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EFFECT OF LIGHTING CONDITIONS ON CIRCADIAN RHYTHM OF RECTAL TEMPERATURE IN MICE

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One of the principal synchronizers for animals is the alternation of light and darkness, changes in which (a phase shift of lighting, in the length of the period, continuous daylight or darkness, reversal of the lighting conditions) lead to disturbances of the circadian rhythms of physiological processes, including those of an integral factor such as the rectal temperature [2, 4, 6, 9].

All the investigations cited above were undertaken under artificial lighting conditions, as regards both experiment and control. Accordingly, it is highly interesting to compare the circadian rhythm of rectal temperature in nocturnal animals kept under conditions of continuous lighting, and under natural conditions of alternation of day and night, for in that situation daylight and darkness do not begin suddenly, as with a fixed lighting schedule, but gradually, with a period of twilight. Moreover, by continuing the study for a long period of time, it is possible, on the one hand, to discover the principles observed in the character of the temperature rhythm during adaptation to continuous light and, on the other hand, to determine what changes may characterize the temperature rhythm under natural conditions during different lengths of daylight in different months of the year.

The circadian rhythm of rectal temperature was studied in the present investigation for 4.5 months in mice kept in continuous daylight and during natural alternation of day and night.

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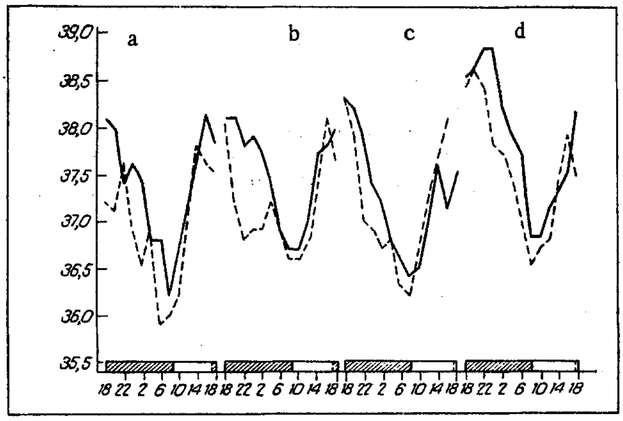

Fig. 1. Circadian rhythm of rectal temperature in mice in experiments of series I (a), II (b), III (c), and IV (d). Abscissa, time of day (24-hour clock; in h; dark period of day corresponding to astronomical time of sunrise and sunset is shaded); ordinate, rectal temperature (in °C). Continuous line — control, broken line — continuous daylight. In all series differences between temperature at 6 p. m. on first day and minimal, and also between minimal temperature and that at 6 p.m. next day are significant ($p < 0.05$).

EXPERIMENTAL METHOD

There were 8 series of experiments in which mature noninbred male mice weighing 18-21 g (at the beginning of the experiment) were used. The mice were allowed food and water ad libitum. The rectal temperature was measured by means of the TPÉM-1 electrothermometer every 2 h for 24 h, starting at 6 p.m. and ending at 6 p.m. next day (13 measurements). Every hour of the investigation, 20 mice were used at the beginning of the experiment (in each of the two groups of animals). Mice of group 1 were kept under natural conditions of alternating daylight and darkness (control), those of group 2 in continuous artificial lighting with an intensity of 60 lx. The experiments of series I were conducted on February 2-3 (the first day was for adaptation to continuous daylight), series II on February 6-7 (5th day), series III on February 9-10 (8th day), series IV on February 13-14 (12th day), series V February 16-17 (2 weeks), series VI on February 25-26 (about 1 month), series VII on March 11-12 (about 1.5 months), and series VIII on June 19-20 (about 4.5 months). In the experiments of series VIII, the temperature of the animals exposed to continuous daylight was measured every 3 h, also beginning at 6 p.m. The results were subjected to statistical analysis by the Fisher–Student method.

