Sleep, 16(7):638–640

When the Human Circadian System is Caught Napping: Evidence for Endogenous Rhythms Close to 24 Hours

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Summary: It is now well acknowledged that napping constitutes an inherent component of the human circadian system. To date, however, few studies have examined the effects of spontaneous napping on human free-running rhythms. This study investigated the free-running circadian periods of rest/activity and body core temperature in a group of young subjects who were permitted to nap during their time in isolation. Based on the frequency of self-reported sleep bouts, subjects were classified as Nappers or Nonnappers. Nappers exhibited free-running rhythms in both rest/activity and body core temperature that were not significantly different from 24 hours. Nappers showed a tendency for shorter free-running periods in both variables, when compared with Nonnappers. These findings emphasize the need for careful reassessment of data obtained from traditional free-run protocols. **Key Words:** Circadian rhythms—Napping—Free-running rhythms—Rest/activity—Body core temperature.

In human subjects, imposition of behavioral controls, as well as compliance with experimental instructions, can influence the overt expression of the circadian system. For example, the phenomenon referred to as "spontaneous internal desynchronization" (1)—the uncoupling of temperature and rest/activity rhythms, typically as a result of significant period changes in the latter—has not been observed when subjects were permitted to nap, or when napping was included in subsequent analyses (2).

Similarly, the degree to which humans exhibit coherent, monophasic sleep depends on the extent to which polyphasic sleep is directly, or indirectly, restricted by behavioral structuring or experimental demands (3,4,5). When permitted to nap, many subjects exhibit polyphasic sleep patterns similar to those observed in nonhuman species (6). When napping does occur in the time-free environment, it does not occur randomly. Rather, sleep episodes taken in the subjective daytime, and subjectively perceived as naps, cluster around the maximum point in the circadian rhythm of body temperature. Such phase-dependence provides perhaps the strongest evidence that napping constitutes an inherent component of the human circadian system (7).

Despite this, in virtually all studies of human subjects in temporal isolation, napping has been explicitly prohibited. Subjects are instructed to eat three meals in normal sequence, and *not* to nap after lunch, but rather, to sleep only when they are certain that their major sleep period is commencing [see, for example (8,9)]. Under these conditions, humans typically exhibit free-running rhythms with an average period length of around 25 hours (1,9).

Because the tendency to nap is clearly a part of the human circadian system, it is of interest to examine the extent to which the occurrence of napping may influence the free-running period of human subjects. In this study we investigated the free-running circadian periods of rest/activity and body core temperature in a group of young subjects who were permitted to nap during their time in isolation.

METHOD

Eight healthy young adults (three females, five males; mean age = 24.6 years) were studied for 12 to 14 days,

Accepted for publication June 1993.
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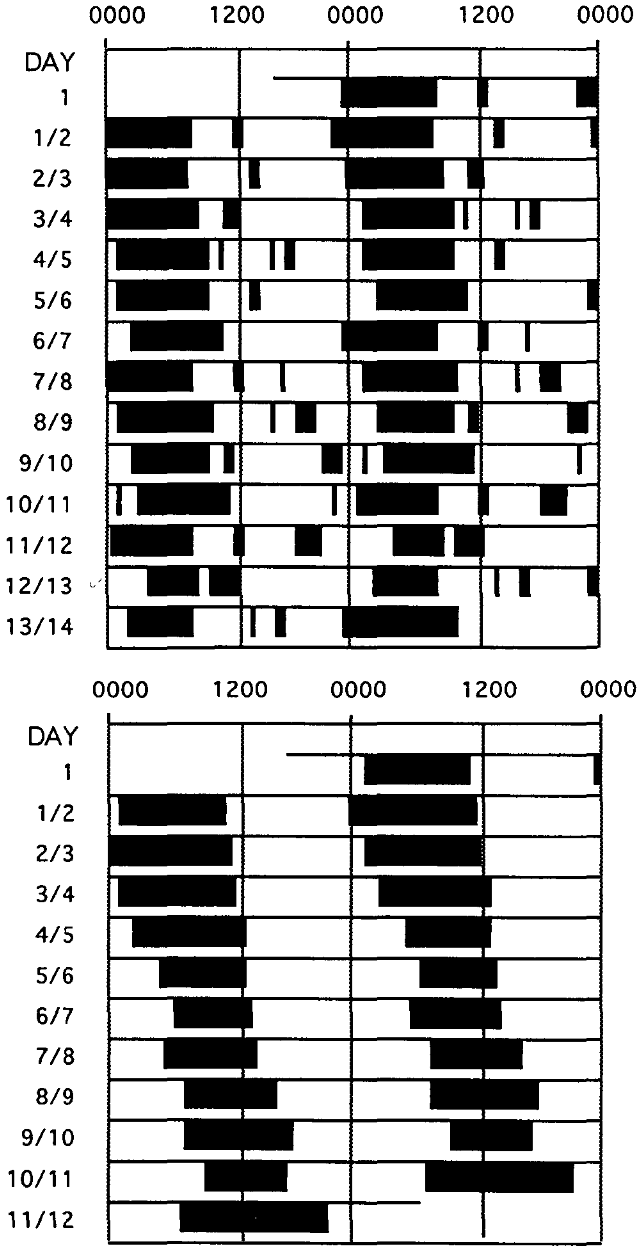

FIG. 1. Rest/activity profiles of a Napper (upper graph; subject 359) and a Nonnapper (lower graph; subject 358) during their time in isolation. Data are double-plotted, with black bars indicating times during which subjects reported major sleep periods and naps.

while they lived individually in an environment (the isolation units at Andechs, Germany) that has been demonstrated repeatedly to be entirely free of time cues. Illumination in the units did not exceed 200 lux, and light and darkness was at the discretion of each subject. The protocol replicated the traditional free-run paradigm, in that subjects were permitted to carry out a daily regimen within the confines of the isolation apartment. They were totally isolated from personal contact throughout the study. Unlike the traditional free-run, however, subjects were specifically instructed to eat (food was prepared by subjects in their apartments) and sleep whenever they felt inclined. Although napping was neither encouraged nor discouraged, subjects were instructed not to resist bouts of sleepiness.

