

## Napping as a Biological Rhythm: Disentrainment of the Human Sleep/Wake System\*

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### Introduction

There has long been suggestive evidence to support the hypothesis that napping is the behavioral expression of one component of the biological timing system governing human sleep. Support for the hypothesis has come primarily from questionnaire and sleep-diary studies, which show napping to be quite common among populations whose life styles are flexible enough to permit such sleep episodes. The existence of siesta cultures and the well-established post-lunch dip in numerous performance measures have often been cited, as well, as evidence of a biological tendency for sleep to occur about halfway through the daily major waking interval (1–6).

Despite such observations, the usual view of human sleep and wakefulness is that of a monophasic system: we sleep for 7 to 8 hours at night and maintain wakefulness for around 16 hours during the day. The extent to which this view has shaped the experimental study of sleep is emphasized by the fact that we typically monitor subjects in the sleep laboratory only from about 2300h to 0700h. Even when subjects have been studied for extended periods, in environments without time cues, they have been requested to lead a «regular» life. That is, they have been requested to carry on their daily activities, and to eat three meals a day in normal sequence. And, most importantly, they have been specifically requested not to nap.

It is, perhaps, because «regular» life is so commonly characterized by monophasic sleep placement that napping is generally not permitted under such conditions. For whatever reason, few laboratory studies have examined the occurrence of spontaneous sleep within the twenty-four hour day. Yet, in the few studies in which no restrictions have been placed on sleep, the results consistently support the notion that monophasic sleep placement is probably not an accurate reflection of the biological timing system mediating human sleep and wakefulness. It has been shown, for example, that simply by removing instructions relative to when and when not to sleep, in an otherwise normal time-free environment, the frequency with which some subjects initiate sleep episodes increases dramatically (7, 8).

Even under these conditions, however, it can be argued that the behavioral controls which may interfere with the true expression of biological sleep tendency are not entirely removed. While external controls on sleep (i.e., experimenters' instructions) are eliminated, the potential for self-imposed alternatives to sleep remains a feature of the environment. Thus, subjects may respond to periods of drowsiness not by sleeping, but rather, by overcoming such episodes by transiently increasing activity, or, for example, by drinking a cup of coffee.

In order to obtain a completely unobstructed view of endogenous sleep organization, it is, therefore, important to provide conditions under which the sleep system is permitted to follow a course of least resistance. Such an environment would not only eliminate experimental instructions regarding when and when not to sleep, but would also remove from the environment the possibility for behavioral options which may be incompatible with the sleep process.

The purpose of this paper is to describe the results of an experimental approach which sought to invoke such conditions. It was reasoned that, in response to the lack of behavioral options in such an environment, subjects would be more likely to respond to periods of drowsiness not by attempting to overcome such a state, but rather by expressing sleep propensity in the unambiguous form of napping. In turn, it was assumed that the view of sleep/wake organization which emerged from this experimental setting would provide a more accurate reflection of the biological mechanisms underlying the human sleep/wake system, unaffected by the putative masking influences normally imposed on the system by self-imposed behavioral controls, or by social and occupational demands.

## Method

**The Disentrained Environment.** The term «disentrainment» was selected to distinguish the current conditions from those typically used in human circadian research (9, 10), in which time cues are eliminated, but otherwise, subjects are encouraged to continue their daily activities, are requested to «structure» their days by eating three designated meals, and are specifically requested not to nap.

In the disentrained environment, subjects were specifically requested **not** to structure their days, but instead to eat and sleep when inclined to do so. Moreover, virtually all behavioral alternatives to sleep were eliminated. Subjects were prohibited from reading, writing, listening to music, strenuous exercise, and so on. They could move freely about the isolation unit, but essentially had nothing to do. Illumination in the isolation unit (overhead fluorescent lighting and table lamps) was at the discretion of each subject.

**Subjects and Procedure.** Nine healthy subjects (19–37 years; mean = 25.1) were individually studied during 72 continuous hours in the disentrained environment. Subjects were selected who reported satisfactory sleep and good general health and who did not report habitual napping. Each was informed of the general aim of the study.

