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The Coupling of Sleep-Wake Patterns with the Rhythm of Body Temperature

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Introduction

The sleep-wake pattern and many physiological functions are periodic and exhibit consistent phase-relationships with each other. In humans, this association is best observed in time-free environments, where sleep episodes typically occur at the circadian minimum of core body temperature. However, such a relationship alters in the state of «internal desynchronization», where the sleep-wake system is considered to become uncoupled from the circadian temperature rhythm, a result which has been found only in humans, and there in only about 30% of the cases (1). Despite the relative infrequency of occurrence, this phenomenon is theoretically important since it provides the strongest support for the assumption of a multiple oscillatory system governing putative circadian rhythms of temperature and sleep-wakefulness in humans.

In the present study, we show that a strong circadian influence from temperature continues to be exerted on sleep-wake patterns even during «internal desynchronization», as reflected in the occurrence of naps at specific phase positions of the temperature cycle. The findings suggest that «internal desynchronization» may occur only with respect to the subjective day, while physiological sleep tendency remains in synchrony with the circadian rhythm of body core temperature.

Method

The data of six subjects were selected from a larger group, whose data were presented previously (2). The experimental conditions were identical to the standard experiments in circadian research described by Aschoff and Wever (1). Subjects lived singly for about 20 days in an isolation unit without time cues. They were allowed to control illumination and to prepare their own meals. Subjects were asked to continue their habitual sleep-wake schedules and to avoid naps. Activity was measured by electrical contacts in the floor of the isolation unit and under the bed. Body temperature was recorded continuously by a rectal probe. Subjects signaled the occurrence of several activities, including going to bed, getting up, napping and meal times by pressing appropriately labeled buttons.

The selection of the subgroup to be presented here was made on the basis of two criteria: that subjects exhibited «internal desynchronization» with a lengthening of the sleep-wake cycle, and that they reported having taken naps during the experiment, despite the instructions to the contrary.

Results

Figure 1 shows the sleep-wake pattern of one subject during a section of his time in isolation. The course of the subjective days (defined as one major wake episode, including naps, and a succeeding major sleep episode) is shown by open bars (wakefulness), shaded bars

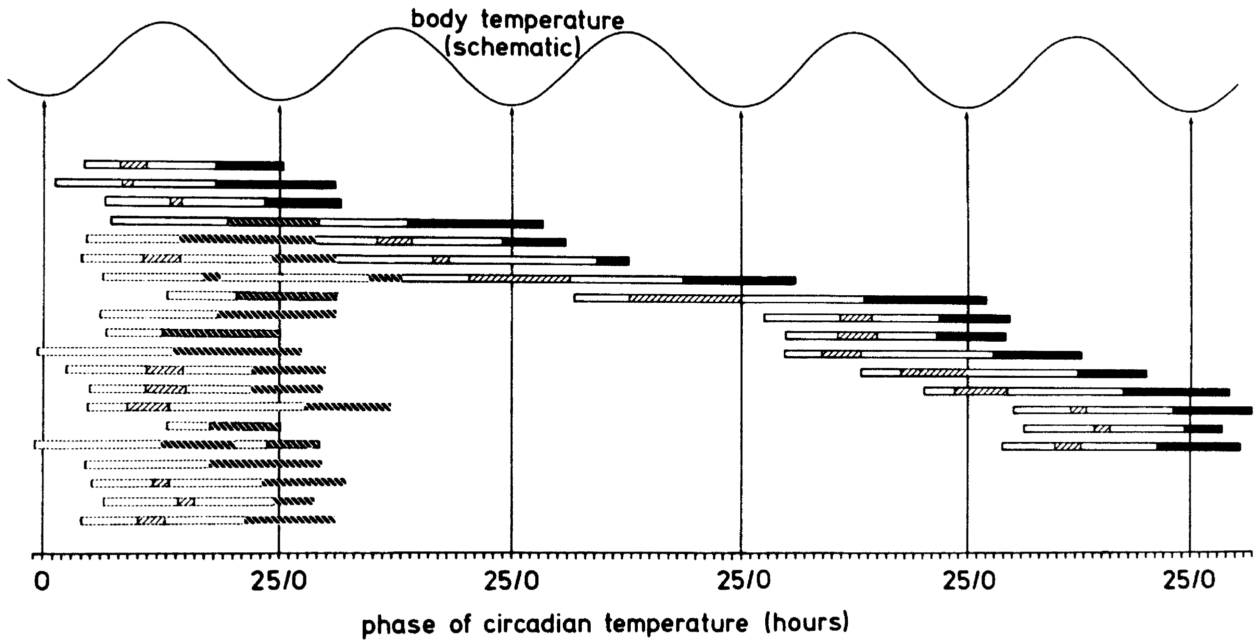

Fig. 1: Alternation of sleep and wakefulness for one subject during a segment of his time in isolation. Succeeding «subjective days» (i.e., major waking episode (open bars), with naps (fine hatched bars), and subsequent major sleep (dark bars)), are drawn beneath each other, in the diagonal. By considering only major sleep episodes, the «subjective day» became dissociated from the temperature cycle. However, by making no distinction between long naps and major sleep episodes (course hatched bars), as shown on the left-hand side of the figure, it becomes clear that only once did the subject fail to obtain sleep at the expected phase position.

