The Circadian Variation of Experimentally Displaced Sleep

*Torbjörn Åkerstedt and †Mats Gillberg

*Laboratory for Clinical Stress Research and †National Defence Research Institute,
Stockholm, Sweden

Summary: In a group of 6 male subjects sleep was displaced to seven different times of day (one displacement condition per week). The subjects were isolated from external time cues (daylight, clocks, noise) and sleep was allowed to terminate spontaneously. The results showed a pronounced time-of-day variation of total sleep time, stage 2, and rapid eye movement (REM) sleep. Maxima occurred after bedtimes at 1900 hr and 2300 hr, while the minima occurred after bedtimes at 0700 hr and 1100 hr. The latter also was the time of maximum propensity to wake up. Slow wave sleep showed a rapid decrease from high initial levels, irrespective of time of day. Ratings of sleepiness showed a highly significant circadian variation peaking between 0500 hr and 0700 hr. The lowest level of sleepiness coincided with the maximum tendency to wake up, and it was suggested that sleep termination may be closely related to the sleepiness/ alertness rhythm. **Key Words:** Circadian rhythm—Sleep—Sleepiness—Self-ratings—Sleep deprivation.

Like most other biological functions, sleep-wake alternation shows a circadian periodicity. This has been established mainly through studies of subjects "free-running" under conditions of isolation from synchronizers (Aschoff and Wever, 1962). Recently, similar studies, exploiting the desynchronization that occurs in some subjects during free-run, have shown that, for example, total sleep time (TST) and rapid eye movement (REM) sleep percent are strongly dependent on the circadian phase of body temperature (Czeisler, 1978; Wever, 1979; Zulley, 1979).

While the free-run studies have clearly established circadian characteristics of sleep, these results have been obtained under highly unusual conditions—e.g., long periods of isolation, non-24-hr periodicity, desynchronization of rhythms, and self-selection of the "optimal" sleep-wake pattern. Thus, it is not clear to what extent the results are applicable to conditions that are more normal, particularly with respect to internal synchronization and adherence to 24 hr periodicity.

Some indication of time-of-day effects may be gained from several studies of regularly spaced, short sleep episodes (naps). Although short and artificially terminated by the imposed schedule, such studies reflect, at least, sleep-onset phenomena. Essentially, the results show a pronounced circadian rhythmicity of sleep length and REM percent, both peaking in the early morning hours (Weitzman et al., 1974; Carskadon and Dement, 1975, 1977; Webb and Agnew, 1975, 1977; Moses et al., 1975, 1978; Lubin et al., 1976; Hume and Mills, 1977).

In contrast to the nap experiments, studies of shift workers usually have allowed more full-length sleep. On the other hand, they have usually been restricted to merely two temporal periods of sleep (e.g., 2300–0700 hr and 0700–1400 hr), which, of course, does not allow any inference about circadian rhythmicity. Still, the shortened TST and early sleep increase of REM found in such studies are in agreement with the notion of a circadian rhythmicity (Ehrenstein, et al., 1970; Bryden and Holdstock, 1973; Foret and Benoit, 1974, 1978; Matsumoto, 1978; Torsvall et al., in press).

Of particular interest is the field study of train drivers by Foret and Lantin (1972), in which sleep episodes were recorded at different times of day as they occurred according to the demands of the irregular work schedule. The longest sleep time was recorded for normal night sleep and the shortest for afternoon-evening sleep, with morning sleep falling in between. This being a naturalistic field study, however, it is not possible separate time-of-day effects per se from the confounding influence of other covarying environmental factors. The short morning and afternoon sleeps may have been artificially restricted by a disturbing environment, since they were recorded in dormitories. Afternoon sleep was further restricted since it really was a pre-work "nap." Also, it is not clear whether the short morning sleep after night work could have been due to this pre-work napping.

The purpose of the present experiment was to study the effects of time of day on sleep, avoiding some of the difficulties indicated above. Thus, the design involved scheduling bedtimes at regular intervals to cover the nychthemeron and ensure full-length sleep with spontaneous termination. The subjects were shielded from environmental disturbances as far as possible.

An additional purpose was to relate possible time-of-day effects to self-rated arousal/sleepiness. The later shows a pronounced circadian rhythmicity (Fröberg et al., 1975; Åkerstedt and Fröberg, 1977), and it seems a reasonable assumption that it may be related to a possible time-of-day variation of sleep. At least, the self-selected bedtimes during free-run seem to cluster around the alertness trough (Czeisler, 1978).