The disentrainment period began at 0800h immediately following one night of adaptation sleep. During the entire period, the EEG, EMG and EOG of each subject was telemetrically recorded and output to paper for subsequent scoring by standard procedures. In addition, body core temperature was continuously recorded, using standard indwelling rectal thermistors.

## Results

**Definitions.** A difficulty in the analyses of data obtained from environments in which sleep and wakeup time is subject-selected is the determination of what constitutes a sleep episode and what constitutes two sleep episodes. That is, how long must sleep continue to be considered a «sleep episode», and how much wakefulness must intervene for successive sleep episodes to be considered as such?

In the current condition, over 99% of all sleep recorded in disentrainment occurred as episodes lasting at least 30 minutes. On nine occasions (13.6% of total), sleep periods continued for shorter intervals (mean duration, 10.2 min.). In the following analyses, therefore, only those continuing for at least 30 minutes are considered as sleep episodes.

For two reasons, it was decided to consider two successive sleep episodes as such if they were separated by at least 60 minutes of uninterrupted wakefulness. First, almost 85% of all waking episodes continued for at least an hour; second, examination of sleep periods, particularly major nocturnal episodes, made it evident that waking periods of less than 60 minutes sometimes occurred within otherwise coherent sleep periods.

**Overall Sleep Patterns.** Fig. 1. shows the alternation of sleep and wakefulness for all subjects,

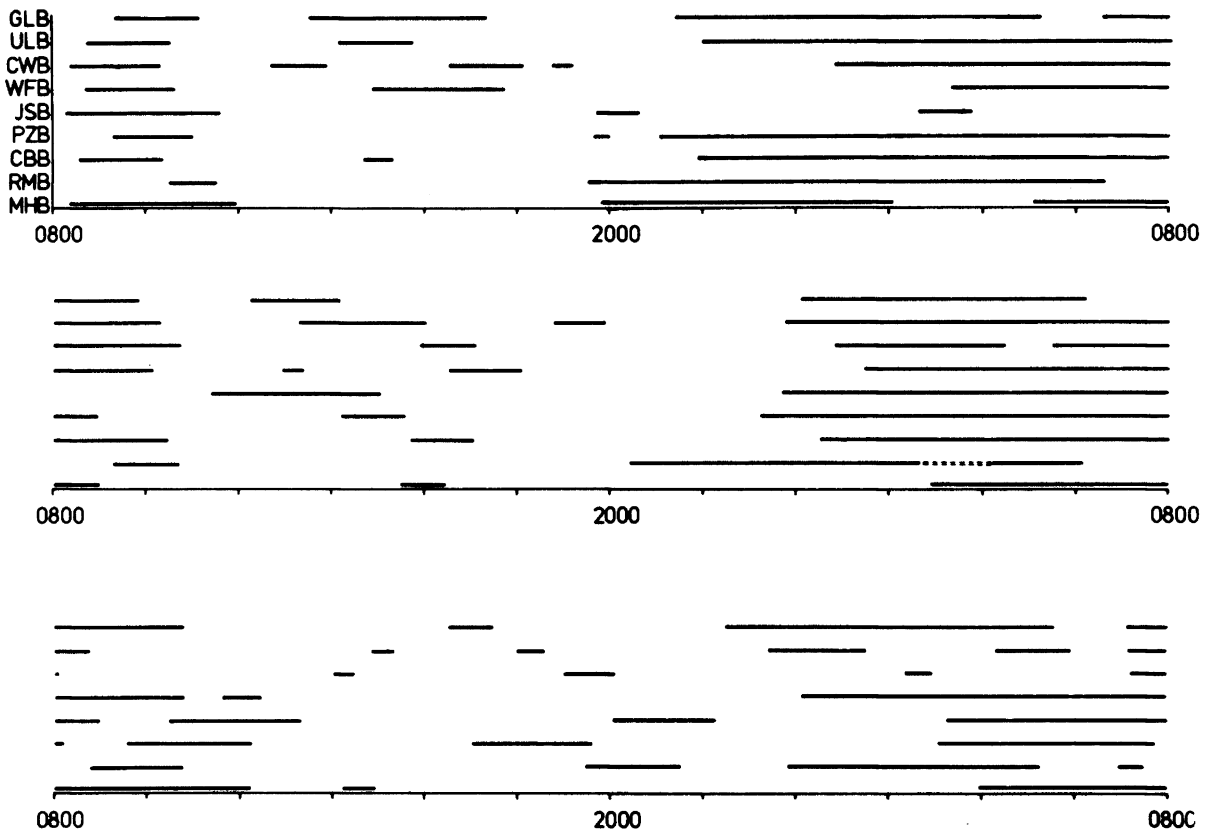


Fig. 1: Alternation of sleep (dark bars) and wakefulness for nine subjects during 72 hours of disentrainment. The EEG of one subject (GLB) was monitored for only the first 48 hours. The broken line in the fourth sleep episode of subject EMB indicates a loss of signal during that interval.