(naps) and black bars (major sleep). With a mean period of about 30.6 ± 7.4 hours, the course of the *subjective* days clearly deviates from the course of the circadian temperature cycle (24.8 ± 0.8 hours). However, if the sleep-wake pattern is redrawn (broken lines) by adjusting episodes of waking and sleep (major or nap) to the respective temperature minimum, it becomes clear that a strong relationship between sleep and temperature continues.

On only one occasion did the subject fail to sleep at a preferred phase position for sleep at the temperature minimum. In the other cases, when a major sleep episode was not initiated, it was replaced by a long sleep episode designated by the subject as a nap. Naps occurring at this phase position were more comparable in duration to corresponding major sleep episodes (6.5 ± 3.1 hours versus 8.0 ± 2.2 hours) than to short naps (2.4 ± 1.1 hours).

The example shown in Figure 1 illustrates the existence of several categories of sleep-wake patterns which differ with respect to the placement of sleep (nap and major sleep episodes) in the temperature cycle. From the analysis of all sleep episodes (i.e. naps and major sleep episodes) of all six subjects, four general categories could be distinguished, three of which are shown in Figure 2:

A) a *circadian* sleep-wake pattern with the major sleep episodes occurring at the temperature minimum and no nap sleep, accounted for 41.2% of all cycles (n = 80) recorded;

B) a *circasemidian* sleep-wake pattern, with the major sleep episodes occurring at the temperatures minimum and a nap sleep occurring around the temperature maximum (22.5% of the cycles);

C) a *circadian* sleep-wake pattern, where a long sleep episode is ***designated by the subject as a nap*** (32.5% of the cycles);

D) a *circabidian* sleep-wake pattern, where a preferred phase position for sleep is skipped (3.8% of the cycles). Because of the infrequency of occurrence, this pattern is not represented in Figure 2.

