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Sleep-enhancing effects of far-infrared radiation in rats

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Abstract. Unrestrained male rats continuously exposed to far-infrared radiation exhibited a significant increase in slow wave sleep (SWS) during the light period but not in the dark period. The change was largely due to the elevated occurrence of SWS episodes but not to the prolongation of their duration. Paradoxical sleep was not affected throughout the observation period except for a significant decrease at the end of the dark period. Thus the far-infrared radiation exerted a sleep modulatory effect closely related to the circadian activity-rest cycle.

Key words: Far infrared – Slow wave sleep – Light period – Circadian activity-rest cycle

Introduction

Far-infrared radiation has been regarded to be indifferent to living organisms, since the limits of radiation effective in inducing a physiological reaction are considered to lie between 300 and 950 nm (Wolken 1971). Recently, we reported that rats continuously exposed to far-infrared radiation from the prenatal period exhibit an acceleration of body growth (Inoué and Honda 1986). This paper describes the first attempts to detect a sleep-modifying effect of the far-infrared radiation.

Materials and methods

Male rats of the Sprague-Dawley strain were raised in our closed colony on a 12 h light and 12 h dark schedule (lights on: 08.00 h to 20.00 h) under a constant air-conditioned environment of $25 \pm 1°$ C and $60 \pm 6\%$ relative humidity. They were allowed free access to rat chow and water.

At the age of 60–70 days, animals weighing 300–350 g were implanted with three cortical electroencephalogram (EEG) and two nuchal electromyogram (EMG) electrodes. The surgical procedures are described elsewhere (Honda and Inoué 1978). The rats were individually isolated to a special recording cage, in which two ceramic disks (diameter: 40 mm, thickness: 5 mm), coated with a thin layer of either far-infrared irradiative film or non-active control film, were placed on the floor. The experimental disk was proven to radiate a band of 4–16 μm far-infrared rays (energy intensity: 12.6–71.5 kcal/m^2 per hour at 60° C). A slip ring connecting the lead wires and a polygraph allowed free movements of the rats.

After a week's acclimatization in the recording cage, the EEG, EMG and locomotor activity of each rat, exposed either to the experimental or the control disks, were continuously monitored for 9–10 consecutive days and processed by routine computer-aided methodology (Honda and Inoué 1978, 1981). Amounts of slow wave sleep (SWS), paradoxical sleep (PS) and wakefulness (W), and the number and duration of their episodes were calculated separately for the light and dark periods. Statistical analysis between the experimental and control groups was done by the Student's t-test.

Results

The results are summarized in Figs. 1, 2 and Table 1. In the light period, the hourly amount of SWS in the experimental group ($n = 16$) slightly but significantly ($P < 0.01$ at 10.00 h) exceeded that of the control group ($n = 16$) during the early phase (Fig. 1, upper traces). The total amounts of W and SWS significantly decreased and increased, respectively, during the first trisection (Table 1). Cumulative values of SWS between 11.00 h and 17.00 h exhibited a significant elevation from the control level, although the total amount in the 12 h period was not significant (Fig. 1, below). The increase in SWS during the light period was largely due to a prolongation of episode duration as compared to the control group (Fig. 2, upper traces; Table 1). The number of SWS episodes decreased. On the contrary, no difference was found in PS parameters between the two groups.

In the dark period, SWS parameters for the experimental group exhibited time-course fluctua-

