

Napping behavior during “spontaneous internal desynchronization”: sleep remains in synchrony with body temperature

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Summary. Patterns of sleep and wakefulness exhibited in an environment without time cues are generally considered to be monophasic, with a distinct relationship between sleep episodes and the minimum of body core temperature. In some cases this relationship between major sleep episodes and temperature becomes replaced by an apparently varying phase relationship between the two variables called “spontaneous internal desynchronization”. In the present study the sleep-wake and temperature data of six subjects living in an environment without time cues and exhibiting internal desynchronization were reanalyzed to include subjectively designated naps. Two groups of naps were identified based on their phase positions relative to temperature, with one group occurring around the temperature minimum and another group clustering approximately halfway between successive minima. The results support the suggestion that neither monophasic sleep placement nor sleep patterns typically associated with spontaneous internal desynchronization reflect biological sleep tendency. Rather, sleep tendency is reflected more accurately by the bimodal sleep patterns exhibited by subjects who are allowed to time their sleep and waking with no restrictions.

Key words: Circadian rhythms – Sleep-wake cycle – Naps – Body temperature

Within the 24-h day the human sleep-wake system is normally characterized by one major wake and a succeeding major sleep episode. This monophasic sleep-wake pattern corresponds to the diurnal alternation of light and darkness. Yet, in conditions in which subjects are isolated from daylight and other time cues, the monophasic organization of sleep and waking typically remains intact, though in about one third of the cases the usual phase-relationship between sleep and the circadian rhythm in body core temperature becomes disrupted (internal desynchronization) (Wever 1979).

That this typical monophasic organization of sleep and waking may not necessarily reflect biological sleep tendency (i.e., the endogenously generated propensity for sleep), is suggested by the finding that in conditions in which social and occupational pressures are reduced, for example in college students and geriatric populations, an increased frequency in napping is reported (Tune 1968; Webb 1978;

Webb and Dube 1981). We present here evidence that suggests that both the continuation of monophasic sleep organization, relative to the temperature cycle, and the phenomenon of “spontaneous” internal desynchronization, observed in environments without time cues, may be largely a consequence of an additional external influence on the sleep-waking system in the form of experimental instructions.

Method

The data base was derived from the reanalysis of rest-activity and temperature records of six subjects who lived singly in an isolation unit for an average of 20 days each (range: 8–27 days). The subjects were selected for reanalysis on the basis of two criteria: that they exhibited “internal desynchronization” with lengthening of the sleep-wake cycle, and that they reported, contrary to instructions, having taken naps during the experiment.

The experimental procedure was identical to that employed in standard experiments with freerunning rhythms as described by Aschoff and Wever (Wever 1979). Briefly, subjects lived without time cues and were permitted to control illumination in the unit. They prepared their own meals and were allowed coffee, tea and limited alcohol (beer). Subjects were requested to structure their days by avoiding naps and by delimiting subjective “days” by a major wake episode and succeeding major sleep episode. Despite such instructions, some subjects did nap. These sleep episodes were not considered as major sleep episodes in original analyses, which focused only on circadian aspects of sleeping and waking. Body temperature was recorded continuously by a rectal probe and activity was measured by electrical contacts in the floor of the isolation unit and the bed. Subjects signaled their intention to go to bed and to get up by pressing a labeled button. If subjects could not avoid napping (i.e., if they decided to sleep outside their major “night” sleep episode), an additional, appropriately labeled button was pressed, prior to the initiation of the nap and upon awakening.

The minimum of body core temperature in each temperature cycle was the reference point for determining phase relationship between sleep episodes and temperature. The following results are based on a total of 99 major sleep episodes and 57 naps.

Results and discussion

Figure 1 shows the typical alternation of sleep and wakefulness for one subject during a segment (1 week) of his time in isolation. As is well-established, major sleep episodes (dark bars) showed a tendency to occur around the minimum of body core temperature. Other sleep episodes, subjectively perceived as naps (hatched bars), occurred generally in two locations relative to the temperature cycle. As with major

