Human Perception of Short and Long Time Intervals: Its Correlation with Body Temperature and the Duration of Wake Time

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Abstract Time estimation was studied in seven human subjects during prolonged sojourn is isolation from time cues. They wore rectal temperature probes throughout the experiments, and during wakefulness recorded each time they thought one hour had passed. At the end of each of these subjective hours they produced a subjective 5 or 10 sec interval. The produced intervals on the 1-h task were not related to body temperature but were correlated with and proportional to the duration of waketime in all subjects. The produced 5 and 10 sec intervals were in all subjects negatively correlated with rectal temperature, but were not associated with wake time. Brief and long time intervals are subjectively experienced via different mechanisms.

Key words Time sense, time perception, temperature, human circadian, waketime

INTRODUCTION

From the point of view of a chronobiologist, human time perception can be divided into 2 distinct classes that differ in their interaction with the circadian system: short time intervals in the range of seconds (up to about 2 min) are not affected by changes in the sleep-wake cycle, as recorded under conditions of temporal isolation. In contrast, the production of long time intervals, such as 1 h, show a strong positive correlation with the duration of wake time (wakefulness) (Aschoff, 1985). The 2 classes also differ in 2 further aspects: the production of short intervals shows a negative correlation with body temperature and a positive correlation with the intensity of illumination, while the 1-h intervals are independent of both these variables. For the short time intervals, the negative correlation with body temperature has often been documented (Aschoff and Daan, 1997; Francois, 1927; Hancock, 1993; Hoagland, 1933; Pfaff, 1968; Wearden and Penton-Voak, 1995), and 2 publications give strong evidence for a positive correlation with light intensity (Aschoff and Daan, 1997; Pöppel and Giedke, 1970). With regard to the 1-h intervals, an independence of light intensity is well supported (Aschoff and Daan, 1997), but data on their interrelationship with body temperature are largely missing. There is one study in which subjects, living singly in temporal isolation, were asked to estimate, sequentially, the time of day; the subjective hour derived from these estimates showed a positive correlation with body temperature (Campbell and Murphy, 1995). In this report, it will be shown that the production of 1-h intervals is independent of rectal temperature, in con-

1. To whom all correspondence should be addressed. Dedicated to my esteemed and irreplaceable coworker Ulla Gerecke, who over the years minutely took care of our protocols, on the occasion of her 80th birthday.

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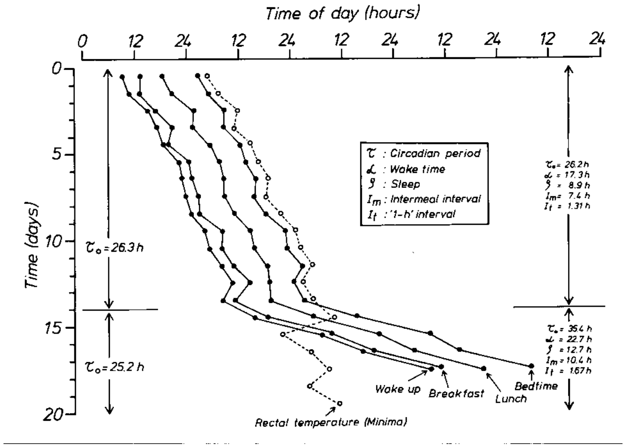

Figure 1. Free-running circadian rhythm of S.35, who remained internally synchronized for 13 cycles and became long desynchronized thereafter. The solid lines connect, for consecutive cycles, the times of waking up, of breakfast and lunch, and of bedtime (sleep onset); the open circles, connected by a dotted line, represent the minima of rectal temperature. On the right and left margins, means are given for the circadian period as measured between successive awakenings (right margin; τ_0) and for the period of the rhythm in rectal temperature (left margin; τ_0).