after applying the criteria for sleep and waking episodes described above. It can be seen that subjects spent a substantial amount of time asleep, and that sleep episodes were distributed across the twenty-four hour day. On average, 43.1% of the 72-hour period was comprised of sleep (10.3 hrs. per 24 hours). A total of 57 sleep episodes were spontaneously initiated and terminated during the disentrained period, with a median duration of 2.4 hours (mean = 4.1 h; SD = 3.7; range .52 to 12.8 hours). Sixty-eight percent of all sleep episodes lasted for less than 4 hours.

**Temporal Characteristics.** While sleep episodes occurred at virtually all times of day, there were clearly preferred phase positions for the initiation of sleep, as illustrated in Fig. 2. There was a bimodal distribution in sleep onset times, with peak occurrences around 2400h and again around 1400h.

Not only placement, but also the duration of individual sleep episodes was strongly dependent upon circadian factors, as shown in Fig. 3. Only 3 sleep episodes initiated between 0800h and 2000h continued for longer than 3 hours. The mean duration of these sleep episodes was 1.7 hours (SD = 0.9h). In contrast, sleep episodes initiated between 2000h and 0800h continued for an average duration of 6.4 hours (SD = 3.5h). This difference was significant (U-test,  $p < .0001$ , two-tailed).

On the basis of their differential durations and times of occurrence, two general types of sleep episodes could be distinguished. There were eighteen sleep episodes with onsets after 2000h with durations similar to typical nocturnal sleep. These sleep episodes were designated as Major Sleep Episodes (MSEs). Naps were operationally defined as any sleep episode occurring between two successive MSEs. Twenty-three sleep episodes could be so designated based on this criterion. Because some sleep episodes resembled neither MSEs nor met the operational definition of naps, they were excluded from the following analyses.

