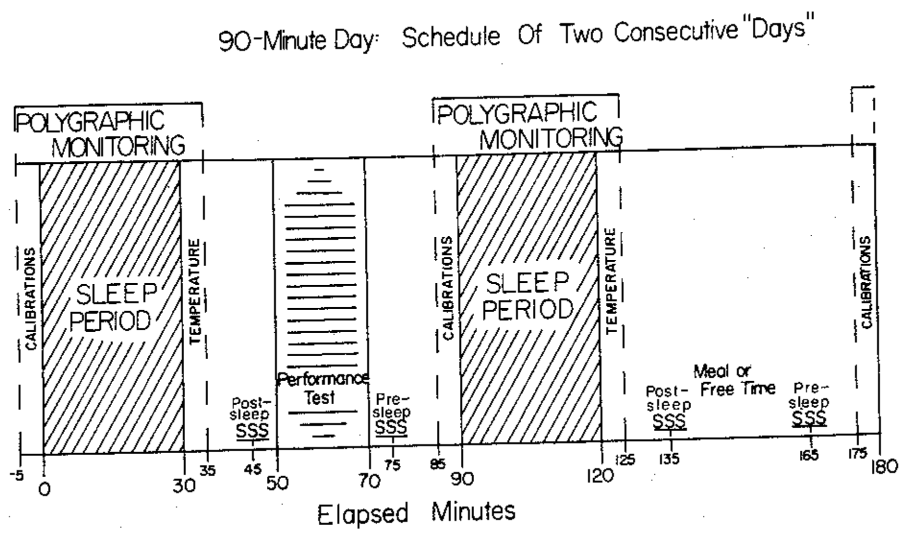

Fig. 1. Schedule of activities on 2 consecutive 90-min periods.

Likert rating scale (Hoddes, Zarcone, Smythe, Phillips, & Dement, 1973), twice during each 90-min period—15 min before (pre-sleep) and 15 min after (post-sleep) the sleep period (see Fig. 1). The SSS was administered at corresponding times during waking periods on baseline and recovery days. The SSS includes the following numbered statements:

1 Feeling active and vital, alert, wide awake
2 Functioning at a high level, but not at peak; able to concentrate
3 Relaxed, awake, not at a full alertness, responsive
4 A little foggy, not at peak, let down
5 Fogginess, beginning to lose interest in remaining awake, slowed down
6 Sleepiness, prefer to be lying down, fighting sleep, woozy
7 Almost in reverie, sleep onset soon, lost struggle to remain awake

Results

The .05 rejection region was adopted in all statistical tests.

Sleep

(More detailed sleep data were presented in Carskadon and Dement, 1975.)

On the baseline nights, all subjects had normal amounts and distributions of sleep stages for their age and sex (Williams, Karacan, & Hursch, 1974). Latencies from sleep onset to SWS (mean=17.6 min; SD=11.6) and to REM sleep (mean=92.1 min; SD=28.6) were within normal limits. SWS always preceded REM sleep.

On the 90-min schedule, the results from the second group of 5 subjects were similar to those of the first group and confirmed the major findings of the original study. Therefore, the data presented below are pooled over the 10 subjects.

Fig. 2 illustrates the distribution of total sleep time and the sleep stages averaged for the 16 "daily" sleep periods. A clearcut 24-hr distribution of sleep was apparent, with maximum sleep times occurring in the late morning and early afternoon hours and minimum sleep times in the evening and early morning hours. SWS and REM sleep reflected this 24-hr distribution, although the tendency was not as clearly defined. SWS occurred at least once in each of the scheduled sleep period times; REM sleep never occurred in the midnight sleep period and was seen only 3 times in the 0130 and twice in the 0300 sleep periods. Similar amounts of stages 1+2 sleep were present in REM sleep periods (mean=12.6 min; SD=4.6) and SWS periods (mean=14.4 min; SD=4.0).