EXPERIMENTAL RESULTS

It will be clear from Figs. 1 and 2 that a definite monomodal circadian rhythm of rectal temperature was observed in animals kept under natural conditions (control) in all the series of experiments. In series I its peak (38.1°C) was observed 4-6 p.m. with a minimum (36.2°C) at 8 a.m.; The mean temperature for the 24-h period was 37.4° C. If the astronomical times of sunset (5:04 p.m.) and sunrise (8:24 a.m.) are taken into account, the maximal rectal temperature occurred at the beginning of the dark period of the day, and the lowest temperature at its end. The circadian rhythm of temperature in the experimental series II-IV in the control animals also was characterized by a peak level during twilight and the beginning of the dark period, and the minimal level in the dawn hours. Incidentally, these results differ from those obtained by other workers [2-6], who studied the circadian rhythm of rectal temperature in mice and rats under a fixed schedule of light and darkness in which, as a rule, the maximum occurred in the middle of the dark period and the minimum in the middle of the light period. In the case of daylight from 6 a.m. to 6 p.m. and darkness from 6 p.m. to 6 a.m. the maximum of temperature was observed at midnight and the minimum at noon [5]. In this case the astronomical time of day had no role to play in these investigations, for in the case of reversal: daylight from 6 p.m. to 6 a.m. and darkness from 6 a.m. to 6 p.m., the maximal temperature of the mice was observed at 2-6 p.m., i.e., in the second half of the period of darkness [6].

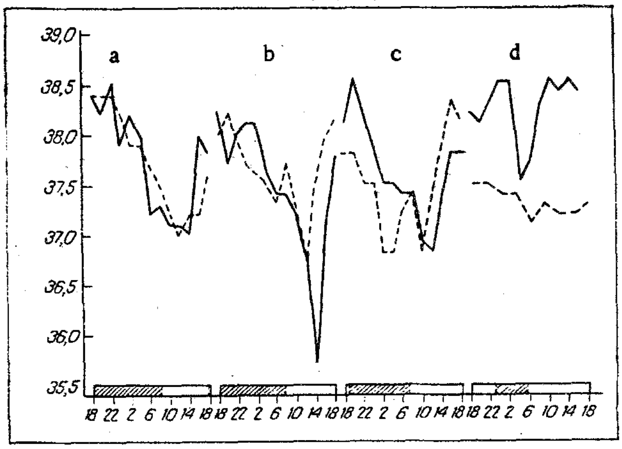

Fig. 2. Circadian rhythm of rectal temperature in mice in experiments of series V (a), VI (b), VII (c), and VIII (d). In series VIII no significant differences in rectal temperature were observed during continuous lighting at different times of the 24-h period. Remainder of legend as to Fig. 1.

Consequently, the character of the circadian rhythm of the rectal temperature under natural conditions obeys somewhat different rules from that on a fixed program of light and darkness.

In the experiments of series V-VII, which took place at the end of winter and beginning of spring (in this period the length of darkness is shortening and the length of daylight lengthening) a shift of the minimum of temperature was observed in the control animals to the period of daylight: in series V the lowest values observed between 6 a.m and 2 p.m. ($p_{6-2} > 0.05$) i.e., at the end of the dark and beginning of the light period, in series VI it was observed at 2 p.m., and in series VII at noon, i.e., the middle of the period of daylight. The maximal rectal temperature continued to be recorded in the first half of the period of darkness, and in series V-VI, bigeminy was observed at 8 p.m., whereas in series VII the temperature was highest at this time. Finally, in the experiments of series VIII, when the length of daylight was 17 h 36 min, the maximal temperature (38.5°C) occurred between 10 and 2 a.m. with bigeminy at 8 p.m.; the minimal (37.5°C) at 4 a.m., i.e., again at the end of the period of darkness (average temperature for the 24-h period 38.2°C). The following fact must be noted: in series I-IV (winter), when the period of darkness (in series I it was 15 h 20 min, in series V it was 14 h 33 min) was significantly longer than the period of daylight (8 h 40 min and 9 h 27 min respectively), the fall of temperature from maximal value to the minimum took place in the course of 12-14 h, i.e., the whole of the period of darkness; whereas in June (summer), when the length of the period of darkness was reduced by more than half to 6 h 24 min, the fall of temperature from maximum to minimum took only 2 h (series VIII).