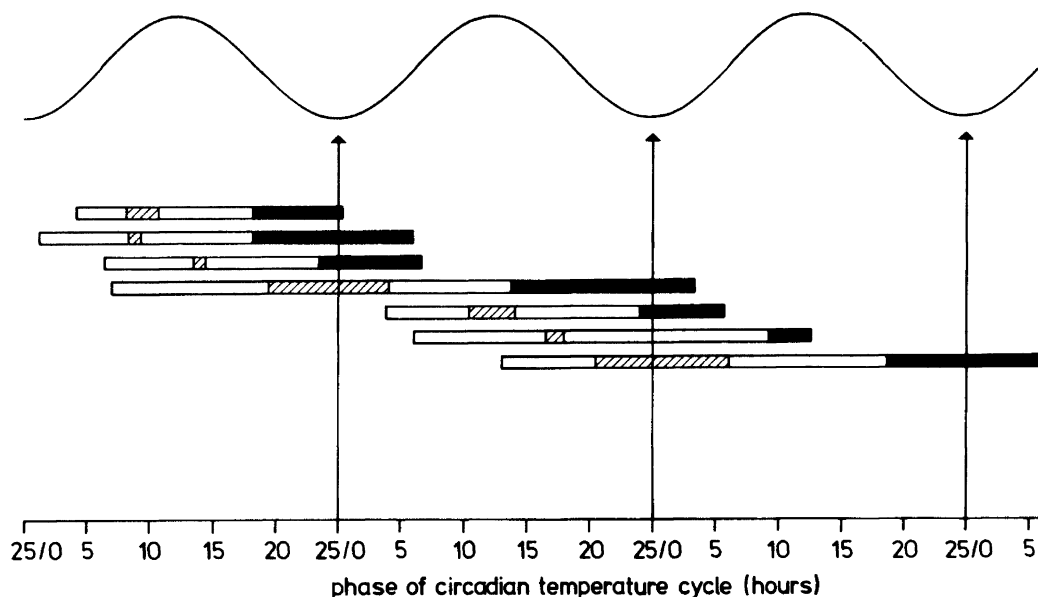


Fig. 1. Alternation of sleep and wakefulness for one subject during a segment (days 3–9) of his time in isolation. Succeeding “subjective days” are drawn beneath each other and referred to the minimum of body core temperature (“25/0” on the time scale). This section was selected because it shows the typical phase positions, relative to body temperature, of subjectively perceived major sleep episodes (dark bars), and long and short naps (hatched bars)

sleep episodes, one group of naps occurred around the minimum of body temperature. A second group of naps showed a tendency to occur approximately halfway between successive temperature minima.

This tendency held across all subjects. Based on initiation times relative to body temperature, two groups of naps were identified. As shown in Figure 2, placement of one group of naps corresponded to that of major sleep episodes, i.e., around the temperature minimum. Specifically, these naps were initiated between 8 h before and 2 h after the minimum. A second, smaller peak in the occurrence of naps clustered approximately 180 degrees away from the minimum of body temperature, that is, between 7 and 15 h after the minimum.

In addition to their differential placements relative to body temperature, the two groups of naps differed in their mean durations, as well. Naps initiated around the temperature minimum were significantly shorter than major sleep episodes (mean: 6.3 h, SD: 2.9 h vs mean: 9.0 h, SD: 3.3 h; $p < 0.001$, t-test, two tailed), but were longer than those naps initiated between temperature minima (mean: 2.4 h, SD: 1.1 h; $p < 0.001$, t-test, two tailed).

The finding that the short naps typically occur halfway between successive temperature minima suggests the existence of a second preferred phase position for sleep, albeit less robust than that at the temperature minimum. The notion of bimodality of sleep placement is supported by data from a further experiment summarized in Figure 3. Shown is the distribution of the occurrence of sleep records from nine young adults living individually in isolation units for 72 continuous hours. Static, basal levels of behavior were maintained (i.e., no reading, writing, exercise, etc. was permitted) and subjects were requested not to structure their days, but rather to eat and sleep when inclined to do so (for a detailed description of this environment see Campbell and Zulley 1985). Again, bimodality in the occurrence of sleep was observed, with relatively brief episodes (mean: 1.7 h, SD: 0.9 h) occurring approximately halfway between successive major sleep episodes. That sleep can occur even more frequently is supported by several studies, in which the experimental paradigm is characterized by minimized controls on sleep (Campbell 1984; Webb and Agnew 1974; Nakagawa 1980).