SWS occurred on 438 and REM sleep on 235 of the 910 sleep periods. The two states appeared together during only 27 sleep periods; of these, the normal relationship (SWS giving way to REM sleep) occurred only 8 times. On 170 of the periods with REM sleep, the onset of REM sleep was within 10 min of sleep onset. (These periods were called sleep onset REM periods or SOREMPs.) The average latency to REM sleep onset in the 235 REM sleep periods was 8.1 min. The average latency to SWS onset in the 438 SWS periods was 13.1 min.

As Table 1 demonstrates, REM sleep periods tended to alternate with periods containing NREM sleep (128 times) and rarely (19 times) appeared on consecutive sleep periods. The 68 REM periods separated by 3 or more intervening sleep periods without REM sleep reflected the tendency for REM sleep to occur during 4 or 5 sleep periods per 24 hrs (usually alternating with sleep periods having no REM sleep) and then to reappear on the next day after a gap of 6 to 9 hrs. SWS, on the other hand,

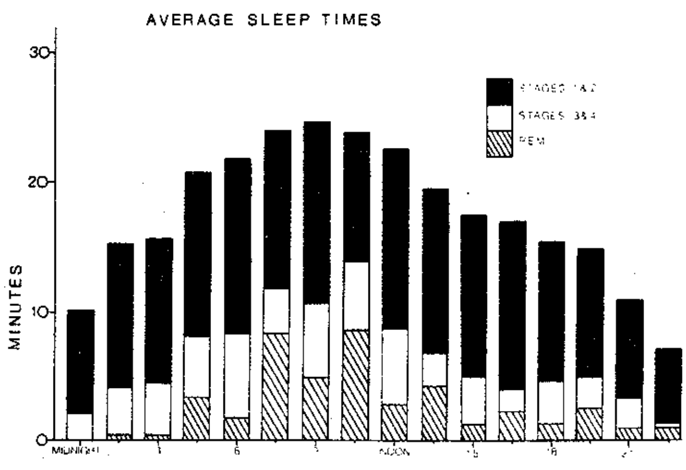

Fig. 2. Average sleep times and stages 1+2, stages 3+4, and REM sleep for each of the 16 daily sleep periods. Shaded portions represent stages 1+2; unshaded portions, stages 3+4; and striped portions, REM sleep.

TABLE 1

Frequency of recurrence of REM and slow wave sleep

Number of Intervening Sleep Periods	Number of REM Sleep Periods	Number of SWS Periods
None	19 (8.3%)	153 (35.4%)
1	128 (55.7%)	185 (42.8%)
2	15 (6.5%)	56 (13.0%)
3 or More	68 (29.6%)	38 (8.8%)

Chi square (df=3) = 96.4, $p<.05$.

recurred during both consecutive (153 times) and alternate (185 times) sleep periods. Thus, when REM sleep periods occurred, SWS periods tended to alternate, and during the daily REM sleep hiatus, SWS tended to occur during each sleep period. Chi square analysis of this frequency distribution showed a significant difference for the patterns of recurrence. The alternating nature of REM and SWS was also reflected in the average values shown in Fig. 2, since 68.9% of the REM sleep periods occurred during periods that began on the half hour (e.g., 0730, 1030, 1330).

Performance

Different performance tests were utilized in each of the studies. In the first, the performance test required subjects to add 7 to a base number and then to the sum and so on for 20 min. In the second study, subjects were given an abridged form of the Wilkinson Addition Test (Wilkinson, 1969). Although these data have not been fully analyzed, the most striking effect in both studies appeared to be a prolonged practice effect that persisted from the first baseline day through the last recovery day.

Sleepiness

Fig. 3 shows the SSS scores averaged across all subjects for pre- and post-sleep SSS ratings on the 90-min schedule and for corresponding times on the baseline days. As in sleep time (Fig. 2), the SSS scores showed a clear 24-hr distribution on the 90-min schedule. The highest (sleepiest) SSS ratings occurred in the late morning hours and the lowest ratings were seen in the evening hours. On the baseline days, the SSS ratings were lowest at 1030 and 1500, reaching highest levels as bedtime (midnight) approached.