METHODS

The study involved 6 subjects in the age range of 29–45 years, all employees of the university departments and without previous experience of regular night or shift work. Seven bedtimes—one session per week—were used to cover the nychthemeron in equal intervals. The base-line bedtime was scheduled at 2300 hr (A) after 16 hr of wakefulness. For other bedtimes, sleep was postponed by 4 hr

for each: to 0300 hr (B), 0700 hr (C), 1100 hr (D), 1500 hr (E), 1900 hr (F), and 2300 hr (G). The longest postponement thus required 40 hr of continuous wakefulness.

The order of exposure, after the habituation sleep night, alternated between long and short sleep postponement. One group of 3 subjects started with the extreme bedtimes (A and G), the other with the middle bedtimes (D and E). For each bedtime, the subjects reported to the laboratory at 1800 hr after a normal day of sedentary work. After application of electrodes, measurements started at 1900 hr. During wakefulness, activity was controlled according to a 2 hr module system. In each module, 300 ml of water and a standard sandwich were consumed. The activity of the subjects (routine work, reading, physiological measurements, and self-ratings) was regulated by the experimenters, with particular emphasis on making the modules as similar as possible. The subjects spent all the time in the sleep laboratory and were thus isolated from daylight, clocks, radios, and other direct time cues. They did, however, have an approximate idea of the time of day because of the measurement intervals.

At bedtime, particular care was taken to instruct the subjects to get as much sleep as they felt they needed. Since it was very important to make sure that no external stimuli influenced sleep, the subjects were instructed to allow a full 36 hr for each study. They were also informed that they would remain in the laboratory some time after awakening to complete some measurements. Immediately after rising the subjects completed self-ratings and voided urine before being allowed any contact with time cues.

The scoring of sleep stages was based on electroencephalograms (O_2 - P_4, bipolar) and electro-oculograms according to the recommendations of Rechtschaffen and Kales (1968). Sleepiness was rated on a 13-point bipolar scale varying between "very, very sleepy" (13) and "very, very alert" (0). To analyze the overall differences across conditions and across modules within each condition, a one-factor analysis of variance for repeated measures was applied (Winer, 1971). Also, the nonparametric "analysis of variance" according to Friedman (Siegel, 1956) was applied. Where appropriate, two-tailed paired t-tests and the corresponding nonparametric Wilcoxon test were used.

RESULTS

The results are summarized in Figs. 1–3 and in Table 1. TST (Fig. 1a) showed a highly significant variation across conditions. The longest sleep (8–10 hr) occurred after evening bedtimes and the shortest (4–5 hr), after morning/noon bedtimes. To illustrate the sleep termination pattern, we computed the proportion of subjects who, having slept 4 hr, woke up within the subsequent 2 hr (4 hr was chosen since this was the shortest sleep period obtained). The resulting curve (Fig. 3a) depicts the probability of continued sleep (or awakening) at different times of day, given 4 hr of preceding sleep. The highest probability of awakening occurred around noon and the lowest between midnight and early morning.