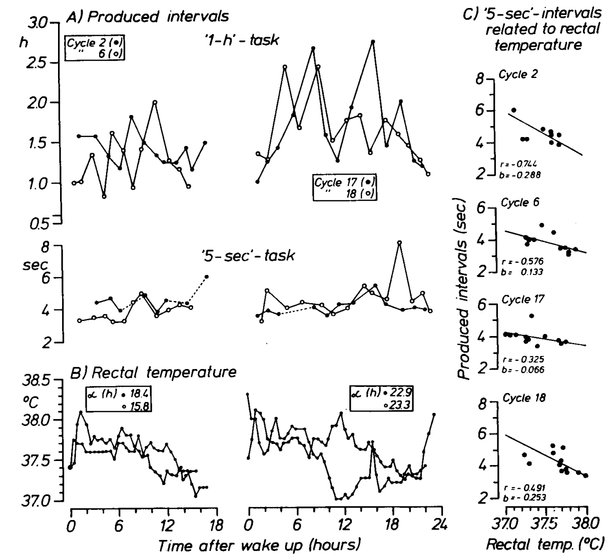

Figure 2. Diagram A: Sequences of time intervals produced by S.35 during 2 cycles of internal synchronization (Cycles 2 and 6) and 2 cycles of long desynchronization (Cycles 17 and 18). In Diagram B, data on rectal temperature are plotted as recorded in half-hour intervals during the 4 cycles. Diagram C shows the dependence of the 5-s intervals on rectal temperature.

trast to the negative correlation between short intervals and temperature.

MATERIALS AND METHODS

Data were collected from 7 subjects (2 females, ages 22 and 28; 5 males, ages 25.8 ± 5.5 years) who lived singly in an underground isolation unit for at least 3 weeks (mean duration 25.8 ± 5.6 days) without knowledge of time of day. In 4 subjects, the free-running circadian rhythms remained internally synchronized with a mean period of 25.8 ± 0.47 h. In the other 3 subjects, the sleep-wake cycle was temporarily lengthened to more than 28 h or shortened to less than 22 h, resulting in a desynchronization of the rhythm of rectal temperature from the sleep-wake cycle (states of long or short internal desynchronization). The 2 subjects who entered long desynchronization had a mean sleep-wake cycle of 25.9 h during internal synchronization and a cycle of 35.5 h during desynchronization; the subject with short desynchronization alternated between 24.2 and 18.2 h, respectively.

The subjects were permitted to schedule their "days" at choice. They signaled the times when they took a (self-prepared) meal. As a measure for the duration of wake time and sleep, the intervals were used between 2 signals given by the subjects immediately after waking up and at the time when they turned off their bedside reading lamp. Body temperature was recorded continuously by means of a rectal probe. To obtain data on time perception, the subjects were asked to press a button whenever they thought that 1 h had passed; they had to perform this task as long as they were awake, throughout the entire experiment.

Before or after the 1-h task, the subjects had to press another button for the assumed duration of 10 s; for one subject (S.35), the task was 5 s. The means of correlation coefficients were calculated after z-transformation.

RESULTS

In Fig. 1, consecutive circadian cycles as recorded in S.35 are plotted beneath each other. The solid lines connect the times (closed circles) of waking up, of the meals, and of bedtime (sleep onset); the minima of

Table 1. Coefficients of correlation and of regression between 1-h intervals and rectal temperature. °C_{mean}: temperature integrated over time. °C_{end}: temperature at the end of the 1-h interval.

	Coefficient of			
	Correlation with		*Regression with*	
Cycle	°C_{mean}	°C_{end}	°C_{mean}	°C_{end}
2	0.227	0.216	0.237	0.209
6	–0.168	–0.161	–0.260	–0.250
17	–0.091	–0.103	–0.162	–0.216
18	0.117	0.088	0.169	0.154

