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Napping in Time-Free Environments

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After a necessarily brief historical orientation, we describe some of the ways in which naps are studied in time-free environments. We then examine the data obtained from such studies, in an effort to address several questions concerning the nature of naps. In the final section of the chapter, we relate these findings to the hypothesis that napping is an expression of part of the biological system mediating the rhythmic occurrence of human sleep.

HISTORICAL PERSPECTIVE

The study of napping behavior in human chronobiology has neither an extensive nor long history. The first study to actually report objective data relative to spontaneous napping in a time-free environment was published only 20 years ago (23). In that study, the duration of naps was the only parameter reported, and then only in passing, in the discussion section of the paper. Since the time of that report, only a handful of studies have examined spontaneous sleep within the circadian day.

The reasons for the paucity of data in this area may be traced to the original aims of time-free studies and the resulting conditions under which subjects were maintained. Such studies were initially undertaken in an effort to eliminate the possible masking influences imposed on putative endogenous rhythms by social and environmental time cues. Subjects were isolated from diurnal variations in light and temperature, as well as from the entraining influences of cultural habit, such as work schedules and the demands of other human beings.

At the same time, however, virtually all studies employing time-free environments specifically prohibited napping by requesting that subjects lead a "regular" life, with three meals taken in normal sequence, and no daytime

TABLE 1. *Descriptions of studies examining napping in the time-free environment*

Study	Approach	*N*	Placement of naps	Duration of naps	Rate of occurrence	Structure addressed
Schaefer et al. (23)	Permitted naps	2	Afternoon	121–212 min	1/day	No
Webb and Agnew (28)	Permitted naps	14	Variable	Not stated	Not stated	No
Nakagawa (21)	Encouraged naps	20	Late morning/ afternoon	92 min	3.5/day	Yes
Weitzman et al. (30)[a]	Encouraged naps	3	Temperature maximum	<half of overall mean	1/day (n = 2) 1/3 days (n = 1)	No
Campbell (7)	Encouraged naps	9	Late morning/ afternoon	115 min	2.2/day	Yes[b]
Campbell and Zulley (9)	Encouraged naps	9	Temperature maximum	102 min	~1/day	Yes
Zulley and Campbell (34,35)	Prohibited naps	6	Temperature maximum	144 min	23% of cycles	No

[a] Abstract.
[b] Campbell and Zulley (10).

sleep. Such instructions were imposed probably for two reasons. First, common experience indicated that the typical sleep/wake system of adult humans was organized monophasically. Instructions not to nap, therefore, were given in an effort to study normal patterns of sleep and wakefulness. In addition, from the standpoint of circadian research, naps were frequently viewed as sources of experimental variance, having the potential to distort the course of other rhythms of interest, such as body temperature, renal excretion, or performance (26).

The imposition of such instructions made it highly likely that compliant, well-motivated subjects would exhibit monophasic, circadian sleep patterns. In effect, cultural demands were replaced by experimental commands or demand characteristics (22). Thus, the original goal of recording biological rhythms in the absence of environmental and social constraints was only partially realized. The alternation of sleep and wakefulness in time-free environments remained, by and large, under the influence of external controls.

Nevertheless, several studies have been published in which at least some features of napping have been described. These are listed in Table 1, along with their general findings with regard to the nature of naps. Also shown in Table 1 is the approach taken by each study to extreme napping behavior. A more detailed description of these strategies is the topic of the next section.

RESEARCH APPROACHES

To be effective, the strategies used to study napping (i.e., sleep episodes other than major nocturnal sleep) in time-free environments must reduce the constraints imposed on sleep by experimental demands. Such approaches can be divided into three general categories, based on the degree to which behavioral controls on the initiation of sleep are a feature of the environment.

Prohibited Naps

Although sleep/wake behavior is clearly influenced in the time-free environment by instructions against napping, total compliance has not always been achieved. In an early paper describing studies in the time-free environment, Aschoff (1) recounted his own experience as a subject:

> On day 8, I got up after only 3 hours of sleep. Shortly after breakfast I wrote in my diary: "Something must be wrong. I feel as if I am on dogwatch." I went to bed again and started the day anew after three more hours of sleep.

The recognition that additional sleep episodes might be, at times, unavoidable led to the practice of requiring subjects to signal the beginning and end of subjectively perceived naps, even though they continued to be prohibited (31).

Presumably, as a result of the original circadian orientation of the studies, these signaled naps were not considered as sleep in subsequent analyses of the data. Yet the reanalysis of such data has proved to be a useful source of information regarding the chronobiology of napping (34,35). Because subjects are required to specifically designate naps, findings from this approach permit the examination of relationships between the perception of what a nap is, and corresponding behavioral and physiological aspects of napping. As will be seen, such analyses allow, on the one hand, inferences to be made regarding biological determinants of why a nap is viewed as such, and on the other hand, what influence this subjective perception may have on the subsequent sleep episode.

Permitted Naps

In a few studies, subjects have been informed that other-than-nocturnal sleep would be allowed during their time in isolation. In one of the first electrographic studies of sleep and waking in the time-free environment, Webb and Agnew (27) gave their subjects the following instructions:

> During isolation we ask that you "loosen" your sleep-waking process and let it follow a course of least resistance. On the one hand, it is possible to take a set of maintaining your typical biphasic [*sic*] sleep and waking pattern. On the other hand, it is possible that you attempt some other pattern, such as a sleep-wake-nap-wake-sleep pattern. We hope that you will do neither. Rather we hope that you will sleep whenever you find this an acceptable response.