The total amounts of stage 2 and REM sleep showed a significant variation across conditions (Fig 1b and c). Both followed the TST-pattern. Slow wave sleep (SWS), stage 1 (Fig. 1d, e), and wake showed no significant variation over time.
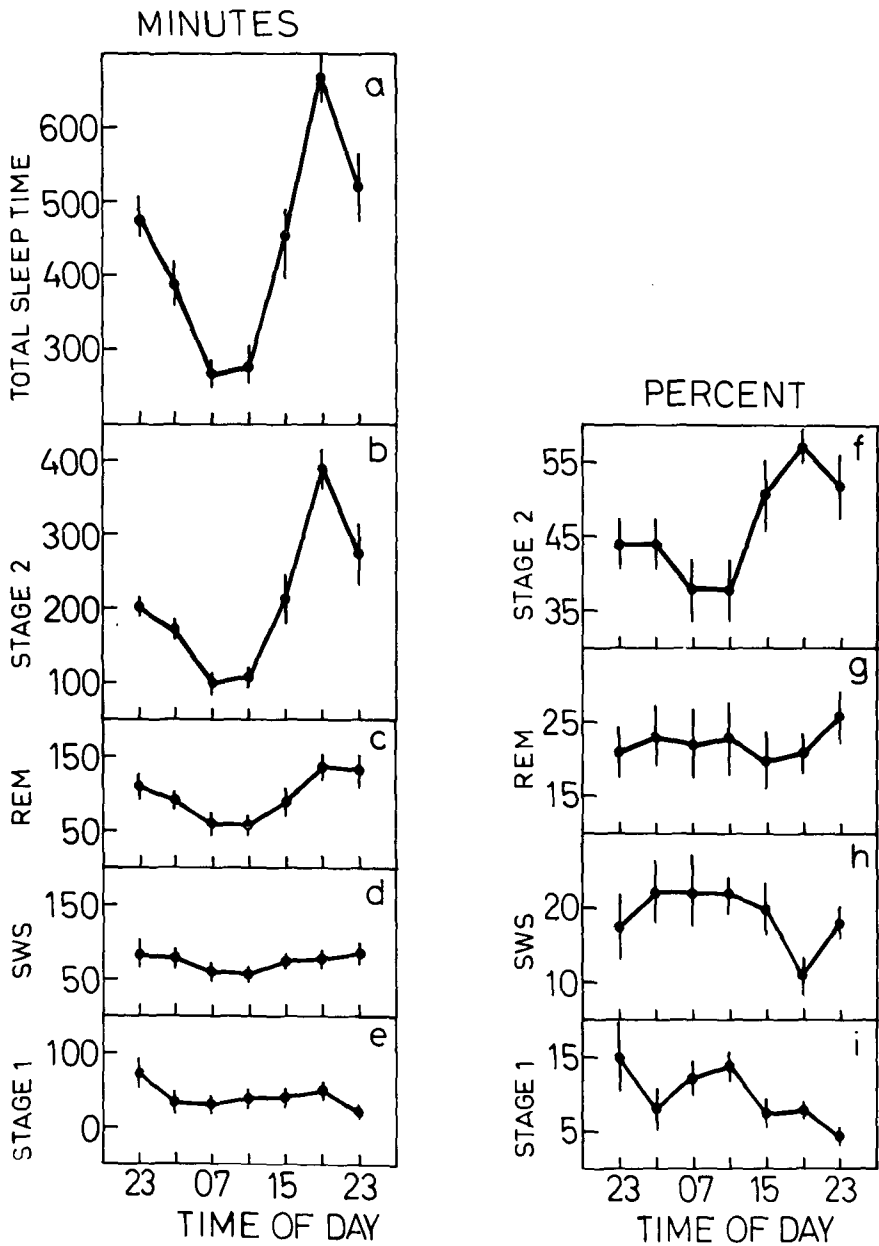
FIG. 1. Total sleep time and the amounts of different sleep stages for each sleep condition. Mean ± 1 SE is expressed in minutes and, for sleep stages, also as a percentage of total sleep time.
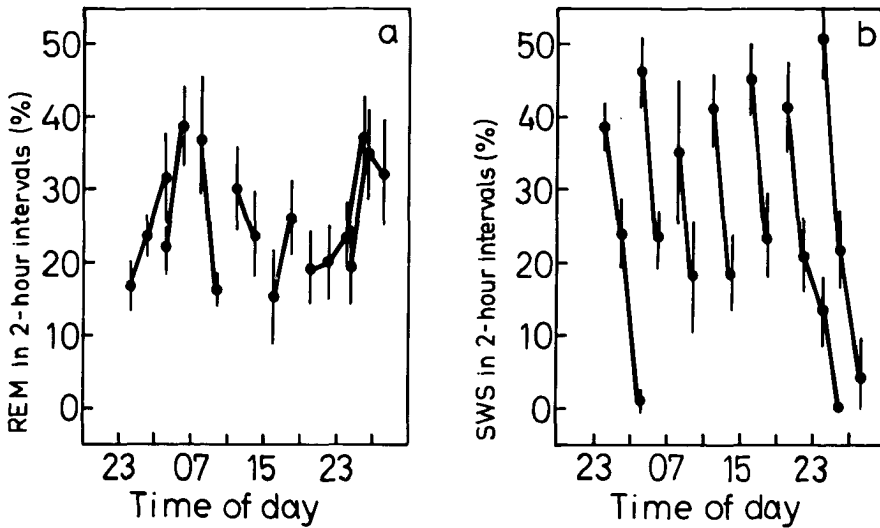
FIG. 2. REM (a) and SWS (b) percents in 2 hr intervals of sleep for each sleep condition. Only intervals which were completed by all subjects are presented (means ± 1 SE).