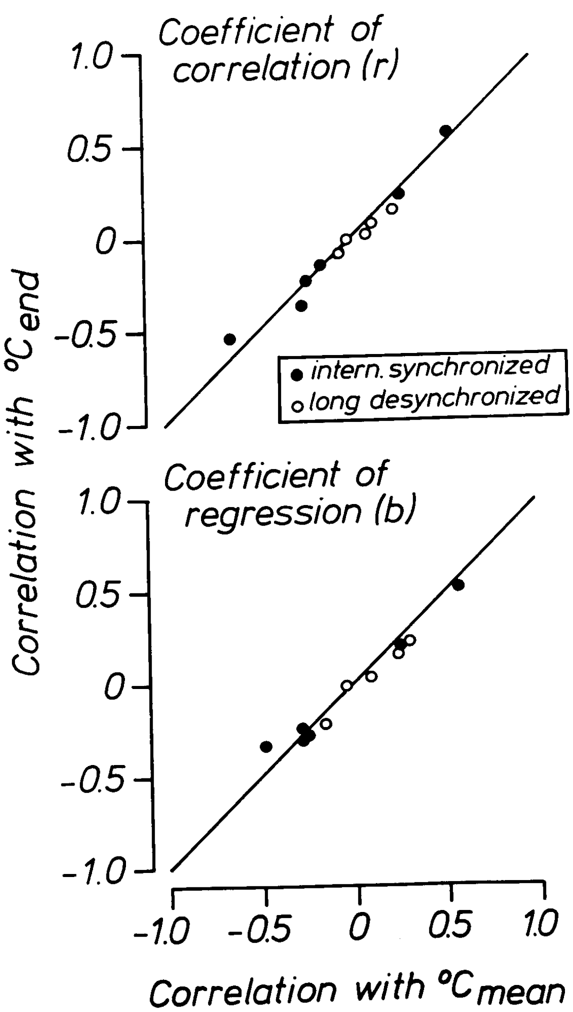

Figure 3. Comparison of the coefficients of correlation (upper diagram) and of regression (lower diagram) between 1-h intervals and rectal temperature, computed either for the integral temperature (°C_{mean}; abscissa) or for the temperature at the end of the interval (°C_{end}; ordinate). Data from 11 cycles of S.35.

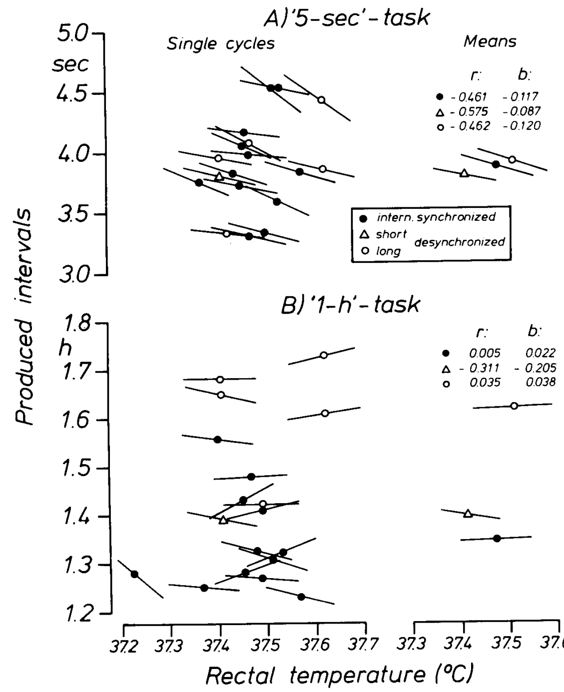

Figure 4. Dependence of 5-s intervals (Diagram A) and of 1-h intervals (Diagram B) on rectal temperature. Left side: means and regression lines for all 18 cycles of S.35. Right side: overall means for the different states of the circadian system. The lines represent the slopes and not the entire ranges used for the calculation.

rectal temperature (open circles) are connected by a dotted line. This subject remained internally synchronized for the first 13 cycles and became, after one short cycle, long desynchronized for the remaining time. The mean circadian period τ of the sleep-wake cycle was 26.2 h during the first and 35.9 h during the second part of the experiment; for the temperature rhythm, the τ-values were 26.3 and 25.2 h, respectively. During both states of the circadian system, S.35 adhered to the habit of taking 2 meals per "day" (breakfast and lunch). Consequently, the intermeal interval (Im) was lengthened during long desynchronization: from 7.4 to 10.4 h. Similarly, the 1-h intervals produced by S.35 (It) increased from 1.31 to 1.67 h (cf. the numbers given at the right margin of Fig. 1).