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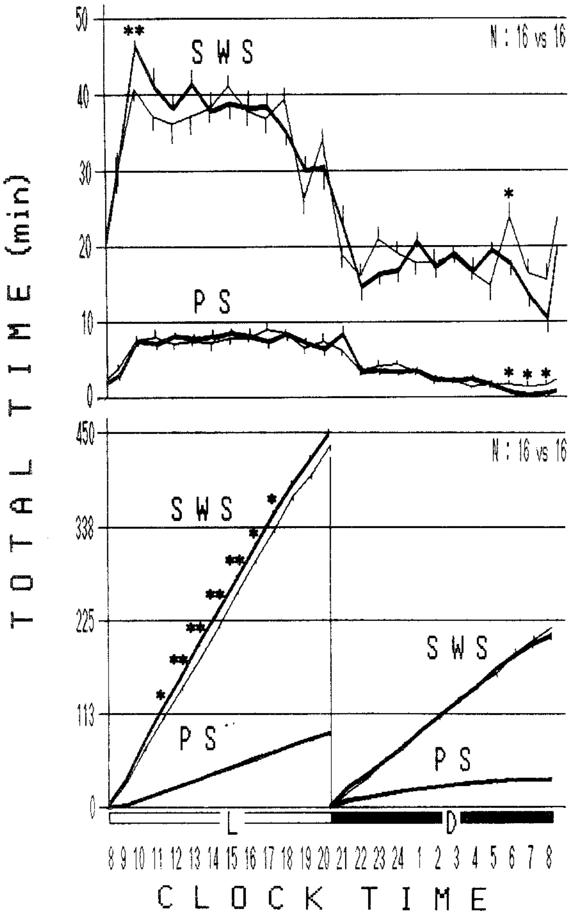

Fig. 1. Time-course changes in slow-wave sleep (*SWS*) and paradoxical sleep (*PS*). *Upper*: hourly amount; *below*: cumulative amount in the light (*L*) and dark (*D*) periods. The *thick* and *thin* lines represent the average values from far-infrared irradiated rats ($n = 16$) and those from control rats ($n = 16$), respectively. Single and double *asterisks* indicate that the difference between the experimental and the control groups is significant at $P < 0.05$ and $P < 0.01$, respectively

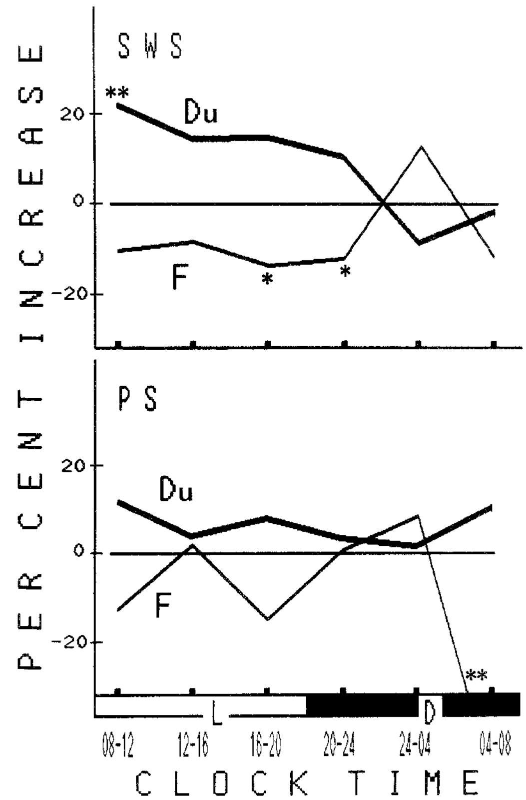

Fig. 2. Percentage changes in frequency (*F*) and duration (*Du*) of episodes of slow-wave sleep (*SWS, upper*) and paradoxical sleep (*PS, below*) of far-infrared irradiated rats as compared to those of the control rats averaged at 4 h recording intervals in the light (*L*) and dark (*D*) periods. Single and double *asterisks* indicate that the difference between the experimental group and the control group (baseline) is significant at $P < 0.05$ and $P < 0.01$, respectively

tions as compared to the control group. The first trisection was characterized by trends similar to those occurring in the light period (Fig. 2, upper traces). A reciprocal crossover occurred in the second trisection and the values for both the duration and frequency of SWS reached control levels. The hourly amounts of both SWS and PS showed a significantly decreasing trend towards the end of the dark period in the experimental group (Fig. 1, upper traces). However, cumulative values were almost identical between the two groups (Fig. 1, below). A significant difference was found between the two groups in the total duration of PS and W for the third trisection (Table 1). This was largely due to a prolongation of episode duration of W and a reduction of that of PS (Fig. 2, below; Table 1).

Discussion

Rats are night-active and day-resting animals: approximately two-thirds of their sleeping time appeared in the light period in our young male Sprague-Dawley rats (Honda and Inoué 1981). Such a circadian rest-activity rhythmicity was little affected by the continuous exposure to the far-infrared radiation. However, the treatment exerted an SWS-promoting influence in the early light period and an SWS/PS-suppressing effect in the late dark period. Thus, the treated animals demonstrated an enhanced contrast of more rest in their resting phase and more activity in their active phase, although the daily amounts of SWS and PS remained unchanged.