Differences in the degree of synchronization of rectal temperature between winter and summer months indicate that the length of the periods of darkness and daylight may play an important role in the character of its circadian rhythm, not only with a fixed photoperiod, but also under natural conditions. Moreover, the appearance of bigeminy, noted above (with the onset of spring), the shift of the minimum to the right, and also the increase in the period of lowering of the temperature to 16-20 h (series V-VII), suggest that the change in the ratio of the duration of light to darkness taking place at this time leads to deformation of the pattern of circadian rhythm, which evidently reflects the period of restructuring throughout the temperature regulating system.

In animals kept under conditions of continuous illumination and investigated in the experiments of series I-VI the rectal temperature also shows significant circadian differences but the character of the pattern of the curves in some experiments differs from that in the control. In series I the maximal temperature (37.8-37.6°C) was observed between 2 and 10 p.m. with bigeminy at 8 p.m., the minimal temperature (35.9°C) at 6 a.m. (mean temperature for the 24-h period 36.9°C). It will be clear from Fig. 1 that the curve is very similar to that of the control but has a noteworthy rise at 4 a.m. ($p_{2-4} < 0.05$), which cannot yet be interpreted as a second maximum, for the differences in temperature between the 2-h and 6-h points are significant ($p_{2-6} < 0.05$). In series II the formation of a second maximum at 4 h can be considered to be significant ($p_{10-4} < 0.05$; $p_{4-8} < 0.05$), for the difference in temperature between the 10 p.m. and 8 a.m. points is not significant ($p > 0.05$). Consequently, on the 5th day of adaptation to constant illumination conditions dissociation of the circadian rhythm takes place into the bimodal type: maximum at 4-6 p.m. and 4 a.m.; minimum at 10 p.m. and 8-10 a.m. In the next three series of experiments (III-V) the circadian rhythm of temperature again becomes monomodal in character with a maximum at 6 p.m. and 6-10 p.m. and with a minimum at 8 a.m. and noon (respectively), which is highly synchronized with the temperature of the control animals. In series VI, despite the similarity of the curves for animals kept under conditions of continuous illumination, and in the control mice, a rise of temperature will be noted, but this time at 8 a.m. ($p_{6-8} < 0.05$, but $p_{6-12} < 0.05$ also). In series VII, after 1.5 months of adaptation to continuous illumination, the formation of a bimodal temperature rhythm with maximal values at 4-6 p.m. and 8 a.m. and with minimal values at 2-4 a.m. and 10 a.m. ($p_{4-8} < 0.05$, $p_{8-10} < 0.05$) was again recorded. In series VIII, i.e., after 4.5 months of continuous illumination, no statistically significant differences of rectal temperature could be found at different times of the 24-h period ($p_{6pm-6am}$ and $p_{6am-6pm} < 0.05$), evidence of disappearance of the circadian rhythm of this parameter. Moreover, the average temperature for the 24-h period was significantly lowered: with alternation of day and night (LD) 38.2°C, with continuous lighting (LL) 37.3°C (p_{LD-LL} 0.05).

During adaptation of mice to continuous illumination conditions, "dissociation" of the circadian rhythm of the rectal temperature into two components with periods of 10-14 h is thus periodically observed. A similar "dissociation" of a monomodal rhythm into bimodal also has been found [7-9] for motor activity in nocturnal animals (mice and hamsters) exposed to continuous lighting. In addition, keeping animals for a long time (4.5 months) under continuous lighting conditions leads to disappearance of the circadian rhythm of rectal temperature, evidence of profound disturbances in the temperature regulating system.

To conclude, the view that circadian rhythms of physiological processes in nocturnal animals are reversed by comparison with those in man is evidently not absolute so far as laboratory animals are concerned. The results described above show that the circadian rhythm of rectal temperature in mice, when compared with data obtained by the writers previously [1] on human body temperature under different conditions of work and rest, is not reversed, but is marked only by a shift of the maximum and minimum within the limits of the 24-h period.

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