To give an idea of the data basis for time perception, sequences of intervals, produced by S.35, are plotted in Fig. 2A. The diagrams on the left present data from 2 cycles during internal synchronization (Cycles 2 and 6) and those on the right data from the last 2 cycles of

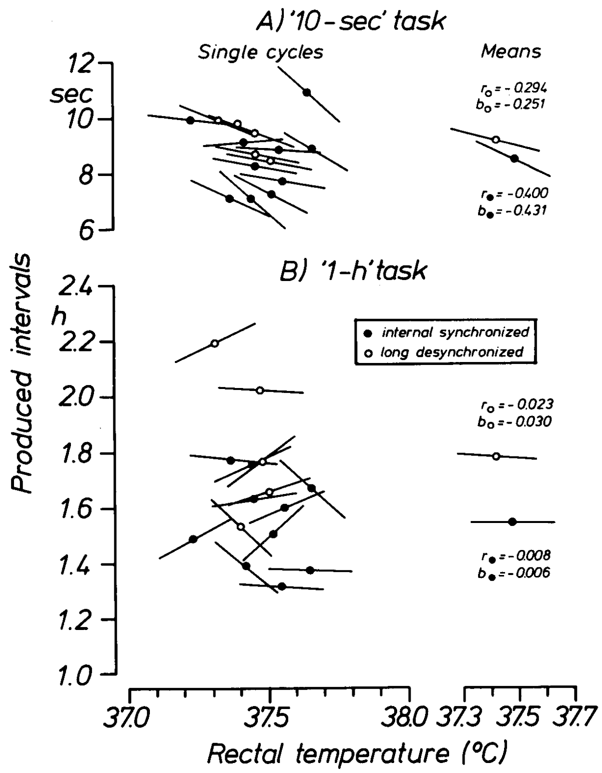

Figure 5. Correlation of 10-s intervals (Diagram A) and of 1-h intervals (Diagram B) with rectal temperature. Data from S.39. Left side: means and regression lines for 15 cycles. Right side: overall means for the different states of the circadian system. The lines represent the slopes and not the entire ranges used for the calculation.

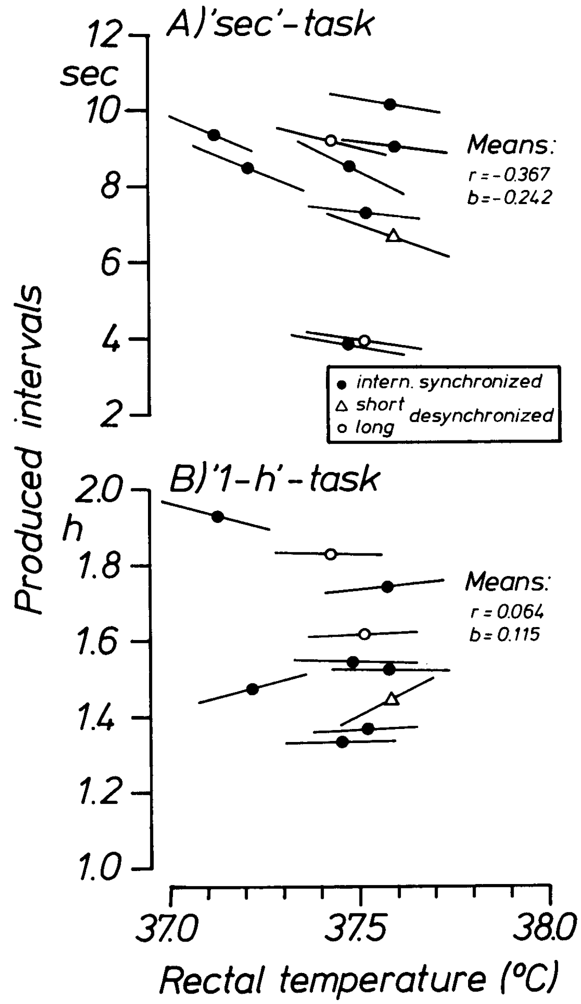

Figure 6. Correlation of short time intervals (Diagram A) and of 1-h intervals (Diagram B) with rectal temperature. Overall means and regression lines from 7 subjects. Symbols represent different states of the circadian system (cf. the inset). The lines represent the slopes and not the entire ranges used for the calculation.

long desynchronization (Cycles 17 and 18). In Diagram B, data on rectal temperature are given as recorded in half-hour intervals during the 4 cycles. Already from a cursory glance, it becomes evident that, on average, the 1-h intervals are much larger during long desynchronization (right) than during internal synchronization (left). In contrast, the 5-s intervals remain more or less at the same level during both states of the circadian system.