The pre- and post-sleep SSS ratings for the 90-min schedule also appeared to demonstrate a regular

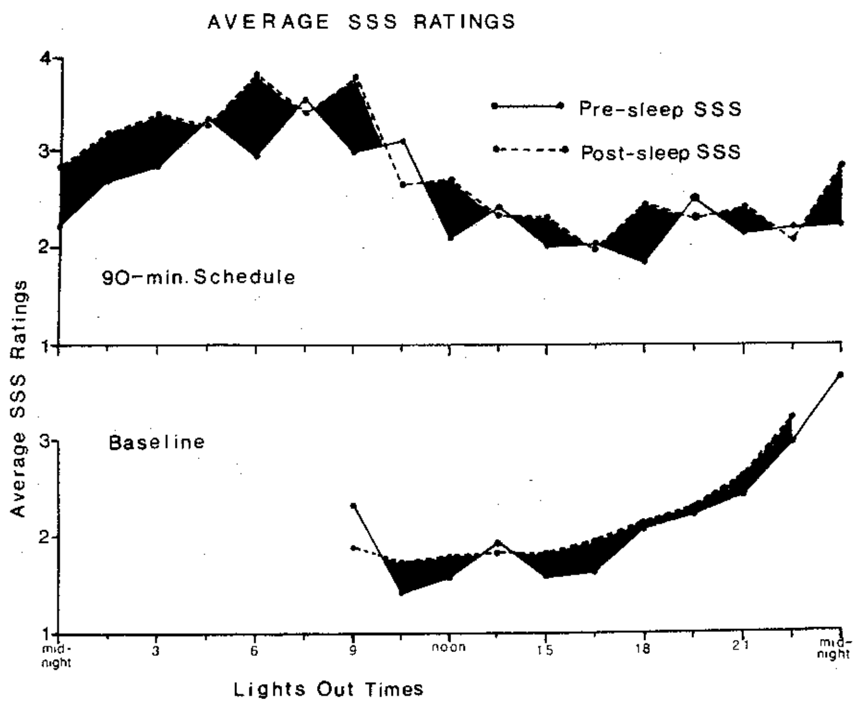

Fig. 3. Average SSS scores for baseline (below) and 90-min schedule (above) days. Solid lines represent pre-sleep ratings and dashed lines are post-sleep ratings on the 90-min schedule and at corresponding times of day on baseline days. Shaded portions show positive (sleepier) changes in SSS ratings, and unshaded portions illustrate negative (less sleepy) changes from pre- to post-sleep ratings.

pattern of differences. The shaded areas of Fig. 3 represent a positive difference in which the post-sleep SSS ratings were higher (sleepier) than the pre-sleep ratings. The unshaded areas show negative differences, with post-sleep ratings lower (less sleepy) than pre-sleep ratings. Except for the first 3 sleep periods (midnight, 0130, and 0300), the mean difference between pre- and post-sleep SSS ratings alternated between positive and negative changes. In addition, if either of the ratings (pre- or post-sleep) is examined independently, an alternation of relatively higher and lower SSS ratings was generally seen after the 0300 nap. These patterns were not evident on the baseline days. By inspection of Figs. 2 and 3, it appears that the changes in SSS ratings were related to the relative amounts of REM or SWS on each of the sleep periods.

Sleepiness and Sleep State

(These results are based on data corresponding only to the sleep periods on which REM or SWS were present.) Pearson product-moment correlation coefficients were calculated for pre- and post-sleep SSS ratings and sleep states for each subject and then averaged across subjects. A *t*-test to determine significant differences from zero was computed for the average correlation coefficients. These results are summarized in Table 2.