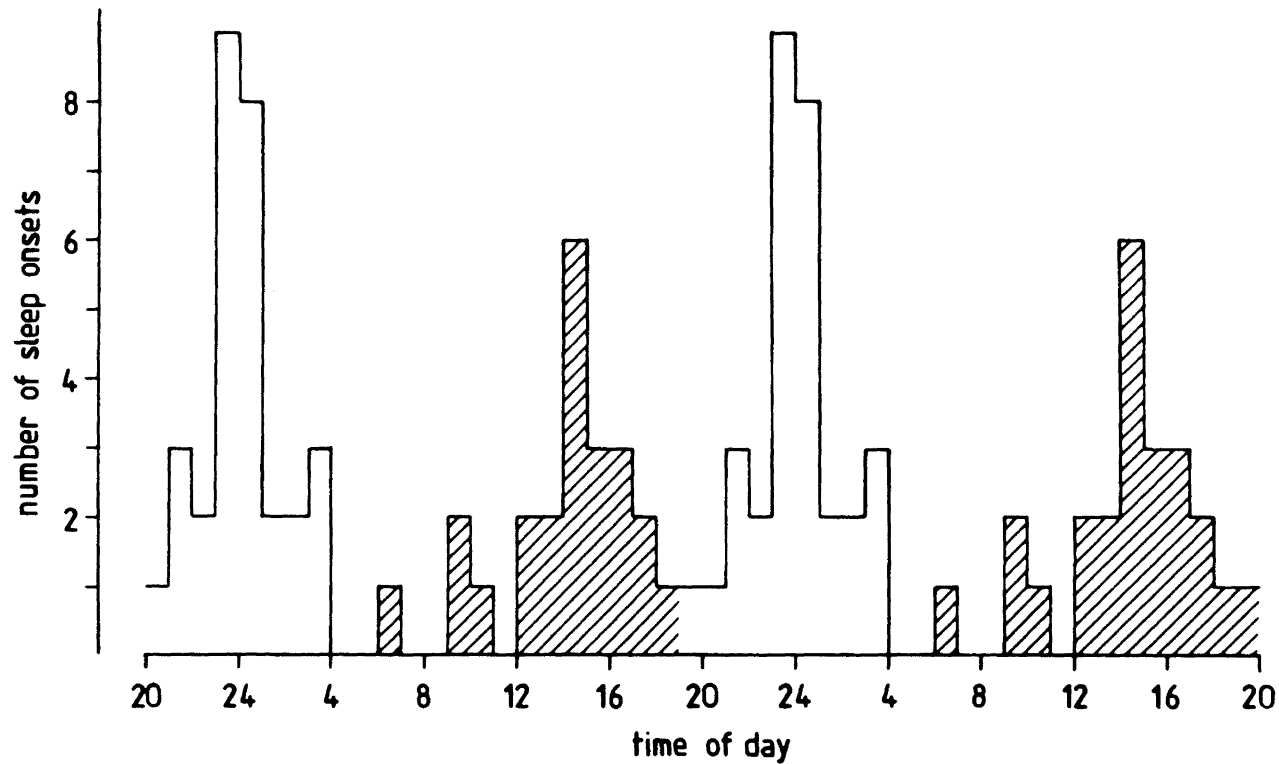


Fig. 2: Distribution of sleep onsets (double plotted) recorded from all subjects during disentrainment. Hatched area shows sleep episodes designated as «naps» on the basis of their placement relative to successive major sleep episodes (MSEs) (see text).