At present, no information is available as to

Table 1. Total amount (*T*) in minutes, frequency (*F*) in number per 4 h and duration (*D*) in minutes of episodes of wakefulness (*W*), slow wave sleep (*SWS*) and paradoxical sleep (*PS*) in far-infrared irradiated and control rats (mean ± SEM)

		Light period			Dark period		
		08–12 h	12–16 h	16–20 h	20–24 h	24–04 h	04–08 h
Control group ($n = 16$)							
W	T	70.6±3.1	55.2±3.0	71.7±3.6	146.4±2.3	159.7±3.3	161.8±4.4
	F	37.4±3.1	36.6±1.3	38.9±1.7	32.9±0.9	29.7±1.5	26.6±1.7
	D	1.9±0.1	1.5±0.1	1.9±0.2	4.5±0.2	5.7±0.4	6.6±0.6
SWS	T	143.4±2.3	154.3±2.9	136.6±2.6	75.3±2.3	70.0±2.9	70.9±3.5
	F	40.2±1.3	39.6±1.1	41.4±1.6	33.6±0.9	29.9±1.6	26.5±1.8
	D	3.6±0.1	4.0±0.2	3.4±0.1	2.2±0.1	2.4±0.1	2.8±0.2
PS	T	26.5±1.6	30.3±0.9	31.5±1.5	18.3±0.8	9.3±0.7	6.5±0.9
	F	14.9±1.0	15.1±0.6	16.7±1.1	13.0±0.8	8.6±0.9	5.8±0.9
	D	1.8±0.1	2.1±0.1	1.9±0.1	1.4±0.1	1.1±0.0	1.1±0.1
Far-infrared irradiated group ($n = 16$)							
W	T	57.9±3.0**	50.7±3.9	76.2±5.7	150.5±3.3	155.5±3.0	175.5±3.4*
	F	32.8±2.1	33.2±2.5	34.4±1.9	29.0±1.3*	32.6±1.4	24.0±2.1
	D	1.9±0.2	1.8±0.4	2.3±0.3	5.4±0.3*	4.8±0.3	8.3±0.8
SWS	T	156.2±2.8**	156.6±3.2	134.1±4.4	69.6±2.8	73.8±2.7	61.3±3.2
	F	36.2±1.6	36.4±2.1	36.0±1.8*	29.7±1.4*	33.6±1.1	23.4±2.2
	D	4.4±0.2**	4.5±0.3	3.8±0.2	2.5±0.1	2.2±0.1	2.8±0.1
PS	T	26.0±1.3	32.4±1.0	29.4±1.5	18.9±1.5	10.7±0.8	3.2±0.6**
	F	13.1±0.8	15.4±0.7	14.3±0.8	13.1±0.7	9.3±0.6	2.8±0.5**
	D	2.0±0.1	2.1±0.1	2.1±0.1	1.5±0.1	1.2±0.0	1.2±0.1

* $P < 0.05$; ** $P < 0.01$

the mechanism involved in this phenomenon. It seems likely that the folklore concerning the health-improving properties to man of far-infrared rays (Yamazaki 1987) might possibly be related to an improved sleep state. In this connection, the acceleration of growth in rats exposed to far-infrared radiation (Inoué and Honda 1986) may be explained by kind of sleep improvement, which causes an increased secretion of growth hormone. Further investigations will clarify such a causality.

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References

Honda K, Inoué S (1978) Establishment of a bioassay method for the sleep-promoting substance. Rep Inst Med Dent Eng 12:81–85

Honda K, Inoué S (1981) Effects of sleep-promoting substance on sleep-waking patterns of male rats. Rep Inst Med Dent Eng 15:115–123

Inoué S, Honda K (1986) Growth of rats exposed to far-infrared radiation. Zool Sci 3:731–732

Wolken JJ (1971) Invertebrate photoreceptors – A comparative analysis. Academic Press, New York London, p 3

Yamazaki T (1987) Ensekigaisen ryoho no kagaku. Ningen-to-Rekishi-sha, Tokyo

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