As was expected from the daily (24-hr) fluctuation in sleepiness (Fig. 3), the pre- and post-sleep SSS ratings were significantly correlated, both varying as a function of time of day. Total sleep time (TST), which also had a 24-hr fluctuation on this schedule (Fig. 2), showed smaller yet significant correlations with pre- and post-sleep SSS ratings. Pre-sleep SSS ratings were uncorrelated with stages 1+2 sleep and post-sleep SSS ratings were significantly correlated with stages 1+2 sleep. In addition, the pre-sleep SSS ratings were significantly correlated with the amount of REM sleep, so that higher (sleepier) pre-sleep SSS ratings tended to precede periods with greater amounts of REM sleep. No significant correlation was found between pre-sleep SSS and SWS; however, post-sleep SSS ratings and SWS were significantly correlated. That is, longer SWS periods tended to precede higher (sleepier) post-sleep SSS ratings. Post-sleep SSS ratings and REM sleep were not significantly correlated.

TABLE 2

Average within-subject Pearson product-moment correlations of pre-sleep and post-sleep SSS ratings and sleep states

Variables	Correlations	t
Pre-Sleep and Post-Sleep SSS Ratings	.53	9.55*
Pre-Sleep SSS Rating and TST	.24	3.97*
Post-Sleep SSS Rating and TST	.33	4.57*
Pre-Sleep SSS Rating and Stages 1+2	.07	1.55
Post-Sleep SSS Rating and Stages 1+2	.21	3.69*
Pre-Sleep SSS Rating and REM	.35	4.93*
Post-Sleep SSS Rating and REM	.09	1.50
Pre-Sleep SSS Rating and SWS	.03	<1
Post-Sleep SSS Rating and SWS	.28	5.53*
ΔSSS and TST	.10	2.05
ΔSSS and Stages 1+2	.12	2.23
ΔSSS and REM	−.28	4.02*
ΔSSS and SWS	.31	6.80*

*$p<.05$.

The pre-sleep and post-sleep SSS ratings were then summed over SWS and REM sleep periods for all subjects. The average pre-sleep SSS rating for SWS periods was 2.60, significantly lower ($t=10.84$) than the average post-sleep rating (3.18) for the same periods. For REM periods, the average pre-sleep rating (3.07) was significantly higher ($t=2.29$) than the average post-sleep rating (2.90).

To determine if these relationships (SWS and greater sleepiness; REM sleep and less sleepiness) were present on a subject-by-subject basis, difference scores (ΔSSS) were calculated for each pair of pre- and post-sleep SSS ratings and then correlated with the TST and the amount of stages 1+2, REM or SWS in each subject. The average correlations in Table 2 show that TST and stages 1+2 were not significantly correlated with ΔSSS, while REM and SWS were significantly correlated with ΔSSS ratings. Thus higher amounts of REM sleep were related to ΔSSS scores indicating a reduction of sleepiness. Fig. 4 illustrates these relationships, as well as the relationship of ΔSSS and total sleep time. Highest sleep times were associated with greatest absolute SSS changes, and the direction of the ΔSSS scores was related to the amount of REM or SWS in the sleep period.

Discussion

One interpretation of these data is that SWS causes or does not forestall the development of sleepiness, while REM sleep causes or is associated with a decrease in subjective sleepiness. Causal attributes, however, are only speculative. It is difficult to rule out the possibility of an underlying ultradian rhythm in sleepiness that independently affects the appearance of the two states of sleep and favors slow wave sleep or NREM sleep on the upswing of the cycle and REM sleep on the downswing. The positive correlation between pre-sleep SSS ratings and REM sleep time also suggests that

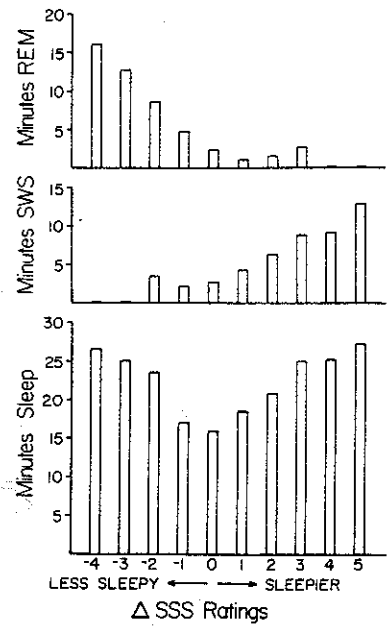

Fig. 4. Average sleep, slow wave sleep (SWS), and REM sleep times as functions of ΔSSS ratings. The ΔSSS ratings were computed by subtracting the pre-sleep rating from the post-sleep rating.