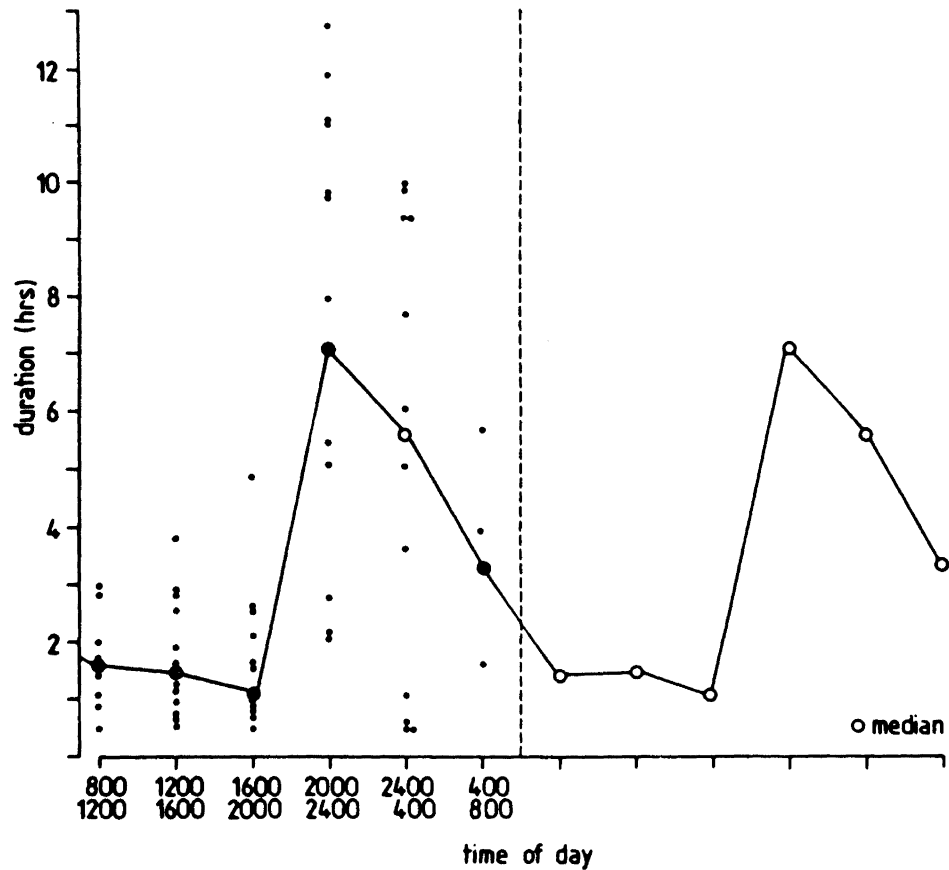


Fig. 3: Distribution of sleep episodes across the twenty-four hour day (in 4-hour time blocks, double plotted), as a function of sleep episode duration. Each black dot represents a sleep episode, the line connects median durations. Baseline nights are included in the distribution.

**Relationships between naps and MSEs.** The average sleep/wake cycle length for all MSEs and naps (i.e., from the onset of each MSE to the onset of a subsequent nap, and from the onset of each nap to the onset of the subsequent MSE) was 12.3 hours (SD = 3.8h; median, 12.3h). However, examination of Fig. 2 makes it clear that there was a difference in the cycle lengths measured from MSEs to naps (designated by the hatched area) and those measured from naps to MSEs. In other words, naps did not occur halfway between successive onsets of MSEs, as might be expected. Rather, the initiation of naps tended to occur about 60% through the MSE-to-MSE (circadian) sleep/wake cycle. Specifically, the average MSE-to-nap cycle measured 14.6 hours (SD = 2.8h), while the mean nap-to-MSE cycle was significantly shorter at 9.9 hours (SD = 3.3h) ( $p < .0001$ , two-tailed).