The advantage of such instructions for the study of napping in the time-

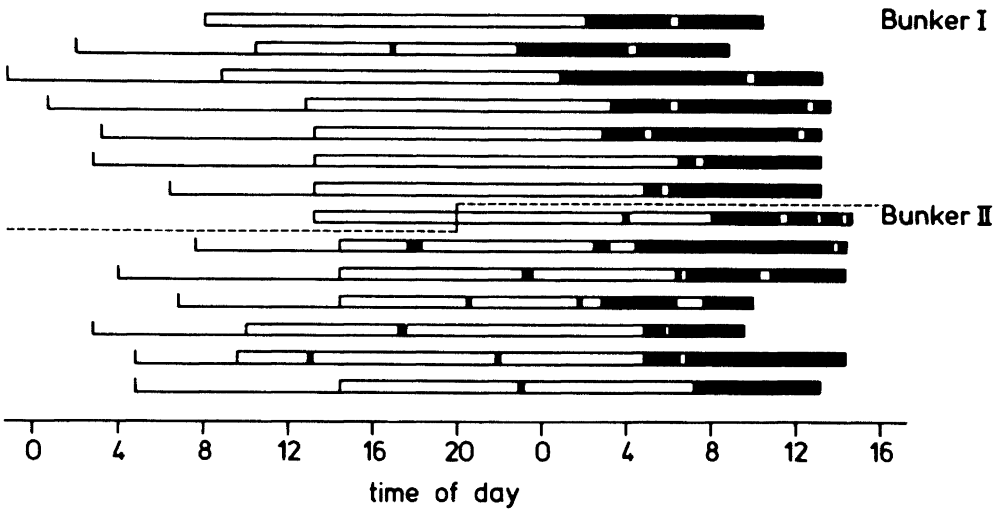

FIG. 1. Episodes of sleep (*solid bars*) and wakefulness (*open bars*) for a single subject living in isolation for 2 weeks. During the first week (Bunker I), the subject was requested to structure her days and to sleep only during her subjective night. During the second week (Bunker II), the subject was instructed to eat and sleep when inclined to do so.

free environment is obvious. Subjects feel no compulsion to structure their days in response to external demands and are more likely, therefore, to express a closer approximation of physiological sleep tendency. The degree to which such instructions can influence the occurrence of sleep is illustrated in Fig. 1. Shown are episodes of sleep and wakefulness exhibited by a subject during a 2-week stay in the time-free environment (Campbell and Zulley, unpublished data). During both weeks, the subject (an artist) was permitted to continue her usual daily activities, which consisted primarily of drawing and painting, exercise, reading, and writing. Prior to the start of the first week (Bunker I), the subject was instructed to organize her days by eating three meals in normal sequence and by sleeping only during her subjective night. With one exception, the subject complied with these instructions and exhibited a typical monophasic sleep pattern.

At the beginning of week 2 (Bunker II), instructions to the subject were changed. She was simply told to eat and sleep when inclined to do so. The result was a more than twofold increase in the number of sleep episodes taken during the week. The subject napped daily, and on three occasions, napped twice a day.

This example notwithstanding, behavioral controls on sleep are not completely removed simply by the removal of experimental restriction on sleep. Consider an individual who agrees to live in the time-free environment because (s)he feels the time would be well-spent studying for upcoming final exams or writing a term paper. This subject may well employ self-imposed behavioral controls, such as drinking a cup of coffee or transiently increasing activity, to overcome periodic episodes of drowsiness, thereby influencing the extent to which napping behavior is observed. As Mills and co-workers have pointed out (9,11,18), even under these permissive conditions there may be a strong tendency for some individuals to continue their usual patterns of behavior. Habits developed throughout many years may be difficult to change simply by the removal of time cues, if the opportunity to continue habitual behaviors remains a feature of the environment.

Encouraged Naps

The persistence of habitual behaviors in time-free conditions can be used to advantage, of course, if the behavior in question is habitual napping. The removal of time cues and cultural demands from the environments of habitual nappers probably leads to an even greater likelihood that their apparent predisposition for napping will be behaviorally expressed. Several authors have employed this approach to examine the chronobiology of napping (23, 30).

For subjects who are not in the habit of napping, such behavior can be encouraged by reducing the number of behavioral options in the environment that may be incompatible with the initiation of sleep episodes. One such experimental approach has been referred to by us as "disentrainment" (6,7). The most radical version of this design entails the elimination of experimental instructions relative to when and when not to sleep, the minimization of behavioral alternatives to sleep (e.g., reading, writing, engaging in conversation, listening to music), and enforced bed rest (7,10,21). A slightly less drastic form of disentrainment permits free movement around the isolation unit but continues to prohibit virtually all behavioral options to do anything other than sleep (9).

It can be argued that such basal static conditions constitute the best environment in which to study the physiological propensity for sleep. Simply from lack of viable alternatives, subjects studied under these conditions are more likely to express a biological sleep tendency in the unequivocal form of napping behavior or polycyclic sleep tendencies.

On the other hand, it may be argued that sleep patterns exhibited under these conditions are abnormal, reflecting a physiological response to boredom rather than natural sleep tendency. An added disadvantage of employing the disentrainment design is the relatively short time during which subjects can be studied under such conditions; 3 to 4 consecutive days is probably the maximum interval that subjects would tolerate. Thus, parameters such as reliability of phase relationships and stability of sleep/wake patterning over time may not be adequately examined using this strategy.

Pathological Naps

Finally, in addition to the approaches mentioned above, it may be of value to examine the napping behavior in time-free environments of individuals with sleep pathology characterized by daytime sleepiness. Narcoleptics may be of particular interest in this regard, since there is some evidence that daytime sleep attacks in this disorder may be periodic in nature, perhaps reflecting an imbalance between circadian and ultradian components of the biological system mediating the timing of sleep (16,20). To our knowledge, however, there are no published reports of sleep patterns of such populations under time-free conditions.