subjective reports of sleepiness may reflect a prodromal state for REM sleep in much the same manner that SWS or NREM sleep normally precedes REM sleep in nocturnal sleep periods. Thus the alternation of SWS and REM sleep periods on the 90-min schedule may be closely related to the normal nocturnal alternation of NREM and REM sleep.

Viewed in this way, it is also possible to interpret the data as reflecting a situation in which the experimental regime has entrained a 3-hr cycle of "sleepiness-alertness." Thus a period of SWS during a nap might set up a CNS state in which the subsequent waking period shows a progressive recovery of sleepiness as seen in the average SSS ratings of 3.18 15 min after the nap and 3.07 45 min after the nap. The presence of REM sleep in the next nap may permit the recovery to continue, with average SSS ratings of 2.90 and 2.60 in the subsequent waking period. The cycle would then repeat with the SWS in the next nap initiating another sleepiness-recovery situation. It is also possible to view the process as one in which REM sleep initiates an "alerting" or "arousing" process in the CNS that continues into the next waking period but is interrupted by SWS in the following sleep period.

The problems associated with analyzing difference scores are also difficult to resolve, although we feel their use is justified in this study. The data clearly showed a relationship between sleep states and subjective sleepiness that we feel is at least partially attributable to differences between REM and SWS, although ongoing rhythmic fluctuations may interact with this process.

Because these findings were obtained in subjects undergoing a radical alteration of their sleep including partial (approximately 30%) sleep deprivation, it is difficult to generalize their significance. Nonetheless, several studies suggest that a similar relationship, at least with REM sleep, may be found in all-night sleep schedules. Hartmann (1970) has reported that subjects' sense of well-being in the morning was positively related to REM sleep time on the night before. In addition, studies of reduced nocturnal sleep (Johnson & MacLeod, 1973; Webb & Agnew, 1974) suggest that daytime drowsiness and fatigue appear coincident with a relatively selective deprivation of REM sleep. Conversely, Globus (1970) found greater sleepiness following extended nocturnal sleep periods, which presumably contained higher amounts of REM sleep without greatly affecting SWS. However, sleepiness was rarely studied systematically.

The pattern of TST on the 90-min schedule is also of some interest. Weitzman, Nogeire, Perlow, Fukushima, Sassin, McGregor, Gallagher, and Hellman (1974), in a similar study that utilized a 180-min schedule of sleep and wakefulness, also found a circadian pattern of TST. In both studies, however, it appeared that the circadian pattern of TST shifted by several hours from what one would expect. In other words, the peak of TST on both schedules occurred between 0600 and noon instead of during the normal nocturnal period (2300–0700 or midnight–0800). We have no explanation for this apparent shift in the circadian propensity for sleep. It did not, however, seem to be related to whether the experimental schedule was instituted after 16 hrs of wakefulness or after 8 hrs of sleep, since a similar shift was seen in both studies on the 90-min schedule.

The altered schedules of sleep and wakefulness, while giving rise to interpretive difficulties, continue to provide interesting data on the relationships of sleep and sleep stages to a number of factors—performance, hormone secretion, circadian rhythms, REM-NREM cycle determinants, sleep efficiency, and so on (Weitzman et al., 1974; Webb & Agnew, 1975; Moses, Hord, Lubin, Johnson, & Naitoh, 1975; Carskadon & Dement, 1975). In the present study, the data showed an intriguing interplay of sleepiness and sleep state in which SWS appeared to be associated with increased sleepiness and REM sleep with decreased sleepiness.

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