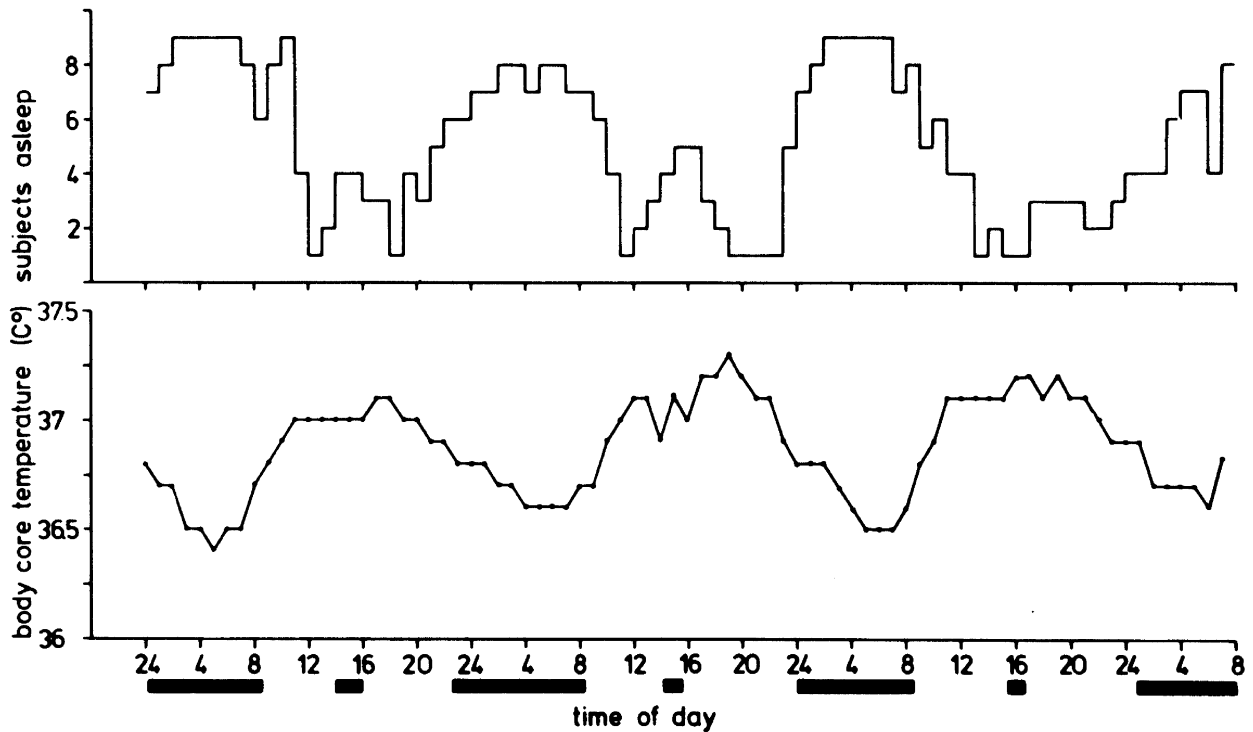


Fig. 4: Relationship between sleep episodes recorded during disentrainment and the circadian rhythm of body core temperature. Above the average group temperature curve is a summation histogram of the number of subjects asleep during each hour of the disentrainment period. Shown below the temperature curve (black bars) are average onsets and durations of MSEs and naps for the group.

**Relationships to temperature.** In typical time-free conditions, sleep episodes maintain a characteristic phase-relationship with the circadian course of body core temperature. This was also the case in the disentrained environment, as illustrated in Fig. 4. Shown is the average temperature curve for all nine subjects, across the 72-hour disentrainment period. Above the temperature curve is a summation histogram showing the number of subjects asleep during all or part of each hour of the experimental period. The dark bars below the temperature curve show the average onsets and durations of MSEs and naps recorded during the period.

As is well established, the occurrence of MSEs was associated with the descending slope of the temperature curve. Clearly, the strongest group tendency for sleep corresponded to this phase of temperature. In addition, there was a relatively robust tendency for the occurrence of naps to be centered around the maximum of body core temperature. This is reflected most clearly on Day 2 of disentrainment, when enough subjects slept to result in a transient dip in the average temperature curve.

**Structural features of MSEs and naps.** Overall structural parameters of MSEs and naps are presented in Tab. 1. With the exception of REM sleep, mean sleep stage percentages did not

differ significantly between the two groups. However, the variability around mean percentages associated with naps was generally about twice that of corresponding values for MSEs. Such variability is particularly evident with regard to slow wave sleep (SWS) measures, in which the difference between mean and median values was striking (15.3% vs. 4.9%).

The degree to which SWS occurred in naps was dependent, in large part, upon their times of occurrence within the circadian day. This is shown at the bottom of Tab. 1, where naps are divided into two general categories based on their times of onset. Naps which occurred toward the middle of the nap distribution (1400h–1700h) tended to have considerably more Stage 4 sleep than those on the borders of the distribution. However, the variability between sleep episodes remained large, and therefore, the difference between the groups was not statistically significant.

Tab. 1: Sleep stage parameters of major sleep episodes (MSEs) and naps recorded during the 72 hours of disenitainment. Mean and median values are given, standard deviations are in parentheses.

		Sleep Stage Percents					R
		0	1	2	3	4	
MSEs (N=18)	mean	5.5	4.6	55.1	7.6	7.3	19.8
	(SD)	(3.4)	(2.2)	(6.3)	(3.9)	(3.6)	(7.1)
	Median	5.5	4.4	53.9	7.2	6.9	20.5
Naps (N=23)							**
		5.6	6.6	58.5	7.5	7.8	13.7
		(6.7)	(6.5)	(12.2)	(8.4)	(11.3)	(10.3)
Naps (1400–1700)		2.9	5.5	58.0	4.3	0.6	15.4
		5.1	8.2	53.8	9.5	9.9	12.7
		(7.8)	(7.9)	(10.9)	(10.6)	(11.6)	(12.7)
Naps (All Others)		2.3	4.8	53.3	4.7	5.5	12.9
		5.8	4.9	61.9	5.3	5.5	15.6
		(5.1)	(4.1)	(11.2)	(4.8)	(11.0)	(7.7)
		5.9	5.7	63.3	4.1	0.0	16.1

\*\* significantly different (p < .01)

Discussion

Given the conditions of disenitainment, in which little was allowed to interfere with the unambiguous expression of biological sleep tendency (i.e., sleep itself), subjects exhibited sleep/wake organization characterized by the presence of two preferred phase positions for sleep per circadian day. These results are consistent with, and seem to lend considerable support to, the notion that the human sleep system is polyphasic in nature.