The existence of long naps at the temperature minimum (Figs. 1 and 2) underscores the strong, well-established rela-

tionship between temperature and sleep duration (Czeisler et al. 1980; Zulley et al. 1981). In addition to the significant difference in duration of long naps versus major sleep episodes, there were also differences in the onsets and durations of waking episodes preceding long naps and those preceding major sleep episodes. As can be seen in Figure 4, wakefulness prior to nap sleep was of shorter duration than that preceding major sleep episodes (mean: 11.6 h, SD: 4.1 h vs mean: 19.8 h, SD: 3.5 h). The shorter average waking duration

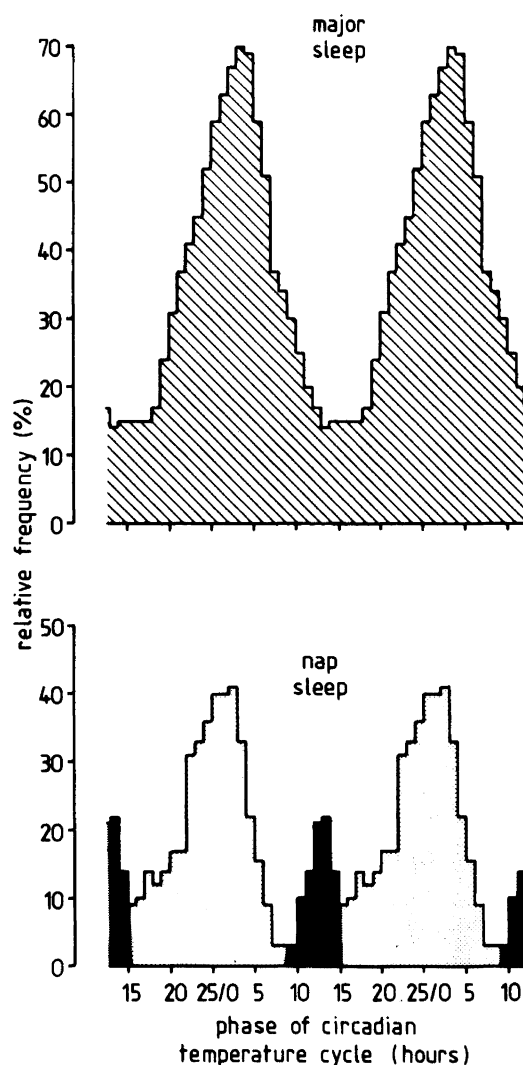


Fig. 2. Distribution (double plotted) of the relative frequency of sleep (number of hours spent in sleep related to the respective total number of cycles) in any given hour of the circadian temperature cycle; major sleep episodes above, naps below (“25/0” on the time scale refers to the circadian temperature minimum). Different shading in the nap diagram designates the two groups of naps based on their initiation times

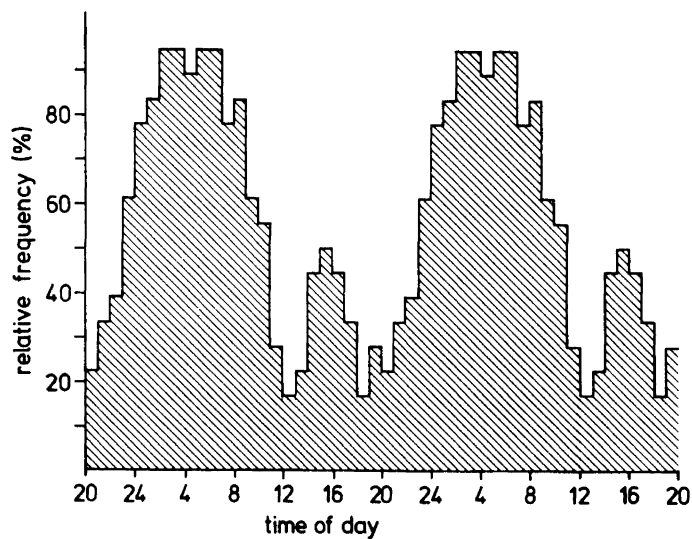


Fig. 3. Distribution (double plotted) of the relative frequency of sleep (number of hours spent in sleep related to the respective total number of cycles) in any given hour across the nychthemeron. These data were obtained from subjects maintained in isolation under highly monotonous conditions (see text)

