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Review

Biological activities caused by far-infrared radiation

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Abstract. Contrary to previous presumption, accumulated evidence indicates that far-infrared rays are biologically active. A small ceramic disk that emits far-infrared rays (4–16 μm) has commonly been applied to a local spot or a whole part of the body for exposure. Pioneering attempts to experimentally analyze an effect of acute and chronic radiation of far-infrared rays on living organisms have detected a growth-promoting effect in growing rats, a sleep-modulatory effect in freely behaving rats and an insomiac patient, and a blood circulation-enhancing effect in human skin. Questionnaires to 542 users of far-infrared radiator disks embedded in bedclothes revealed that the majority of the users subjectively evaluated an improvement of their health. These effects on living organisms appear to be non-specifically triggered by an exposure to far-infrared rays, which eventually induce an increase in temperature of the body tissues or, more basically, an elevated motility of body fluids due to decrease in size of water clusters.

Key words: Far-infrared radiation – Growth – Health – Skin blood flow – Sleep

Introduction

Far-infrared rays are defined as electromagnetic waves having a wavelength of more than 4 μm. The rays have been considered biologically inactive, since the limits of radiation inducing a physiological reaction to living organisms were presumed to lie between 300 and 950 nm (Wolken 1971). However, accumulated evidence seems to indicate that this is not the case. Recently much attention has been paid to health-improving or food-preserving activities of far-infrared rays, especially among the people in Japan; this has eventually stimulated the publication of newspaper articles and some popular books (Fukazawa 1986; Yamazaki 1987; Mitsuhashi 1988). Nevertheless, only a few papers deal with the scientific analysis of biological activities of far-infrared radiation. Here the authors summarize the results of such investigations with reference to some unpublished original findings.

Technique for far-infrared irradiation

In order to expose biological organisms to far-infrared rays, a conventional method has been established, for which a small sized far-infrared radiator is available (Fig. 1, top). This is a ceramic disk of 40 mm in diameter, 5 mm in thickness and 10 g in weight. It is produced by a special sintering technique after the surface is coated with a special glaze including alumina, silica and zirconia. The radiator disk can emit far-infrared rays with a peak wavelength of 8–14 μm when warmed to a temperature of 35.5° to 36.5° C. The disk is also proven to emit a band of 4–16 μm far-infrared rays of which the energy intensity is 12.6 to 71.5 kcal/m^2 per h at 60° C.

Far-infrared irradiation can be applied to either a local spot or a whole part of the body by placing these ceramic disks near to the target. For example, the disks were placed on the floor of rat cages (Inoué and Honda 1986; Honda and Inoué 1988), directly attached to the human skin (Ise et al. 1987) or embedded in bedclothes (*futon* and mattress, U.S. Patent No. 4 680 822; Fig. 1, bottom; Kotorii et al. 1988).

Ceramic disks of the same size and composition but coated with non-irradiative glaze were used for control experiments in animals (Inoué and Honda 1986; Honda and Inoué 1988) and in hu-

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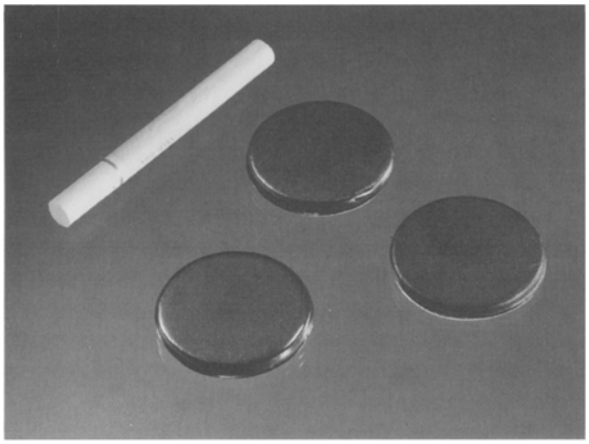

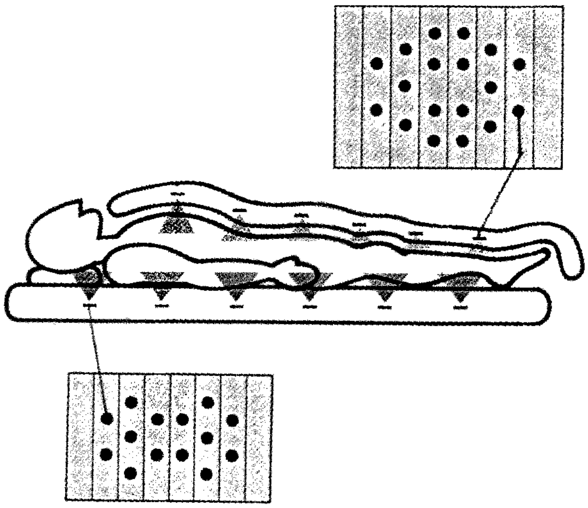

Fig. 1. The far-infrared radiative ceramic disks compared to a cigarette (*top*) and embedded in bedclothings such as a cover futon with 18 disks and a mattress with 14 disks (*bottom*)