Recomputed as percentage of TST, only stage 2 (Fig. 1f) showed a significant variation, with an afternoon trough. The number of stage shifts per hour varied significantly, with a minimum at 1100 hr. No significant variation was found for sleep or REM latencies.

Figure 2a and b shows the amounts of SWS and REM for each completed 2 hr sleep interval. On the whole, REM showed a tendency to increase for all bedtimes except those at 0700 and 1100 hr. None of the differences between the first and second 2 hr intervals were significant, however. Of those sleep episodes which contained three complete 2 hr intervals, the increase was significant for the last two bedtimes ($t_F = 3.16, p < 0.05; t_G = 4.22, p < 0.01$)[1]. The SWS pattern involved a steep decline for all bedtime conditions. The difference between the first two intervals, however, was significant only for the second and last conditions ($t_B = 2.67, p < 0.05; t_G = 4.83, p < 0.01$)[1]. The difference between the first and the third interval was significant for all three that were completed ($t_A = 10.47, p < 0.001; t_F = 5.94, p < 0.01; t_G = 5.94, p < 0.01$)[1]. The REM and SWS content of the first 2 hr interval did not vary significantly across bedtime conditions (Table 1).

Sleepiness at bedtime and at rising varied significantly across conditions. Both showed a minimum at 1500 hr and a maximum between 0300 and 0700 hr. With respect to the 2 hr sleepiness ratings, between the start of each session and the bedtime, a significant variation over time was obtained for all bedtimes except the first (A). For all sessions except the first two (A and B), in which the early bedtime prevented the estimation, maximum sleepiness occurred between 0300 and 0700 hr. Minimal sleepiness occurred between 1100 and 1500 hr, although only the last condition (G) had a period of wakefulness long enough to provide an estimate.

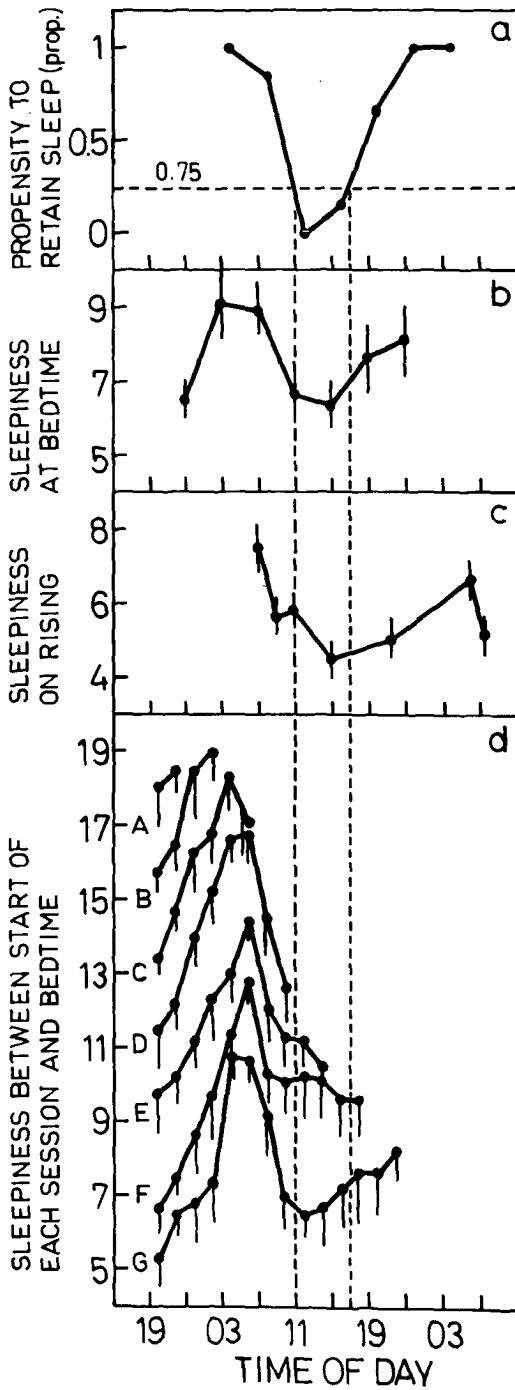[1] Wilcoxon *t* values = 0, i.e., $p < 0.05$.

FIG. 3. a: Propensity to remain asleep, expressed as the proportion of subjects who continued to sleep during a 2 hr interval (preceded by 4 hr of sleep)—see text. **b,c:** Sleepiness ratings at bedtime and after rising for each condition (mean ± 1 SE). **d:** Sleepiness in 2 hr intervals between the start of each session and bedtime (mean − 1 SE). The scale is correct only for the longest postponement of sleep (G). The other conditions are displaced in steps of two scale units. The letters to the left of each curve designate the position of point 5 on the scale.