The interrelationship between produced intervals and body temperature is not immediately obvious from the curves displayed in Diagrams A and B of Fig. 2, but it is easy to compute the coefficients of correlation for the short intervals because the temperature at the time of the task is well defined (i.e., temperature is unlikely to change much during a few seconds). As shown in Diagram C of Fig. 2, in all 4 cycles, the 5-s intervals are negatively correlated with rectal temperature. With regard to the 1-h intervals, it could be argued that the relevant variable is not the temperature measured at the time when the subject pressed the button—that is, at the end of the interval ($°C_{end}$)—but the integral over the whole interval ($°C_{mean}$). Results from these 2 ways of computation are listed in Table 1. The coefficients of correlation (*r*) and of regression (*b*) have the same sign and are of the same order of magnitude. A comparison of coefficients derived by the 2 different procedures is given in Fig. 3 for 6 internally synchronized and 5 long desynchronized cycles. It turns out that $°C_{mean}$ and $°C_{end}$ again reveal the same coefficients. Hence, in the further analysis,

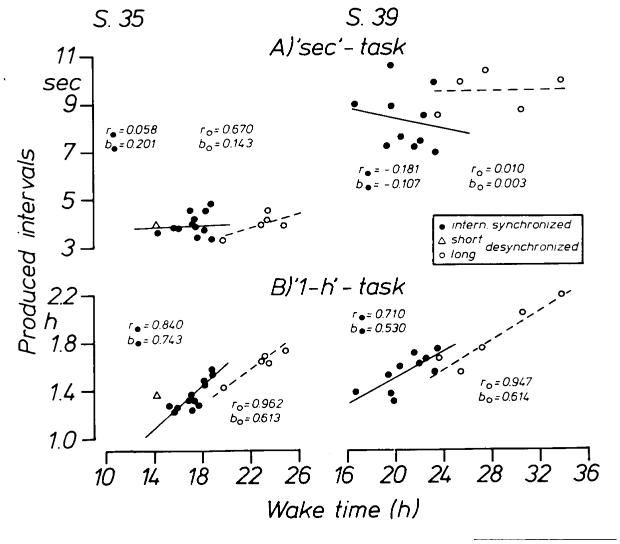

Figure 7. Correlation of short time intervals (Diagram A) and of 1-h intervals (Diagram B) with the duration of wake time, as recorded in S.35 and S.39. Symbols indicate different states of the circadian system (cf. the inset).

the temperatures recorded at the end of the 1-h interval are used throughout.

An overview on the correlation between produced intervals and rectal temperature for all cycles of S.35 is given in Fig. 4. The short intervals (Diagram A) are without exception negatively correlated with temperature; the means of the coefficients range from –0.461 to –0.575. In contrast, the 1-h intervals show no systematic dependence on temperature, and the means of the coefficients are close to zero (with the exception of the one short desynchronized cycle; cf. the inscribed numbers). A similar overview is given in Fig. 5 for all cycles of subject 39 (S.39), whose rhythm alternated between internally synchronized and long desynchronized cycles. Again, the coefficients of correlation for the short intervals (10-s task; Diagram A) are all but one negative, with a mean of –0.400 for the internally synchronized cycles and –0.294 for the long desynchronized cycles; the 1-h intervals (Diagram B) show as many positive as negative correlations, and the means of the coefficients are close to zero (r = –0.008 for internally synchronized cycles, and r = –0.023 for long desynchronized cycles).

To summarize the results obtained from all 7 subjects, the individual means of the produced intervals, together with the regression lines, are plotted in Fig. 6; for each of the 3 subjects who became internally desynchronized, 2 means are shown in correspondence to the states of the circadian system (cf. the inset). In all subjects, the short intervals are negatively correlated with rectal temperature, with an overall mean r = –0.367; the 1-h intervals are independent of rectal temperature (overall mean r = 0.064).