CHRONOBIOLOGY OF NAPPING

Implicit in the rationale behind studying napping in a time-free environment is the assumption that napping represents a component of the endogenously mediated sleep/wake system of adult humans. This assumption, in turn, suggests certain hypotheses regarding the nature of naps: (a) naps should maintain some characteristic pattern of occurrence with a given time frame, (b) the occurrence of naps should maintain a stable phase relationship with other components of the human circadian system, such as core body temperature, and (c) the duration and infrastructure of such sleep episodes should be governed by the same circadian principles governing the length and architecture of typical nocturnal sleep. The following sections will examine these hypotheses by addressing several basic questions regarding the nature of naps under time-free conditions.

When Do Naps Occur?

There is good agreement across studies that the initiation of naps in the time-free environment does not occur randomly. Depending on the conditions under which they are studied and the manner in which napping is defined, such sleep episodes may show one, or several, preferred times of occurrence within the circadian day.

Consistently, naps show a tendency to cluster around a phase position corresponding to the time of maximum values in the circadian course of body core temperature (see Fig. 2). Indeed, this phase of the circadian day has been referred to as the "nap domain" (30). This designation was based on findings from studies of two elderly habitual nappers who lived in time-free environments for 14 and 18 days, and a third subject who was not a habitual napper but was strongly encouraged to nap, during 31 days under time-free conditions. The sleep/wake profiles of all three subjects were characterized by the presence of relatively short sleep episodes (i.e., less than half the mean duration of all sleep episodes taken during the free-run) occurring "approximately 180° before mid-low temperature, close to the maximum temperature."

That a preferred phase position for the occurrence of naps exists around

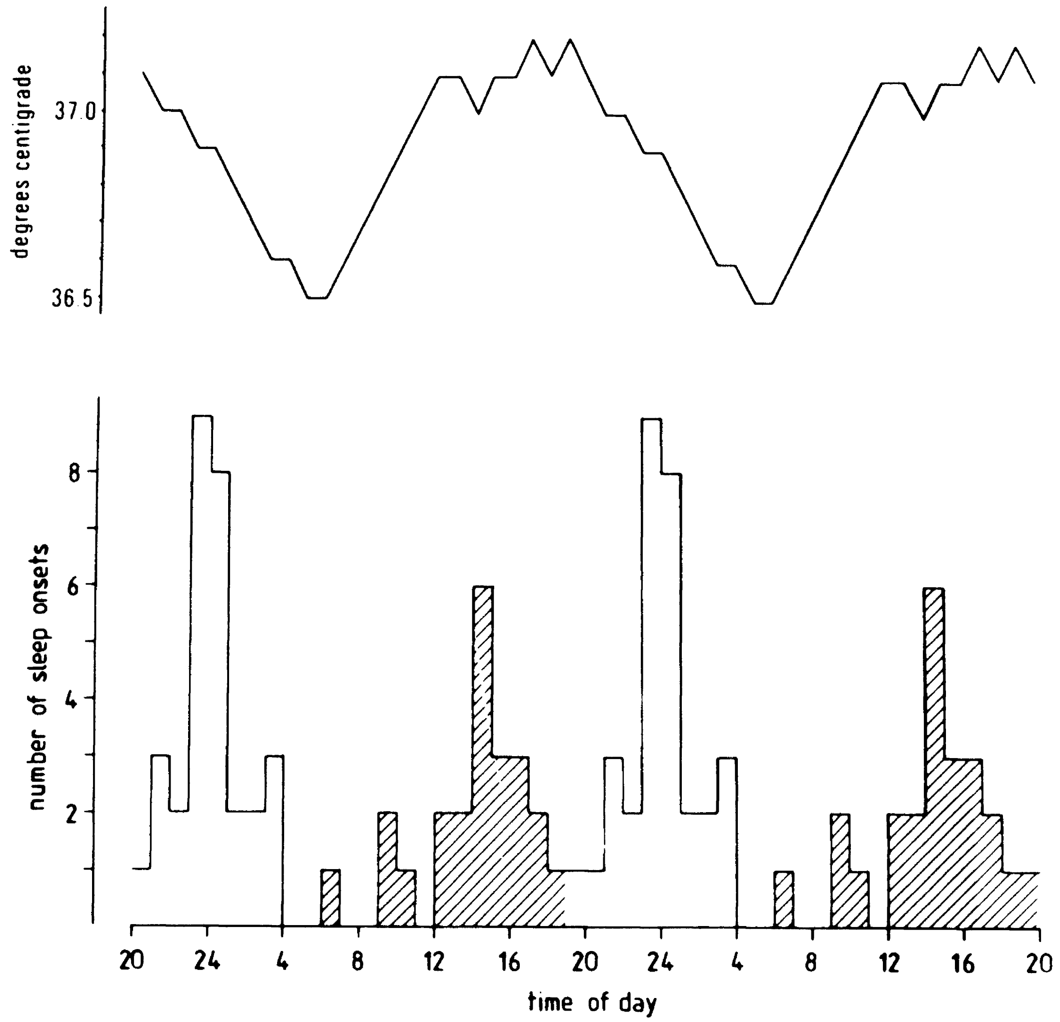

FIG. 2. Distribution of sleep onsets (double plotted) recorded from nine subjects during 72-hr disentrainment period (9). *Hatched area* shows sleep episodes designated as naps in subsequent analyses (see text). Above the distribution is the course of body core temperature (rectal) averaged for the nine subjects.

the temperature maximum is supported by studies involving nonhabitual nappers as well. For example, six subjects who signaled having taken naps, contrary to experimental instructions, initiated naps between 7 and 14 hr after the temperature minimum, an interval corresponding to the temperature maximum (35). (It should be noted that under these conditions, in which subjects designated naps, they sometimes called sleep episodes that occurred at the temperature minimum "naps." These sleep episodes were of a length generally associated with major sleep. Thus, major sleep episodes may be subjectively perceived as naps as well. The reasons for such perceptions are discussed in a later section.)