TABLE 1. *Summary of conventional analysis of variance and Friedman's corresponding, nonparametric version*

Test	F	df	χr^2	df
Across conditions				
TST (min)	9.87[c]	(6/30)	24.6[c]	(6)
REM (min)	6.63[c]	(6/30)	19.8[b]	(6)
REM (%)	0.94	(6/30)	2.5	(6)
SWS (min)	1.16	(6/30)	8.4	(6)
SWS (%)	1.60	(6/30)	10.2	(6)
Stage 2 (min)	9.87[c]	(6/30)	28.9[c]	(6)
Stage 2 (%)	5.43[c]	(6/30)	23.4[c]	(6)
Stage 1 (min)	2.15	(6/30)	11.8	(6)
Stage 1 (%)	2.04	(6/30)	7.9	(6)
Wake (min)	1.02	(6/30)	3.5	(6)
Wake (%)	1.36	(6/30)	4.5	(6)
1st 2 hr REM (%)	1.78	(6/30)	9.7	(6)
1st 2 hr SWS (%)	1.03	(6/30)	10.2	(6)
Stage 1 latency	1.49	(6/30)	1.5	(6)
REM latency	1.71	(6/30)	7.1	(6)
Stage shifts/hr	3.28[a]	(6/30)	17.6[b]	(6)
Sleepiness at bedtime	4.03[b]	(6/30)	14.1[a]	(6)
Sleepiness at rising	4.48[b]	(6/30)	13.6[a]	(6)
Within conditions				
Sleepiness A	0.36	(1/5)	0.7	(1)
Sleepiness B	9.90[b]	(3/15)	11.7[b]	(3)
Sleepiness C	8.72[c]	(5/25)	19.2[c]	(5)
Sleepiness D	9.92[c]	(7/35)	31.1[c]	(7)
Sleepiness E	4.39[c]	(9/45)	26.4[b]	(9)
Sleepiness F	6.27[c]	(11/55)	31.5[c]	(11)
Sleepiness G	5.38[c]	(13/65)	38.9[c]	(13)
Overall sleepiness	6.64[c]	(13/65)	39.7[c]	(13)

[a] $p < 0.05$; [b] $p < 0.01$; [c] $p < 0.001$.

Degrees of freedom (*df*), *F*-ratio (*F*), Friedman's χr^2, and associated levels of significance.

Abbreviations: TST, total sleep time; REM, rapid eye movement sleep; SWS, slow wave sleep.

To form an overall mean curve of sleepiness, individual mean curves were first constructed by averaging the data from the different bedtimes (in 2 hr intervals) for each individual. These individual mean curves were then averaged to form the overall mean curve. The statistical analysis of this curve showed a highly significant variation (Table 1). This is depicted in Fig. 4, which is divided into panels corresponding to the mean time asleep for each bedtime, except for F and G, which were not covered by the 2 hr ratings. The long A-sleep corresponded to the segment of the overall mean curve that showed a significant ($F = 28.00, p < 0.001; \chi r^2 = 21.9, p < 0.001$) pattern of steady increase from low to high (peak) sleepiness. The B-sleep gave a significant ($F = 7.34, p < 0.01; \chi r^2 = 11.8, p$
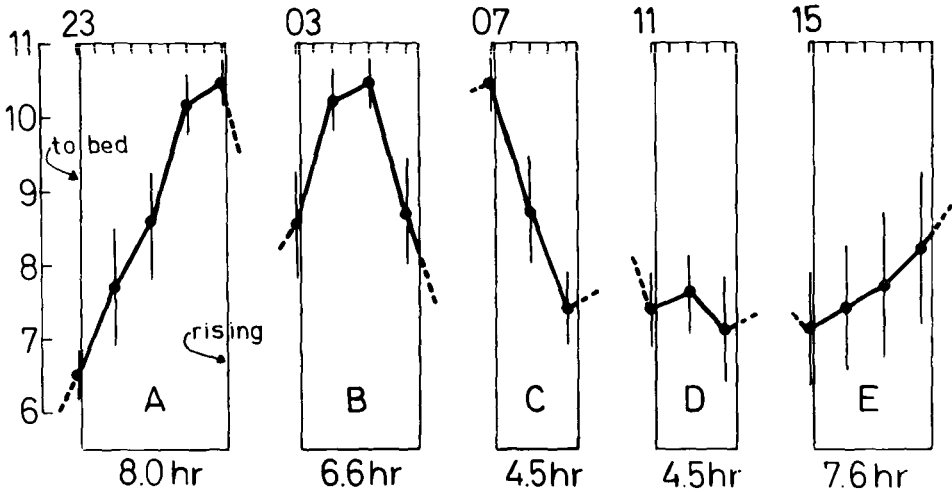
FIG. 4. Mean (± 1 SE) curve of sleepiness ratings, divided into segments corresponding to the mean time spent asleep during conditions A−E (ratings did not extend to F and G).