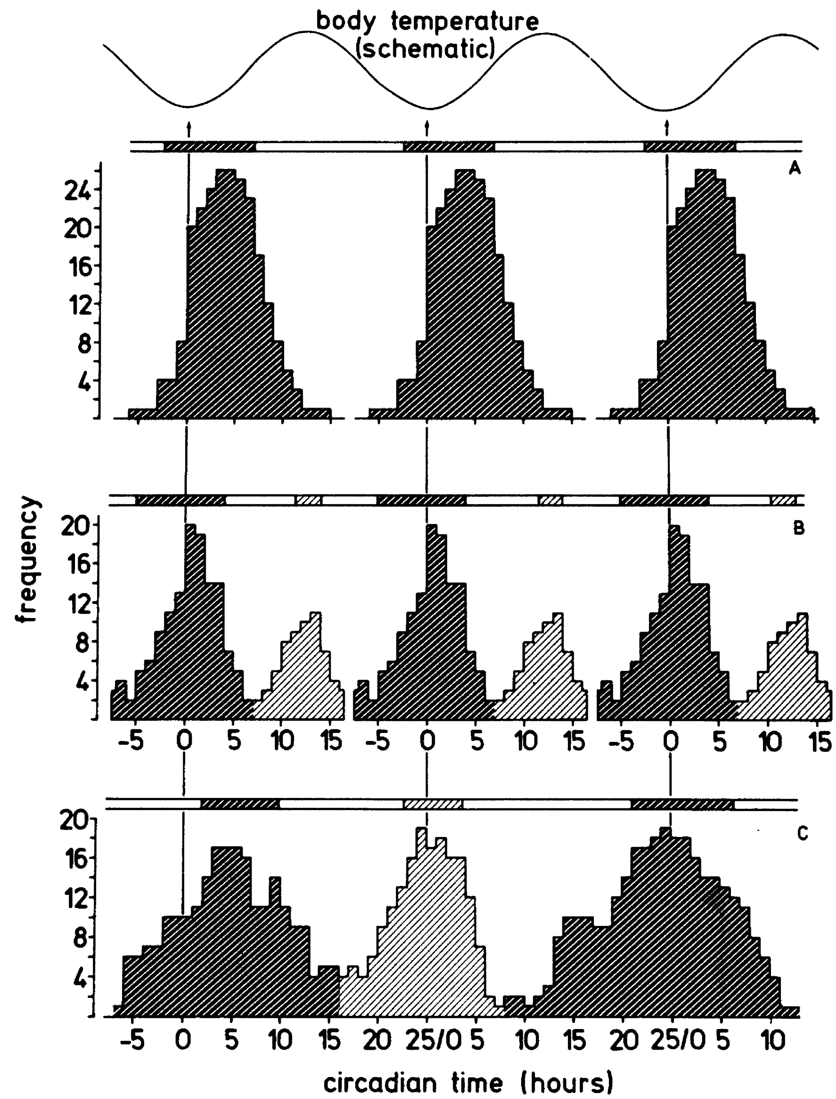

Fig. 2: Distribution of the frequency with which major sleep episodes (course hatched) and subjectively perceived naps (fine hatched) occurred for each hour relative to the circadian temperature minimum (‹0› on the time scale). Three groups are shown which differ with respect to the placement of sleep episodes. In group A (triple plot) every temperature minimum is accompanied by a major sleep episode. In addition to the pattern shown in group A, a nap occurred in group B. In group C (single plot) some long sleep episodes occurring at the temperature minimum were designated by subjects as naps (fine hatched).

In addition to differences in sleep placement between groups A–D, there were also differences in the onsets of preceding waking episodes relative to the temperature cycle. The earliest onset of wakefulness (group B; 4.2 ± 2.3 hours after temperature minimum) was associated with a short nap halfway between two preferred phase positions for sleep. While group A (circadian pattern with no nap) was preceded by awakenings at 7.3 ± 3.2 hours after temperature minimum, awakenings prior to sleep patterns shown in group C (designating an expected major sleep as a nap) were begun even later, at 10.2 ± 3.6 hours after the minimum. The latest awakenings occurred prior to the pattern in group D where subjects skipped the following (preferred) phase position for sleep, with wake period onset beginning 14.8 ± 3.3 hours after the temperature minimum.

Discussion

These analyses of experiments in which subjects took naps during the state of «internal desynchronization», indicate that physiological sleep-wake tendency may not become dissociated from the temperature cycle. By considering subjectively perceived naps, which are similar in placement and duration to major sleep episodes, as major sleep episodes, sleep occurs with rare exception (3.8% of all cycles) around the temperature minimum, indicating continued synchrony between the two variables. Even in these rare exceptions (i.e. circabidian sleep patterns), sleep and temperature cannot be said to become truly desynchronized since sleep continues to be placed around temperature minima, albeit every second one. It is clear, then, that the trough of body temperature corresponds to a time of robust physiological sleep tendency, typically culminating in a sleep period of relatively long duration.

Nevertheless, the occurrence of sleep is not limited to such a preferred sleep phase and, depending on experimental conditions or behavioral controls, sleep can occur polyphasically within the temperature cycle (3). The patterning of sleep is clearly associated with the preceding time of getting up (and hence the duration of prior wakefulness) relative to the temperature cycle (4). If a subject wakes up earlier than is typical under those conditions (Fig. 2, case B), an additional, brief sleep episode is added about halfway through the waking episode. If waking begins later (case C) the time interval between waking up and the following preferred sleep episode is perceived by the subject as being too short to be called a full day (4). As such this sleep phase is «bridged» by a long sleep episode, designated as a nap. If getting up is even later (case D), an expected sleep episode can be skipped.

This possibility is also favored by experiments employing *forced* «internal desynchronization», in which subjects are asked to skip preferred phase positions for sleep and, rather, to follow artificial time-cues regarding sleep-wake scheduling. If a subject «masks» the sleep-wake pattern by skipping a preferred phase position for sleep, or replaces it by a nap, the *subjective* day and the physiological sleep-wake cycle become dissociated. This also results in a «desynchronization» between the *subjective* day and body temperature. Skipping or replacing a sleep episode leads obviously to a drastic lengthening of the subjective day (median 44 hours) (5). Yet, there is no hint that the physiological tendency for sleep is also removed. As Webb (6) has noted (p. 315), «an apparent absence of a timed event within a time sequence is not evidence that the rhythm does not exist». Simply, in response to behavioral controls and experimental conditions, humans have the capacity to overcome sleepiness.

Taken together, these results suggest that deviations of the subjective day from the temperature cycle may not reflect the course of a physiological sleep tendency, which appears to remain in synchrony with the temperature cycle. On the other hand, sleep can occur at virtually any time within the circadian temperature cycle with preferred phase positions for sleep existing (7). Thus it may be concluded that phase position and duration of sleep episodes are related to the circadian temperature cycle, while the actual frequency with which sleep occurs is primarily governed by environmental and behavioral controls.

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