In most cases, the maximum in body temperature corresponds to a time approximately halfway between successive major sleep episodes, as shown in Fig. 2. This figure shows the distribution of sleep onsets recorded from nine young adults during 72 hr in a disentrained environment (9). In this study, subjects were permitted free movement around the isolation unit but were allowed virtually no behavioral alternatives other than to sleep. With respect to successive onsets of major, nocturnal sleep episodes, naps showed a tendency to begin approximately 60% of the way through the cycle. Specifically, the average onset of naps was 14.6 hr after the onset of the preceding nocturnal sleep and 9.9 hr prior to the onset of the subsequent nocturnal sleep episode. Viewed in a different way, this places naps, on average, approximately halfway (48.7%) through the waking episode separating successive nocturnal sleep periods (i.e., between the termination of one and the onset of the next major sleep episode).

Although naps show a strong tendency to cluster around the temperature maximum, and thus the middle of the typical waking period, their occurrence is not restricted to that phase of the circadian day. Under certain experimental conditions, a relatively robust propensity for napping in the late morning has been reported. Nakagawa (21), for example, reported that subjects confined to bed for 12 hr during the day, following a full night's sleep, spent a greater proportion of time asleep between 0800 and 1100 hr than during any other 3-hr time block (63.2%). For the group, the tendency to initiate sleep at approximately 1030 hr was as strong as that observed about 4 hr later, at the expected nap phase.

In a similar study, in which subjects were confined to bed for 60 consecutive hr (7), more sleep episodes were initiated between 1000 and 1200 hr (17% of total) than during any other 2-hr interval within the 24-hr day. The two additional peak times for sleep onset were between 1500 and 1700 hr and between 0200 and 0300 hr. Overall, 42% of all sleep recorded during the 60 hr was initiated during these intervals, despite the fact that they comprise only 21% of the 24-hr day.

It is unclear how napping at this phase relates to the circadian course of body temperature. This variable was not recorded in either of the studies mentioned. However, there is no evidence to suggest that individual differences in nap domains (i.e., temperature acrophase) are responsible for the occurrence of two peaks within the circadian day. To the contrary, in the study just described (7), sleep episodes initiated between 1000 and 1200 hr were contributed by eight of the nine subjects studied. Furthermore, more than half of these late morning naps were followed several hours later by an additional nap, suggesting that the bimodal distribution of nap times is not simply a reflection of differential placement of naps from one day to the next.

It has been suggested that the two preferred phase positions for the occurrence of naps may reflect an ultradian rhythm in sleep and wakefulness, in the 4- to 6-hr range (7,9,21). Such polyphasic organization of rest and activity is widespread across the animal kingdom (2). There is no reason, therefore, why humans should not exhibit such patterns as well, given an environment in which the expression of these patterns is not masked by behavioral options that may be incompatible with the initiation of sleep episodes.

On the other hand, the environments in which this bimodal distribution in napping is observed can clearly be considered unusual. The question remains whether such sleep/wake patterns reflect natural sleep tendency or whether they should be considered behavioral responses to the extremely static, basal condition characterizing the environments in which they occur.

How Long Do Naps Last?

It is clear from the previous discussion that, for the most part, the timing of naps is tied to the circadian rhythm of body core temperature. Likewise, the relationship between the durations of sleep episodes and the circadian course of body core temperature is well established (12,33,36). In general, the longest sleep episodes are initiated several hours prior to the temperature minimum, with decreasing durations as onset times approach the temperature maximum. In light of this relationship and that between the initiation of naps and temperature phase, it is no surprise that naps are typically short, relative to major nocturnal sleep episodes.

As with the placement of naps within the circadian day, there is general agreement across studies with regard to the duration of such sleep episodes, as shown in Table 1. As a general rule, naps taken in time-free environments continue for longer durations than do naps under entrained conditions (see Chapter 9). For the 71 naps recorded during 12 hr of bed rest, Nakagawa (21) reported a mean duration of 92.3 min. Similar values (115.8 min) were reported for day phase (0600–1800 hr) sleep episodes recorded during 60 hr of bed rest (7) and for naps occurring in coincidence with temperature maxima during 72 hr of disentrainment, without bed rest (102 min) (7).

In the earliest study to employ continuous polygraphic recording in the time-free environment, Schaefer and co-workers (23) reported average nap durations of 212 and 121 min, for two young adults recorded for 8 consecutive days. Both subjects also napped during a 4-day control period immediately prior to the start of the time-free condition, with average nap durations of 103 and 117 min. Thus, one subject lengthened his average nap duration by a factor of 2 in the time-free environment, whereas the other showed no change.

Weitzman et al. (30) referred to a similar lengthening of nap duration for two elderly subjects studied in isolation. Instead of a consistent pattern of short nap/long sleep observed under entrained conditions, the total daily sleep of these subjects was divided into "2 episodes of varying length" during the time-free portion of the study. Nevertheless, as mentioned earlier, sleep episodes occurring within the nap domain consistently lasted for less than half the mean sleep length for the entire experimental period.

Because of the relationship between circadian phase and sleep duration, it might be expected that the late morning naps observed under bed rest conditions would have a longer average duration than those taken in the afternoon. Alternatively, given the well-established relationship between sleep duration and prior wakefulness one could predict the converse—that afternoon naps would be longer than those occurring closer to the termination of preceding nocturnal sleep episodes. The limited available data suggest a substantial influence of time-of-day, but little effect of prior wakefulness on nap duration.

In the disentrainment study described earlier (7), naps that occurred between 1000 and 1200 hr were significantly longer than those initiated between 1500 and 1700 hr (130.2 versus 96 min), despite the fact that the early naps were preceded by significantly less prior wakefulness than were the afternoon naps (95 versus 172 min). The overall correlation coefficient between prior wakefulness and nap duration was +0.28.