< 0.01) inverted U-pattern of increase-decrease; the C-sleep a significant ($F = 13.95, p < 0.01, \chi r^2 = 10.3, p < 0.01$) steady decrease; and the D- and E-sleeps, low levels of sleepiness without change ($F = 0.41, p > 0.05; \chi r^2 = 0.7, p > 0.05;$ and $F = 0.37, p < 0.05, \chi r^2 = 1.3, p > 0.05$ respectively).

Values from A and G, with 24 hr of wakefulness intervening, differed significantly only for stage 1 percent, which was reduced after the extended period of waking ($t = 2.61, p < 0.05$)[1]. Within G, sleepiness at 1900−2100 hr was rated significantly higher after 38 hr of wakefulness than after 14 hr ($t = 3.62, p < 0.05$)[1].

DISCUSSION

The length of sleep clearly varied with the time of day; maximum length occurred after evening bedtimes and the minimum after morning/noon bedtimes. This finding, in synchronized subjects with preselected bedtimes, apparently reflects the circadian rhythm of sleep length found in the studies of the *ad libitum* sleep of desynchronized subjects during long spans of isolation (Czeisler, 1978; Wever, 1979; Zulley, 1979).

It is notable that as time awake increases with the postponement of sleep from 2300 towards 1100 hr, sleep length actually *decreases*. This suggests something of a barrier to sleep around noon. This barrier emerges more clearly in the computation of the propensity to awaken, which reaches a peak around noon. A similar clustering of awakenings was observed in the field study of Foret and Lantin (1972), as well as in the isolation/free-run studies of Czeisler (1978) and Zulley (1979). It appears, then, that the circadian rhythm of sleep may account for most of the shortened day-sleep of shift workers; a disturbing sleep environment does not seem to be a ''necessary'' component.

There seem to be exceptions, however, from the time-of-day effects on sleep. Several laboratory studies have shown the length of day-sleep to be close to that of night sleep (Weitzman et al., 1970; Berger et al., 1971; Webb et al., 1971;

Knauth and Rutenfranz, 1972; Webb and Agnew, 1978). Part of the reason for the discrepancy could be age differences; the ability to sleep during the day deteriorates with age (Åkerstedt and Torsvall, 1981), and the laboratory studies cited were carried out with young subjects (18−25 years old). In the present experiment and in the shift work studies, most subjects have been well beyond this age range.

Another reason may be what kind of expectations about rising the subject perceives upon awakening. None of the laboratory phase shift studies mention any explicit instructions about rising, but since time in bed was restricted, the subjects may have felt obliged to remain in bed the whole period allotted, irrespective of the "need" for it. This may have induced "oversleeping." In the present study the subjects were instructed to sleep as long as they needed and always to try to go back to sleep for a while before finally rising. Still, the dark room probably discouraged the subjects from remaining in bed without sleeping. Importantly, the significantly lower sleepiness ratings after the short daytime sleeps indicate that the subjects, despite the short sleep, rose because they felt genuinely alert and ready to rise. Incidentally, the subjects consistently overestimated the length of day sleep D and E (D = 130 min, t_D = 6.45, p < 0.001; E = 65 min, t_E = 4.60, p < 0.01)[1], while the estimate of the other sleep lengths did not differ from the EEG data.

Interestingly, rated sleepiness actually *decreased* across the first four sleep sessions, despite decreasing sleep length and increasing pre-sleep wake time. This morning decrease of sleepiness was part of the significant time-of-day variation across awakenings. A parallel variation, also significant, was found for sleepiness ratings across bedtimes and for the 2 hr ratings within each condition (from the start of each session to bedtime). This time-of-day variation of sleepiness apparently reflects a circadian rhythm of psychological arousal (Fröberg et al., 1975; Åkerstedt and Fröberg, 1977).