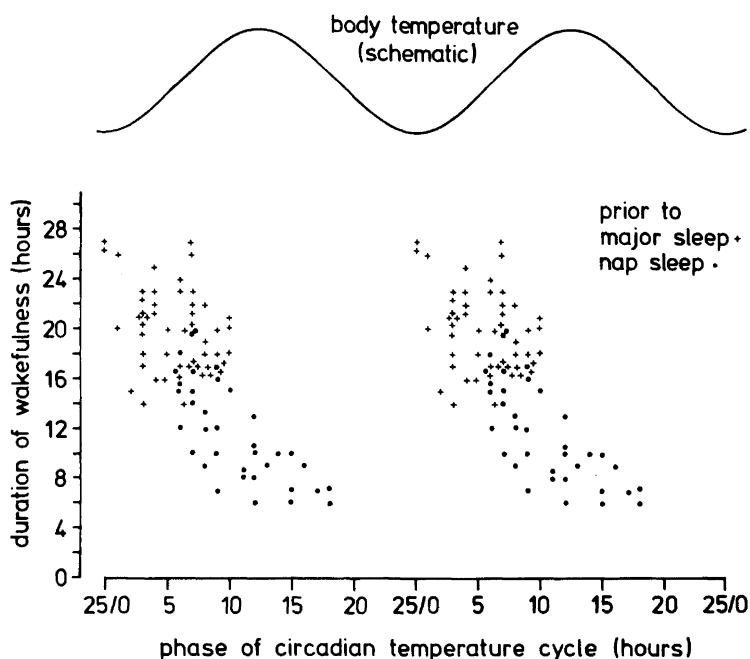


Fig. 4. Duration of waking episodes (double plotted) prior to major sleep episodes (crosses) and long nap sleep (dots) as a function of their onset relative to circadian temperature minimum ("25/0" on the time scale)

preceding long naps was a result of subjects' tendencies to awaken later in the temperature cycle and hence, closer to the following temperature minimum. Waking episodes preceding long naps began 14.5 h (SD: 3.7 h) before the next temperature minimum, while those preceding major sleep episodes began 19.7 h (SD: 3.0 h) before the temperature minimum.

Following such late awakenings and upon reaching the next temperature minimum (the next preferred phase position for sleep), a subject had to make a decision whether to sleep or to overcome the present sleep tendency by, for example, drinking a cup of coffee. If the decision was to sleep, the subject's designation of this sleep episode as a "nap", rather than a "major" sleep episode, appears to have been related not to differences in sleep duration (since the decision was made prior to sleep onset) but to the subjective perception that the interval between the previous awakening and the current sleepiness (temperature minimum) was too brief to be called a "full day" (subjects' diaries and post-

experiment interviews indicate that such decisions were, in fact, common). Such delays in the onset of wakefulness are associated with an alteration in circadian organization which may be reflected not only in such changes as subjective perception of the "day" and time estimation, but also in metabolic events (Aschoff et al. 1984; Aschoff 1985).

That subjects discriminate between two groups of long sleep episodes (long naps versus major sleep episodes) that share a common phase-relationship with body temperature (i.e., the minimum) indicates that the "psychological day" (i.e., subjectively perceived "day") may become dissociated from the "biological day". In this sense, then, internal desynchronization may clearly occur between the subjective day and body core temperature. Yet sleep, when considered as a whole (i.e., including long and short naps), may retain specific phase-relationships with body temperature. In other words, sleep and temperature remain synchronized. Furthermore, the usual experimental instructions prohibiting naps when followed by the subject, may force a subject to skip a preferred phase position for sleep. In effect, adherence to such instructions may be viewed as a masking effect on the sleep-wake system. From this point of view, an additional consequence of instructions not to nap would be the masking of a putative polyphasic sleep organization by the imposition of a monophasic sleep system. Such masking is tantamount to raising a sleep threshold as suggested by Daan et al. (1984).

Taken together, the results indicate that the human sleep-wake system is characterized by a polyphasic organization, modulated by a circadian influence, which is typically in phase with the circadian oscillation of body temperature. Under the present experimental conditions, this polyphasic organization was reflected in a bimodal distribution of sleep episodes within the circadian cycle. The presence of a second preferred phase position for sleep corresponds to transient "dips" in the course of other circadian variables such as alertness, performance (Colquhoun 1971) and temperature (Aschoff 1955; Home et al. 1983) which also occur approximately 180 degrees from the minimum of normal body temperature.

Our data further suggest that external influences such as experimental instructions, and psychological factors such as motivation to follow experimental instructions, or capacity to overcome sleepiness, may strongly affect the degree to which subjective sleep-waking behavior reflects biological sleep tendency. Finally, the results support models of the human sleep-wake system (c.f., Daan et al. 1984) that include not only circadian aspects, but which can account for other periodicities, as well as alterations in the system in response to behavioral and environmental influences.

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