An interesting additional influence on nap duration must be considered under conditions in which subjects have been instructed to signal their intentions to nap. In such cases, the subjective perception of an imminent sleep episode as a nap appears to be associated with the subsequent duration of the episode. This point is illustrated in Fig. 3. The average durations of sleep episodes, as a function of circadian phase of onset, are shown for six subjects who signaled naps during their stays in the time-free environment (34,35). When compared with major sleep episodes taken at the same circadian phase, subjectively designated naps were, on average, 57% shorter. Thus, simply by deciding that an upcoming sleep episode will be a nap,

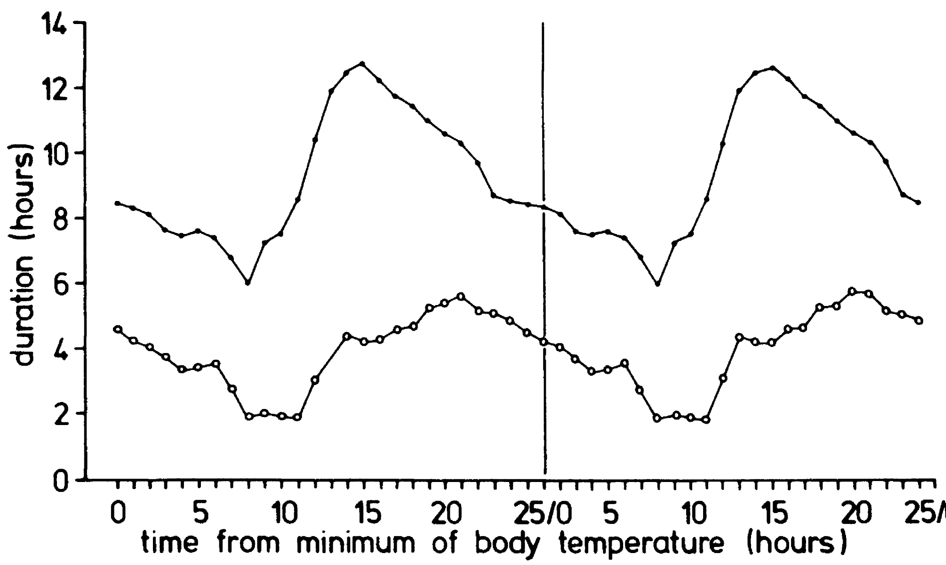

FIG. 3. Average durations of sleep episodes, as a function of circadian phase of onset, for six subjects who signaled naps during their stay in the time-free environment (34,35). The designation of a sleep episode as a nap was associated with a 57% reduction of subsequent sleep period duration. (●) major sleep; (○) nap sleep.

an individual effectively places an upper limit on the duration of that episode. Whether this is primarily a result of the behavioral set accompanying such a designation, or the consequence of physiological factors (e.g., effects of prior wakefulness), is unclear. However, we have all had the experience of lying down for a nap, frequently in an illuminated room, fully clothed, and on the bed rather than in the bed. These conditions are clearly not conducive to extended sleep and very likely play a role in the restriction of nap duration.

How Are Naps Structured?

The common view of naps is that they are short and involve lighter sleep than nighttime sleep episodes. We have just shown that, although naps taken in the time-free environment are typically longer than those taken under entrained conditions, they are nevertheless characterized by shorter durations than major nocturnal sleep.

The very limited data that address the structure of naps in the time-free environment suggest that the common perception of naps as lighter sleep episodes is also generally correct. This is illustrated in Table 2, which compares several structural parameters of normal nocturnal sleep (32) with those of daytime sleep episodes derived from three different studies of spontaneous napping (9,10,21). In all three of these studies, naps were characterized by larger proportions of stages 1 and 2 sleep and less slow wave sleep (SWS), when compared with normative data on nocturnal sleep episodes.

TABLE 2. *Mean values of sleep-stage parameter recorded from spontaneous daytime sleep episodes in time-free environments, relative to normal nocturnal sleep values*

Study	Source of data	Sleep stage percentages					REM latency
		1	2	3	4	REM	
Williams et al. (32)[a]	Normal nocturnal sleep (ages 20–29)	4.2	45.5	6.2	14.6	28.0	94.2
Nakagawa (21)	12-hr bed rest	15.4	51.0	7.5	4.3	21.7	Not reported
Campbell (7)	Disentrainment (bed rest)	2.8	60.8	4.9	11.0	17.5	35.4
Campbell and Zulley (9)	Disentrainment (no bed rest)	6.2	58.7	7.5	7.4	14.5	46.1
Campbell (8)	1400–1700-hr naps (n = 13)	7.5	53.8	9.8	10.6	13.3	
	All other naps (n = 13)	4.8	63.6	5.2	4.7	15.7	

[a] Normative nocturnal sleep values for healthy young adults.

Perhaps as a result of this reduction in SWS (3,4,8), average latency to rapid eye movement (REM) sleep in naps in temporal isolation was substantially shortened relative to typical nocturnal sleep. Indeed, sleep onset REM periods were a common feature of naps taken during bed rest (8,10,21). The average REM latency for naps recorded in the studies shown in Table 2 was about 45 min—approximately half that of normal nocturnal sleep.

Although generally accurate, the profile of naps as lighter sleep episodes than nocturnal sleep requires an important qualification. A closer inspection of the composition of individual naps taken during 72 hr of disentrainment (8) indicates that this view may be slightly misleading. There appears to be a subgroup of naps that tends to cluster around a specific phase position in the circadian day and more closely resembles typical nocturnal sleep in its basic structure. Shown at the bottom of Table 2 is a comparison of sleep-stage parameters between two groupings of naps that were separated on the basis of their placement within the nap distribution (i.e., their times of onset). Naps in the middle of the distribution (see Fig. 2 for the distribution of naps used in these analyses), with onsets between 1400 and 1700 hr, showed a mean SWS percentage of more than two times the average SWS for all other naps. Nakagawa (21) likewise found a higher percentage of SWS in naps with onsets between 1400 and 1700 hr than in naps initiated during any other 4-hr block during the day. In neither of these studies was duration of prior wakefulness a significant factor in the differential placement of SWS. (Interestingly, 1400 to 1700 hr is the time of day that naps are most likely to occur in healthy young adults—see Chapter 9.)