There was no preparatory behavior required before retiring (e.g. electrode placement). Subjects indicated rest periods (retiring and arising) by pressing a buzzer within their apartment. Rest periods were verified by actigaphs situated beneath the mattress. Core temperature was measured using a continuous indwelling thermistor. Free-running period measures for rest/activity and temperature values were calculated using least-squares cosine spectrum analyses. Period measures and raster plots were obtained using a commercially available data analysis package (Circadia, Behavioral Cybernetics, Cambridge, MA).

TABLE 1. *Characterization of Nappers and Nonnappers based on frequency of napping during the period of isolation. Each subject's free-running period (tau) for rest/activity and for body core temperature is shown, as well as group means and standard deviations. There was a trend for Nappers to exhibit shorter tau for both variables (rest/activity: p = 0.06; temperature: p = 0.09)*

Subjects	Total naps	Naps/day	Tau rest/activity	Tau temperature
Nappers				
333	18	1.28	23.89	24.08
334	15	1.08	24.00	24.33
359	20	1.42	24.13	24.25
Mean	17.64	1.26	24.01	24.22
SD	2.39	0.17	0.12	0.13
Nonnappers				
335	3	0.20	25.03	25.08
336	2	0.14	24.02	24.17
347	2	0.14	25.20	24.92
358	0	0	24.88	24.75
Mean	1.68	0.12	24.78	24.73
SD	1.40	0.08	0.61	0.39

RESULTS

Three subjects (two males and one female) exhibited clear polyphasic sleep patterns, averaging more than one nap per day. Four of the subjects (three males and one female) were clearly Nonnappers, showing only isolated naps. One subject showed an intermediate position. Figure 1 shows rest/activity data for one of the Nappers (1a) and one of the Nonnappers (1b). Based on these sleep–wake patterns, subjects were identified as Nappers and Nonnappers, as shown in Table 1. The intermediate subject was omitted from subsequent analysis.

There was a significant correlation between the period (tau) of the rest/activity and body core temperature rhythms ($r = 0.962$, $p < 0.05$), indicating that none of the subjects exhibited internal desynchronization. No gender differences were found in the average period of either rest/activity or temperature. The Nappers showed free-running periods very close to 24 hours: a mean free-running rest/activity period of 24.01 hours [standard deviation (SD) = 0.12 hour] and an average temperature rhythm of 24.2 hours (SD = 0.13 hour). In contrast, the Nonnappers exhibited free-running periods very close to those reported in traditional free-run studies: 24.78 hours (SD = 0.61 hour) for rest/activity and 24.73 hours (SD = 0.39 hour) for body core temperature. As a group, the Nappers showed a trend for shorter free-running periods than the Nonnappers for both rest/activity ($F(1,5) = 6.02$, $p = 0.06$) and for temperature ($F(1,5) = 4.38$, $p = 0.09$).

DISCUSSION

These results indicate that when spontaneous napping occurs, the free-running period of rest/activity and body core temperature is shortened relative to that associated with monophasic sleep and is not significantly different from 24 hours. Such findings may be interpreted in several ways. On one hand, napping behavior itself may shorten the endogenous free-running period. Alternatively, altered periodicity may be a reflection of individual differences in circadian timing that mediate rest/activity behavior. That is, polyphasic sleep may be the overt expression of a circadian system in which the endogenous period is shorter, for example in the elderly. One way to address this question would be to restudy the Nappers under conditions in which napping was prohibited. Unfortunately, we were unable to do this. Still another possibility is that the actual endogenous circadian cycle in humans is, in fact, closer to 24, than to 25, hours. Under this assumption, some aspect(s) of the traditional free-run protocol, such as experimental instruction to avoid napping, would be responsible for artificially lengthening the intrinsic free-running period.

In light of our small sample size, the findings and any interpretations derived from them, must be viewed with considerable caution. They are, however, consistent with recent mathematical simulations that examined free-running rhythms under traditional free-run protocols, and those in which the timing of the sleep–wake cycle was uncoupled from the endogenous rhythm of body core temperature by an imposed 28-hour sleep/wake and light/dark schedule (10). In that simulation study, the average endogenous period was 24.3 hours, whereas the "apparent" period was close to 25 hours. Klerman and coworkers concluded that the self-selected light/dark cycles typical of traditional free-run experiments may have been a confounding influence, as the result of feedback on the endogenous circadian pacemaker. The result would be a significant increase in the apparent period length of body core temperature.

Whether such putative confounds in traditional free-run protocols are the result of experimental instruction, self-selected light/dark schedules or some other factor(s) remains to be determined. However, these data clearly indicate the need for continued and more critical reassessment of free-running circadian rhythms in human subjects.

Acknowledgements: These data were collected while the first author was a Visiting Scientist at the Max-Planck Institute for Psychiatry, Munich (supported by a grant from the Max-Planck Society). The support and advice of Dr. Hartmut Schulz is gratefully acknowledged. Analysis and write-up of the data were supported in part by grants R01-MH45067, R01-OH02758 and K02-MH01099.

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