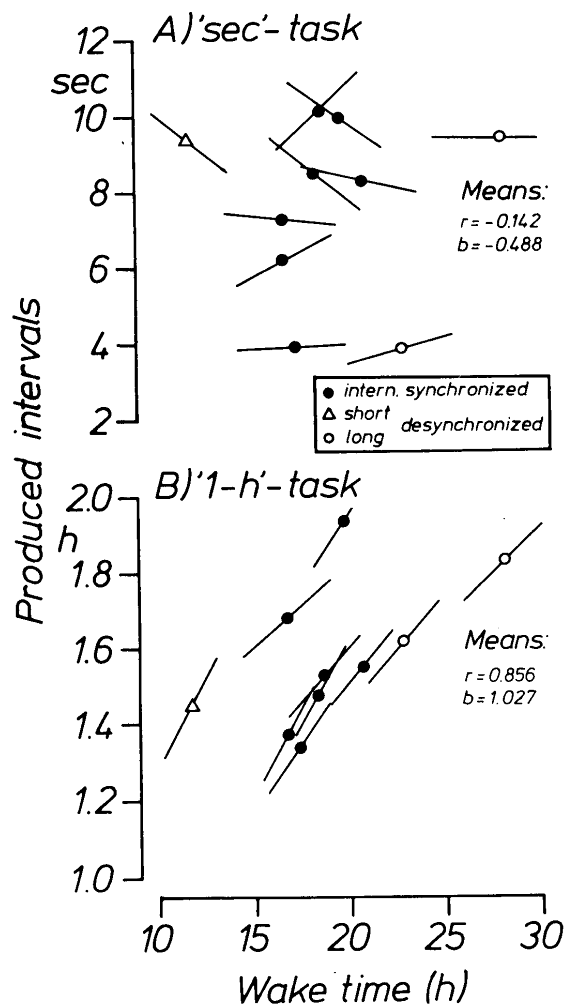

Figure 8. Correlation of short time intervals (Diagram A) and of 1-h intervals (Diagram B) with the duration of wake time. Overall means and regression lines from 7 subjects. Symbols as in Fig. 7. The lines represent the slopes and not the entire ranges used for the calculation.

The interrelationship between produced intervals and duration of wake time (α) follows the well-known principles (Aschoff, 1985). As shown in Fig. 7 for S.35 and S.39, the short intervals are, on average, independent of α, while the 1-h intervals show a strong positive correlation (cf. the inscribed r- and b-values). A summary of these correlations derived from the protocols of all 7 subjects is given in Fig. 8. The short intervals are not systematically related to α, but the 1-h intervals show, without exception, a strong positive correlation.

Final remark: in the foregoing paragraphs, as well as in the legends to the figures, often the expression is used that short time intervals "depend" on body temperature and that 1-h intervals are "independent" of body temperature. Although such a phraseology most likely is appropriate in the 2 cases mentioned, one has to keep in mind that text and figures deal with correlations and that no hasty conclusions should be drawn with regard to causal relationships (cf. the paragraph on "Cause and Effect" in Aschoff, 1997, p. 42).

DISCUSSION

Important steps in the analysis of the circadian system and its properties and adaptive usefulness were the experimental demonstration of a "time sense" in bees (Beling, 1929) and the discovery of "sun compass orientation" in bees (von Frisch, 1950) and birds (Kramer, 1950). Kalmus (1934) emphasized the necessity that a "clock" used to measure time of day, as done by bees, should be independent of changes in body temperature, and he studied this mechanism by exposing time-trained bees either for 6 h to 5-7ºC or for 3 h to 38ºC. It was Pittendrigh (1954) who then convincingly demonstrated that the principle of temperature compensation is a characteristic of the circadian system as a whole by showing that the period of the emergence rhythm in fruit flies was almost independent of the temperature at which the cultures had been kept.

The 1-h intervals produced by subjects under conditions of temporal isolation are independent of rectal temperature—that is, the perception of hours falls into the class for "orientation in time," as defined by Eson and Kafka (1952), which more adequately may be called orientation in time of day. It is intelligible why this function of orientation in time of day has evolved in addition to be independent of light intensity (Aschoff and Daan, 1997).

In contrast to orientation in time of day, the perception of short time intervals in the range of seconds serves other purposes. It is programmed to deal with short-lasting events that run at a higher speed, and it follows the general rule that biological processes are accelerated with increasing temperature. In short, it is the class of time perception for the awareness of fast events.

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