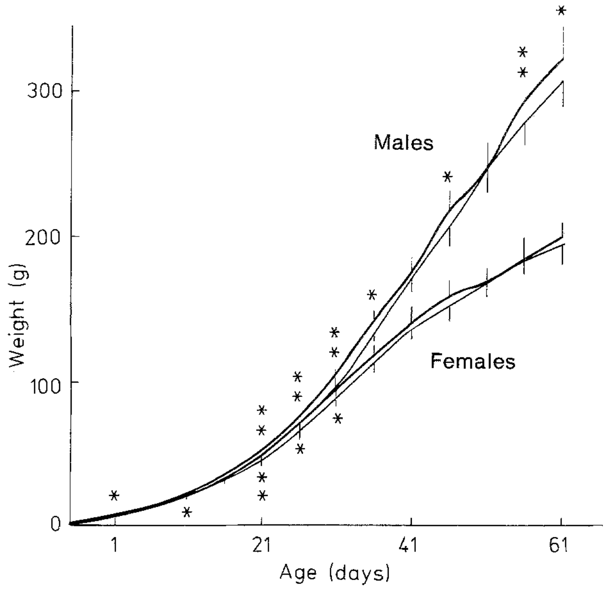

Fig. 2. Growth curves of male and female rats exposed to the far-infrared radiation (*thick line*), as compared to those of the non-exposed control (*thin line*). *Vertical* lines indicates the standard error of the mean. The single and double asterisks indicate that the difference between the experimental and control groups was statistically significant at $P<0.05$ and $P<0.01$, respectively

mans (Kotorii et al. 1988). Plastic disks of the same size and shape are also used as controls (Ise et al. 1987).

Growth promotion in rats

Inoué and Honda (1986) first reported that a chronic exposure to far-infrared radiation caused an increased weight gain in growing rats of the Sprague-Dawley strain. Both male and female rats continuously exposed to far-infrared radiation from the prenatal period exhibited a significant acceleration of body growth during postnatal life for up to 61 days. Body weights of the rats exposed to far-infrared were heavier than non-exposed controls by up to 7%, except for a short period immediately after birth. The difference was most pronounced at the ages between 21 and 31 days (Fig. 2).

The rats used in this study were raised in a closed colony and kept on a 12 h light: 12 h dark schedule under a constant air-conditioned environment of $25 \pm 1°$ C and $60\% \pm 6\%$ relative humidity with free access to rat chow and water. At first, pregnant rats were individually isolated to a polycarbonate cage ($26.5 \times 42.5 \times 15.0$ cm) at 17–20 days of gestation. In each cage were placed 3 to 5 ceramic disks that were either far-infrared radiative or non-radiative. On the second day of delivery, pups were weighed and the litter size was adjusted to 8 pups per mother. Body weights were recorded at 5-day intervals. At 11 days of age, the mother and pups were transferred to a metal mesh cage ($26 \times 38 \times 18$ cm), in which either 5 far-infrared radiating disks or 5 non-radiating disks were placed. Pups were weaned at 21 days of age. Males and females were then separated and 4 to 5 rats were housed per cage containing similarly placed disks.

The experimental results apparently show that the far-infrared irradiation provoked a growth-promoting effect in the growing rats, although the magnitude of the effect was small. Since the far-infrared ray with a peak wavelength of 8–14 μm may penetrate into the body and warm it up from inside (see below), the effects may be based upon an indirect action of the irradiation to bring about a general improvement of the body state. It is suggested that, as a result, there might be increased secretion of growth hormone in the immature, treated rats.

Sleep modulation in rats

Honda and Inoué (1988) reported that a chronic exposure to far-infrared rays brought about a modulation of the circadian sleep-waking pattern in freely behaving rats. Adult male rats of the Sprague-Dawley strain were kept on a 12 h light: 12 h dark schedule under a constant air-conditioned environment of $25 \pm 1°$ C and $60\% \pm 6\%$ relative humidity with free access to rat chow and water. At 60 to 70 days of age, they were implanted with 3 cortical and 2 nuchal electrodes for recording electroencephalogram (EEG) and electromyogram (EMG), respectively. The rats were then individually kept in a special recording cage, in which either 2 far-infrared radiating disks or 2 non-radiating disks were placed. A slip ring connecting the lead wires of the electrodes and a polygraph allowed free movements of the rats. One week after the surgery, the EEG, EMG and locomotor activity of each rat were continuously monitored for 9 to 10 days. The amounts of slow wave sleep (SWS), paradoxical sleep (PS) and wakefulness, and the number and duration of their episodes were calculated at 4-h intervals.