Is it possible then to attribute sleep-wake behavior to a sleepiness (or psychological arousal) rhythm? Clearly, the initiation of sleep is easier at the sleepiness peak (Carskadon and Dement, 1977); and during free-run, bedtimes tend to cluster at that point (Czeisler, 1978). Does this relation also extend to sleep termination: that is, does awakening occur because some critical level of psychological arousal has been reached? This could be the interpretation of the covariation in the present study between sleepiness and the propensity to wake up. The longest sleeps were the ones started with rather low sleepiness, i.e., at or shortly after the sleepiness trough (1900 hr), with most of the rising slope of sleepiness remaining to be covered. Conversely, the shortest sleeps were the ones started either at a high level of sleepiness prior to a steep decrease or at the beginning of the rather flat and wide sleepiness trough. On the whole, the results show that sleep becomes progressively shorter as the bedtime approaches the trough. Obviously, however, it is not solely the absolute amount of sleepiness that is critical, since awakenings occur at all levels of sleepiness. Rather, there seems to be a combined effect of sleepiness levels and the need for sleep due to sleep loss.

The sleepiness rhythm should not be seen as isolated from the physiology, but rather as reflecting an underlying biological rhythmicity that has yet to be iden-

tified conclusively, although Czeisler (1978) and Zulley (1979) have shown a close connection between sleep and temperature rhythm. Moreover, such a relation was also found in the present series of studies (Gillberg and Åkerstedt, unpublished).

In contrast to REM, SWS was not related to length of sleep or time of day. For all conditions, SWS always fell steeply from high initial levels and appeared to be "finished" before it could be affected by an early termination of sleep.

Comparison of the results from the two 2300 hr bedtimes, with 24 hr of wakefulness in between, showed almost no sleep loss effects. Usually, recovery sleep after sleep loss is characterized by increased TST and SWS (Johnson, 1974). The reason for the lack of effects in the present study is unclear, but the sleep loss difference fell in an intermediate range (16−40 hr). Webb and Agnew (1971a,b) have shown that while there is a linear increase of SWS within the interval of 0−16 hr of sleep loss, the curve rapidly levels off beyond 16 hr of waking; that is, the effect of each additional hour of sleep loss diminishes rapidly. Thus, it does not seem unlikely that had a lower "base level" of sleep loss been included in the present study (e.g., 12 hr compared to 36) the expected effects would have been obtained. For example, the sleep after the 1900 hr bedtime (36 hr of sleep loss) was the longest.

In conclusion, sleep length and the characteristics of sleep vary as a function of the time of day and closely covary with a similar variation of subjective sleepiness.

ACKNOWLEDGMENTS

REFERENCES

Åkerstedt T and Fröberg JE. Psychophysiological circadian rhythms in women during 72 h of sleep deprivation. *Waking Sleeping* 1:387−394, 1977.

Åkerstedt T and Torsvall L. Age, sleep, and adjustment to shift work. In: W Koella (Ed), *Sleep 1980*, Karger, Basel, 1981.

Aschoff J and Wever R. Spontanperiodik des Menschen bei Ausschluss aller Zeitgeber. *Naturwissenschaften* 49:337−342, 1962.

Berger RJ, Walker JW, Scott TD, Magnusson LJ, and Pollack SL. Diurnal and nocturnal sleep stage patterns following sleep deprivation. *Psychon Sci* 23:273−275, 1971.

Bryden G and Holdstock TL. Effects of night duty on sleep patterns of nurses. *Psychophysiology* 10:36−42, 1973.

Carskadon MA and Dement WC. Sleep studies on a 90-minute day. *Electroencephalogr Clin Neurophysiol* 39:145−155, 1975.

Carskadon MA and Dement WC. Sleepiness and sleep state on a 90-min schedule. *Psychophysiology* 14:127−133, 1977.

Czeisler CA. *Human circadian physiology* Ph.D. Thesis, Stanford University, Palo Alto, 1978.

Ehrenstein W, Müller-Limmroth W, Schaffler K, and Thébaud C. Polygraphische Schlafuntersuchungen des Tagschlafs nach einer Nachtschicht und des Nachtschlafs nach einer Tagschicht an 8 Krankenschwestern. *Pfluegers Arch* 319:121, 1970.

Foret J and Benoit O. Structure du sommeil chez des travailleurs à horaires alternants. *Electroencephalogr Clin Neurophysiol* 37:337−344, 1974.