These findings strongly support Broughton's (5; Chapter 5) hypothesis that there exists a circasemidian rhythm in the occurrence of SWS, with a specific relatively well-delineated phase position within the circadian day during which SWS is likely to approach typical nocturnal percentages. The findings further suggest the existence of essentially two types of naps, at least with respect to structure. One group corresponds to the common perception of naps as lighter, more fragile sleep episodes. A second group of naps, however, located centrally within the nap distribution, tends to look very much like miniatures of major nocturnal sleep.

How Common Are Naps?

To a certain extent, the frequency with which napping occurs in the time-free environment depends on how often it is allowed to occur. Under the most permissive conditions [i.e., disentrainment with bed rest (7)], daytime sleep episodes (onsets between 0700 and 1900 hr) comprised 36% of all sleep recorded. All nine subjects in this study exhibited some degree of napping behavior, with an average of 2.2 daytime sleep episodes per 24 hr. Nakagawa (21) reported a similar frequency of occurrence for 20 subjects studied during

12 hr of bed rest. Nakagawa's subjects reported that they were periodically "overcome by an uncontrollable desire to sleep," despite explicit instructions to the contrary. Given these basal static conditions, then, napping seems to be an unavoidable component of the sleep/wake system of all subjects.

The degree to which bed rest specifically contributed to the occurrence of naps can be seen by comparing these results with those of a study that employed a disentrainment design, without confinement to bed (9). Under these conditions, all nine subjects continued to exhibit daily napping behavior, although these sleep episodes comprised a substantially smaller proportion of total sleep time (TST) than in the bed-rest condition.

However, as behavioral alternatives to sleep become a more prominent feature of the environment, individual differences in the propensity to nap become more evident. We recently completed a study in which 10 subjects lived for 2 weeks in the time-free environment, with instructions to eat and sleep when inclined to do so (Campbell and Zulley, unpublished data). Whereas 7 of the 10 subjects exhibited substantial napping, 3 subjects exhibited no napping during their time in isolation. Likewise, an examination of the individual sleep patterns of subjects studied by Webb and Agnew (28) (Fig. 2), under similar conditions, reveals substantial interindividual variability in the frequency with which napping occurred. It seems clear from these examples that, just as there are long and short sleepers (28,29), and morning and evening types ("larks" and "owls") (15), there are individual differences in the predisposition to nap (see Chapter 9). There are nappers and nonnappers. Perhaps this point is most strongly emphasized by the finding that even under conditions in which subjects were encouraged to continue their normal activities and specifically instructed to avoid napping, a certain proportion of these individuals found it impossible to comply (34).

Why Are Naps Perceived as Such?

From the examination of Fig. 3, it can be concluded that subjectively perceived naps, as well as major sleep episodes, may occur at any time, although preferred phase positions for sleep clearly exist. These preferred phase positions are not mutually exclusive but rather overlap to a certain extent (34,35). That is, subjectively perceived naps may occur around the temperature minimum and subjectively perceived major sleep episodes may occur around the maximum. What conditions, then, make a subject decide that a sleep episode is a nap rather than a major sleep?

Although it is clear that the duration of sleep episodes is an effective discriminator, it is only so in retrospect. Since subjects signaled their intention to nap prior to the sleep episode, different factors must have been involved in their decisions. Daily logs kept by subjects during isolation reveal

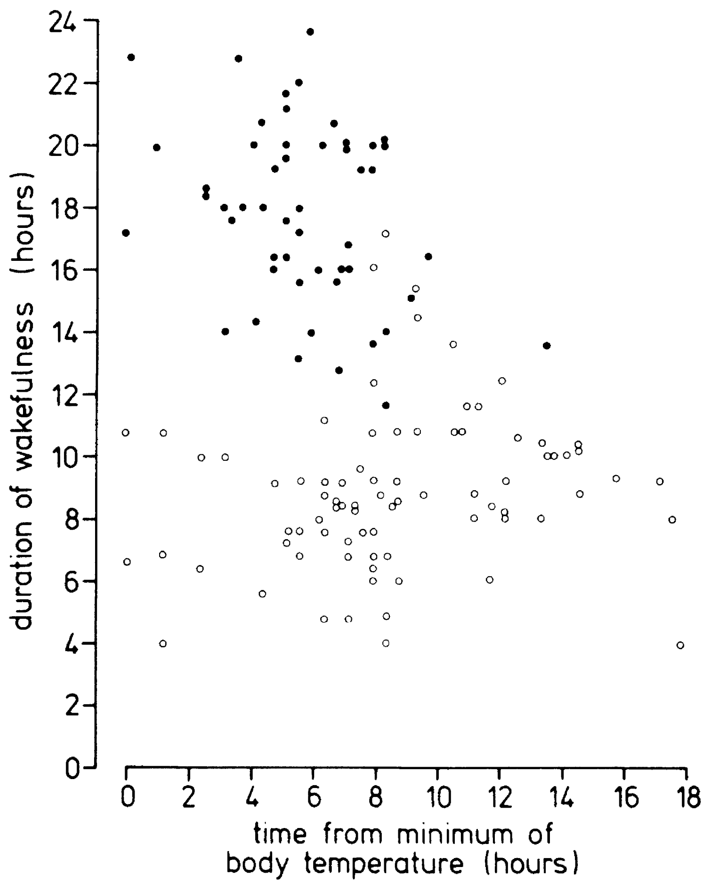

FIG. 4. Distribution of prior wakefulness, as a function of duration and circadian phase, recorded from six subjects who signaled naps during their time in isolation (34,35). (○) waking episodes preceding subjectively perceived naps; (●) those preceding major sleep. On average, naps were preceded by waking episodes of approximately half the duration of those prior to major sleep.

that the decision to call an impending sleep episode a nap was based on the subject's perception that not enough time had elapsed since the previous awakening for the episode to be considered a full day.