Yet, because of the unusual environment in which the experiment occurred, it could be argued that such patterns of sleep and waking are not the expression of an underlying biological timing system of human sleep, but simply the reflection of a behavioral response to the relatively sedentary conditions of disenitainment.

**Napping as a biological rhythm.** If the napping behavior observed here is, indeed, to be considered a component of the endogenous rhythm of sleep and waking, then nap sleep should conform to the same rules which govern the placement, duration and internal organization of major nocturnal sleep. Under conditions of disenitainment, that was clearly the case. The placement of naps, like that of major sleep episodes, was not random. Rather, the initiation of daytime sleep was as closely associated with maximum daily levels in the circadian course of body core temperature as major nocturnal sleep was with the minimum.

Likewise, the duration of naps was strongly determined by their placement within the circadian day. Circadian factors effectively placed a ceiling of about three hours on the duration of daytime sleep episodes. That ceiling was abruptly lifted at approximately 2000h, a time corresponding to the beginning of the descending slope in the average daily course of body temperature (see Fig. 4).

With regard to the internal organization of naps, the strong circadian influence which is largely responsible for the mode of appearance of REM sleep in major nocturnal sleep was evident in naps, as well, resulting in the only significant difference in sleep stage percentages between naps and MSEs. In addition, the degree to which slow wave sleep was present in daytime sleep episodes appeared to be substantially determined by circadian factors.

The likelihood that the sleep patterns recorded in disentrainment actually reflect the natural timing of sleep is further supported by findings from other studies, some of which have recorded subjects under far less drastic conditions. As mentioned earlier, simple instructions to «sleep when inclined to do so», given to subjects in an otherwise normal time-free environment, resulted in a substantial increase over the number of sleep episodes recorded in an equal interval during which napping was prohibited. Even under conditions in which subjects have been encouraged to continue their normal daily activities, and in which napping was expressly prohibited, a substantial proportion of subjects found it impossible to entirely suppress napping behavior (11, 12). The very strength of this propensity for sleep around the maximum of body core temperature provides perhaps the most convincing proof of the natural place of napping within the temporal organization of human sleep and wakefulness.

**The polyphasic nature of sleep.** In the disentrained environment, and in the studies just described employing less drastic environments, the polyphasic nature of sleep was expressed in the form of a bimodal distribution in sleep placement, with an average cycle length between successive sleep onsets of around twelve hours. There are indications, however, that still shorter cycles in sleep propensity may underlie the endogenous timing systems of human sleep. Nakagawa (13) found that subjects confined to bed for 10 to 12 hours during the day, following a full night's sleep, showed a clear tendency to sleep at approximately four-hour intervals, and suggested the presence of «another ultradian rhythm . . . that is related to the work-rest rhythm of daily life».

Sleep/wake cycles of similar duration (4 to 6 hours) have been reported for subjects confined to bed for 60 consecutive hours (14); and Zulley and Wever (15) have noted that sleep onset times recorded from free-running subjects are «not randomly distributed, but show several clearly separated peaks». The average interval from peak to peak was 5.7 hours. Under entrained conditions, as well, it has been reported that subjects attempting to sleep every 20 minutes across the twenty-four hour day exhibit cycles of sleep propensity in the 4 to 6 hour range (16). It is probably no coincidence that this 4 to 6 hour cycle in sleep tendency corresponds to the natural sleep/waking cycle exhibited by neonates, prior to their entrainment by social cues and the demands of other humans.

In conclusion, such findings serve to underscore not only the polyphasic nature of human sleep. They also illustrate the high degree of flexibility inherent in the system, and emphasize the essential role of behavioral controls in the temporal organization of sleep within the twenty-four hour day. The aim of the present study was to examine the temporal organization of sleep and waking under conditions in which the influence of such behavioral controls was minimized. The profile to emerge from such conditions was that of a rather labile system of sleep and wakefulness, characterized by at least two intervals of elevated sleepiness per day, tied to the circadian rhythm of body core temperature and distinguished by their differential strengths. It is the presence and relative strength of environmental restraints that determines the extent to which these non-circadian variations in sleep propensity will be expressed in the form of napping behavior.

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