Foret J and Benoit O. Etude du sommeil chez des travailleurs à horaires alternants: Adaptation et récupération dans le cas de rotation rapide de poste (3−4 jours). *Eur J Appl Physiol* 38:71−82, 1978.

Foret J and Lantin G. The sleep of train drivers: An example of the effects of irregular work schedules on sleep. In: WP Colquhoun (Ed), *Aspects of Human Efficiency*, English Universities Press, London, 1972.

Fröberg JE, Karlsson C-G, Levi L, and Lidberg L. Circadian rhythms of catecholamine excretion, shooting range performance and self-ratings of fatigue during sleep deprivation. *Biol Psychol* 2:175–188, 1975.

Gillberg M and Åkerstedt T. Body temperature and sleep at different times of day. (Unpublished)

Hume KI and Mills JN. Rhythms of REM and slow-wave sleep in subjects living on abnormal time schedules. *Waking Sleeping* 1:291–296, 1977.

Johnson LC. The effect of total, partial, and stage sleep deprivation on EEG-patterns and performance. In: N Burch and HL Altschuler (Eds), *Behavior and Brain Electrical Activity*, Plenum Press, New York, 1974.

Knauth P and Rutenfranz J. Untersuchungen zum Problem des Schlafverhaltens bei experimenteller Schichtarbeit. *Int Arch Arbeitsmed* 30:1–22, 1972.

Lubin A, Hord DJ, Tracy ML, and Johnson LC. Effects of exercise, bedrest, and napping on performance decrement during 40 hours. *Psychophysiology* 13:334–339, 1976.

Matsumoto K. Sleep patterns in hospital nurses due to shift work: An EEG study. *Waking Sleeping* 2:169–173, 1978.

Moses JM, Hord DJ, Lubin A, Johnson LC, and Naitoh P. Dynamics of nap sleep during a 40-hour period. *Electroencephalogr Clin Neurophysiol* 39:627–633, 1975.

Moses J, Lubin A, Naitoh P, and Johnson LC. Circadian variations in performance, subjective sleepiness, sleep, and oral temperature during an altered sleep/wake schedule. *Biol Psychol* 6:301–308, 1978.

Rechtschaffen A and Kales A. *A Manual of Standardized Terminology, Techniques and Scoring System for Sleep Stages of Human Subjects.* Brain Information Service/Brain Research Institute, University of California at Los Angeles, 1968.

Siegel S. *Nonparametric Statistics.* McGraw-Hill, London, 1956.

Torsvall L, Åkerstedt T, and Gillberg M. Age, sleep and irregular work hours. A field study with electroencephalographical recordings, catecholamine excretions, and self ratings. *Scan J Work Environ Health* (in press).

Webb WB and Agnew HW Jr. Variables associated with split-period sleep regimes. *Aerospace Med* 42:847–850, 1971a.

Webb WB and Agnew HW Jr. Stage 4 sleep: Influence of time course variables. *Science* 174:1354–1356, 1971b.

Webb WB and Agnew HW Jr. Sleep efficiency for sleep-wake cycles of varied length. *Psychophysiology* 12:637–641, 1975.

Webb WB and Agnew HW Jr. Analysis of the sleep stages in sleep-wakefulness regimes of varied length. *Psychophysiology* 14:445–450, 1977.

Webb WB and Agnew HW Jr. Effects of rapidly rotating shifts on sleep patterns and sleep structure. *Aviat Space Environ Med* 49:384–389, 1978.

Webb WB, Agnew HW Jr, and Williams RL. Effects on sleep of a sleep period displacement. *Aerospace Med* 42:847–850, 1971.

Weitzman ED, Kripke DF, Goldmacher D, McGregor P, and Nogeire C. Acute reversal of the sleep-waking cycle in man. *Arch Neurol* 22:483–489, 1970.

Weitzman ED, Nogeire C, Perlow M, Fukushima D, Sassin J, McGregor A, Gallagher TF, and Hellman L. Effects of a prolonged 3-hour sleep-wake cycle on sleep stages, plasma cortisol, growth hormone, and body temperature in man. *J Clin Endocrinol Metab* 34:1018–1030, 1974.

Wever RA. *The Circadian System of Man.* Springer, New York, 1979.

Winer BJ. *Statistical Principles in Experimental Design.* McGraw-Hill, New York, 1971.

Zulley J. *Der Einfluss von Zeitgebern auf den Schlaf des Menschen.* Rita G. Fischer Verlag, Frankfurt am Main, 1979.