The data support the validity of this perception. Figure 4 shows the distribution of prior wakefulness, as a function of duration and phase, recorded from six subjects who signaled naps during their time in isolation (34). Sleep episodes designated as naps were preceded by significantly shorter episodes of wakefulness (8.8 hr) than were major sleep episodes (17.9 hr). There was virtually no overlap in the distributions of prior waking for the two groups of sleep episodes.

NAPPING AS A BIOLOGICAL RHYTHM

Of the experimental paradigms used to study napping, the time-free environment is probably the best suited to address the question of whether napping behavior is the expression of part of an endogenously mediated tendency for the recurrence of sleep throughout the nycthemeron. Within the general framework of time-free environments, the degree to which the putative biological tendency for sleep is expressed as napping behavior is strongly influenced by the number of behavioral controls extant in the experimental environment. Yet, even under conditions in which subjects are encouraged to continue their normal daily activities, and in which it is expressly prohibited, more than half of all subjects find it impossible to entirely suppress napping behavior. The very strength of this tendency suggests that napping is the response to some physiological predisposition to rest periodically throughout the day.

It was suggested throughout the beginning of this chapter that if the propensity to nap is, indeed, a component of the endogenous rhythm of sleep and waking, nap sleep should conform to the same rules that govern the placement, duration, and internal organization of major nocturnal sleep. Taken together, the studies reviewed in the previous sections provide convincing evidence in support of this hypothesis.

The placement of naps, like that of major sleep episodes recorded in time-free environments, is not random, but rather is closely related to the circadian oscillation of body core temperature. Likewise, the duration of naps is determined primarily by their placement within the circadian day, a relationship well-established for major nocturnal sleep as well. With regard to structure, the strong circadian influence is largely responsible for the mode of appearance of REM sleep in nocturnal sleep episodes, which is evident in naps, both in percentage and latency values. In addition, the degree to which SWS occurs within naps appears to be substantially determined by circadian factors.

The hypothesis that napping is the expression of an endogenous propensity for sleep raises additional questions regarding the nature of the biological system mediating sleep and waking. For example, what kind of rhythmic system includes one component which, in normal adults, is most conspicuous by its frequent lack of occurrence? If napping is part of a biologically mediated rhythmic system, what are the consequences of its chronic absence?

With regard to the first question, it is clear that the human sleep/wake system is a flexible one (see Chapter 8). Both the onset and termination of major nocturnal sleep are routinely shifted in response to the demands of daily life. The duration of major sleep episodes can be dramatically and chronically curtailed, and shift work requires the frequent rotation of major sleep to virtually any placement within the 24-hr day. Indeed, the very fact that the circadian component of the sleep/wake rhythm is forever entrained to a 24-hr periodicity is clear testimony to its flexible nature.

As with any instinct, the sleep/wake system interacts with and is responsive to the environmental conditions under which it functions. The absence of naps in daily life, therefore, may be a more accurate reflection of the environment than of the rhythm [cf. (24)]. Simply, the expression of this component of the sleep/wake rhythm may be effectively masked by social and occupational demands. This view is supported by the observation that certain populations report an increased incidence in napping behavior, in response to lifestyles that are less structured than the usual "8-to-5" work environment (17,25,26; see also Chapters 9 and 10). Results of studies using the various time-free environments cited throughout this chapter also reflect the strong influence imposed on the occurrence of naps by behavioral controls.

Although the sleep/wake system is flexible, it is generally not manipulated without cost. For example, both chronic restriction of nocturnal sleep and sleep period time displacement (e.g., shift work) are accompanied by decrements in performance, alterations in mood, and changes in sleep itself. If napping is an integral component of the sleep/wake system, the exclusion of naps from our daily schedules might be expected to result in similar decrements. Stated differently, the inclusion of napping in our daily regimens might be expected to augment such measures. Few studies have adequately addressed the effect of napping on nonsleep-deprived subjects (see Chapter 9). It is, therefore, difficult to estimate the consequences of its chronic absence. There is, however, limited evidence to suggest that napping may indeed be effective in enhancing performance over nonnap levels in normal rested adults (13,14).

Such findings raise interesting questions. Do our nonnapping societies impose an artificial ceiling on performance potential? Could we function better by adapting our behavior to reflect more closely underlying biological sleep tendency? Is the siesta a natural, yet generally ignored, aid to performance? Common experience indicates that most people perform reasonably well without benefit of regular napping. However, that we can get along adequately without naps should not be interpreted to mean that we would not function more efficiently with them.

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REFERENCES

1. Aschoff, J. (1965): Circadian rhythms in man. *Science*, 148:1427–1432.
2. Aschoff, J. (1966): Circadian activity pattern with two peaks. *Ecology*, 47(4):657–662.

3. Borbély, A. A. (1984): Sleep regulation: Outline of a model and its implications for depression. In: *Sleep Mechanisms*, edited by A. Borbély and J.-L. Valatx, pp. 272–284. Springer-Verlag, Berlin.
4. Borbély, A. A., and Wirz-Justice, A. (1982): Sleep, sleep deprivation and depression. *Hum. Neurobiol.*, 1:205–210.
5. Broughton, R. (1975): Biorhythmic variations in consciousness and psychological functions. *Can. Psychol. Rev.*, 16:217–239.
6. Campbell, S. S. (1983): Human sleep patterns under conditions of "disentrainment." In: *Sleep '82: Proceedings of the 6th European Congress on Sleep Research*, edited by W. P. Koella, pp. 212–215. Karger, Basel.
7. Campbell, S. S. (1984): Duration and placement of sleep in a "disentrained" environment. *Psychophysiology*, 21:106–113.
8. Campbell, S. S. (1988): Bed rest induces depressed sleep patterns in healthy young adults. In: *Sleep '86: Proceedings of the 8th European Congress on Sleep Research*, edited by W. P. Koella, pp. 223–226. Fischer, New York.
9. Campbell, S. S., and Zulley, J. (1985): Ultradian components of human sleep/wake patterns during disentrainment. In: *Ultradian Rhythms in Physiology and Behavior*, edited by H. Schulz and P. Lavie, pp. 234–255. Springer-Verlag, Berlin.
10. Campbell, S. S., and Zulley, J. (1987): Induction of depressive-like sleep patterns in normal subjects. In: *Chronobiology and Neuropsychiatric Disorders*, edited by A. Halaris, pp. 117–132. Elsevier, New York.
11. Conroy, R. T., and Mills, J. N. (1970): *Human Circadian Rhythms*. Churchill, London.
12. Czeisler, C. A., Weitzman, E. D., Moore-Ede, M. C., Zimmerman, J. C., and Knauer, R. S. (1980): Human sleep: Its duration and organization depend on its circadian phase. *Science*, 210:1264–1267.
13. Godbout, R., and Montplaisir, J. (1986): The performance of normal subjects on days with and days without naps. *Sleep Res.*, 15:71.
14. Godbout, R., and Montplaisir, J. (1986): Effects of napping on performance of normal non-sleep-deprived subjects. Paper presented at the Eighth European Congress of Sleep Research, Szeged, Hungary.
15. Horne, J., and Ostberg, O. (1977): Individual differences in circadian rhythms. *Biol. Psychol.*, 5:179–190.
16. Kripke, D. F. (1976): Biological rhythm disturbances might cause narcolepsy. In: *Narcolepsy: Advances in Sleep Research, Vol. 3*, edited by C. Guilleminault, W. C. Dement, and P. Passouant, pp. 475–484. Spectrum, New York.
17. Lewis, H., and Masterton, J. (1957): Sleep and wakefulness in the Arctic. *Lancet*, 1:1262–1266.
18. Mills, J. N. (1973): Transmission processes between clock and manifestations. In: *Biological Aspects of Circadian Rhythms*, edited by J. N. Mills, pp. 28–74. Plenum Press, New York.
19. Mills, J. N., Minors, D. S., and Waterhouse, J. M. (1974): The circadian rhythms of human subjects without timepieces or indication of the alternation of day and night. *J. Physiol.*, 240:567–594.
20. Mosko, S. S., Holowach, J. B., and Sassin, J. F. (1983): the 24-hour rhythm of core temperature in narcolepsy. *Sleep*, 6:137–146.
21. Nakagawa, Y. (1980): Continuous observation of EEG patterns at night and in daytime of normal subjects under restrained conditions. I. Quiescent state when lying down. *Electroencephalogr. Clin. Neurophysiol.*, 49:524–537.
22. Orne, M. T. (1962): On the social psychology of the psychological experiment: With particular reference to demand characteristics and their implications. *Am. Psychol.* 17:776–783.
23. Schaefer, K. E., Clegg, B. R., Carey, C. R., Dougherty, J. H., and Weybrew, B. B. (1967): Effect of isolation in a constant environment on periodicity of physiological functions and performance levels. *Aerospace Med.*, 38:1002–1018.
24. Soldatos, C. R., Madianos, M. G., and Vlachonikolis, I. G. (1983): Early afternoon napping: A fading Greek habit. In: *Sleep '82: Proceedings of the 6th European Congress on Sleep Research*, edited by W. P. Koella, pp. 202–205. Karger, Basel.
25. Tune, G. (1968): Sleep and wakefulness in normal human adults. *Br. Med. J.*, 2:269–271.

26. Webb, W. B. (1978): Sleep and naps. *Specul. Sci. Technol.*, 1:313–318.
27. Webb, W. B., and Agnew, H. W. (1970): Sleep stage characteristics of long and short sleepers. *Science*, 168:146–147.
28. Webb, W. B., and Agnew, H. W. (1974): Sleep and waking in a time-free environment. *Aerospace Med.*, 45:617–622.
29. Webb, W. B., and Friel, J. (1971): Sleep stage and personality characteristics of "natural" long and short sleepers. *Science*, 171:587–588.
30. Weitzman, E. D., Kronauer, R., Fookson, J., Moline, M., Zimmerman, J., and Ronda, J. (1982): Endogenous oscillators control nap and sleep during non-entrainment. *Sleep Res.*, 11:221.
31. Wever, R. A. (1979): *The Circadian System of Man: Results of Experiments Under Temporal Isolation*. Springer, New York.
32. Williams, R. L., Karacan, I., and Hursch, C. J. (1974): *Electroencephalography (EEG) of Human Sleep: Clinical Applications*. Wiley and Sons, New York.
33. Zulley, J. (1976): Schlaf und Temperature unter freilaufenden Bedingungen. In: *Bericht uber den 30. Kongres der dtch. Ges. fur Psych.*, edited by W. H. Tack, pp. 398–399. Hogrefe, Gottingen.
34. Zulley, J., and Campbell, S. S. (1985): Napping behavior during "spontaneous internal desynchronization": Sleep remains in synchrony with body temperature. *Hum. Neurobiol.*, 4:123–126.
35. Zulley, J., and Campbell, S. S. (1985): The coupling of sleep-wake patterns with the rhythms of body temperature. In: *Sleep '84: Proceedings of the 7th European Congress on Sleep Research*, edited by W. P. Koella, E. Ruther, and H. Schulz, pp. 81–85. Fischer, New York.
36. Zulley, J., Wever, R., and Aschoff, J. (1981): The dependence of onset and duration of sleep on the circadian rhythm of rectal temperature. *Pflugers Arch.*, 391:314–318.