The rats continuously exposed to the far-infrared radiation exhibited a significant increase and decrease in the total time of SWS and wakefulness, respectively, during the first trimester of the light period (Fig. 3). These changes were largely due to a significantly prolonged duration of SWS episodes. In contrast, the total time of wakefulness was significantly increased during the last trimester of the dark period. In addition, the frequency and duration of SWS and wakefulness also exhibited significant changes between the late phase of the light period and the early phase of the dark period. PS was little affected throughout the observation period except for a significant decrease in total time at the last trimester of the dark period. This was largely due to a significant decrease in the episode frequency.

The results suggest that the far-infrared radiation provoked a sleep-modulating effect on the freely behaving adult rats. The far-infrared treated animals demonstrated an enhanced contrast of their circadian variations of sleep and wakefulness, i.e., more rest in their resting period and more activity in their active period. It must be noted that the daily amounts of sleep and wakefulness remained unchanged.

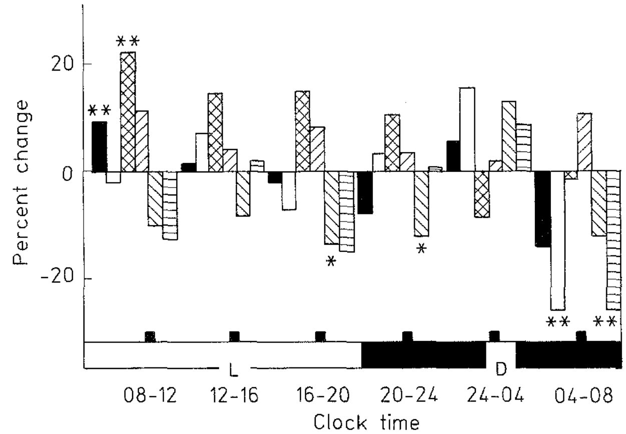

Fig. 3. Percent changes in the total time (T), episode frequency (F) and episode duration (Du) of slow wave sleep (SWS) and paradoxical sleep (PS) in far-infrared irradiated rats compared to control rats (=0). L and D indicate the light and dark period. The single and double asterisks indicate that the difference between the experimental and control groups was statistically significant at $P < 0.05$ and $P < 0.01$, respectively

Sleep modulation in humans

Kotorii et al. (1988) investigated the sleep-modulatory effect of far-infrared radiation in humans. Seven healthy male students were asked to sleep on the mattress embedded with either radiator disks or control disks for 7 consecutive nights at home. They were then invited to sleep on the same mattress for 3 consecutive nights at a sleep laboratory. During the last 2 nights, continuous 8-h polysomnographic recordings including EEG, EMG, electro-oculogram and rectal temperature were done in combination with subjective scoring of sleep content at awaking. These experiments were conducted in a double-blind manner.

No objective sleep parameters such as total sleep time, amounts of each sleep stage, sleep latency, sleep efficiency, etc. were affected by exposure to the far-infrared rays. Heart rate, blood pressure, core temperature and subjective feeling of sleepiness after awaking were also little influenced. However, the use of the mattress embedded with radiator disks resulted in a subjective assessment of slightly longer and deeper sleep and fewer wakeful episodes during the night, compared to controls, although the polysomnographic data did not demonstrate such evidence.

In contrast to the fact that the healthy young volunteers exhibited no objective change in the quality and quantity of sleep, an insomniac patient reacted positively to exposure to the far-infrared rays (Kotorii et al., unpublished). The patient expressed not only a subjective feeling of improved

Table 1. Age groups among users of the far-infrared radiator disk-embedded bedclothes

Age (years)	Females (%) $n=343$	Males (%) $n=199$	Total (%) $n=542$
Up to 9	0.3	2.0	0.9
Teens	2.0	1.5	1.8
20s	5.0	3.0	4.2
30s	9.3	11.6	10.1
40s	18.1	19.6	18.7
50s	30.3	32.2	31.0
60s	19.0	16.6	18.1
70s	7.6	6.0	7.0
Older than 80	0.6	1.5	0.9
Unanswered	7.7	6.0	7.2

Table 2. Subjective evaluations of far-infrared radiator disk-embedded bedclothes

	Females (%) $n=343$	Males (%) $n=199$	Total (%) $n=542$
Feelings after use:			
Very good	36.6	37.2	36.6
Good	42.6	44.7	43.4
Indifferent	9.6	9.6	9.6
Bad	0.5	0	0.4
Very bad	0	0	0
Unanswered	11.1	8.5	10.1
Efficacy:			
Very effective	22.2	21.1	21.8
Effective	44.6	36.7	41.7
Slightly effective	10.5	19.1	13.7
Ineffective	0.5	0	0.4
Unanswered	22.2	23.1	22.5
Remarkable improvements[a]:			
Feeling of coldness	23.2	15.9	20.5
Stiffness of loins and legs	17.9	23.3	19.9
Insomnia	15.1	15.1	15.1
Stiffness of shoulders	15.4	14.3	14.9
Poor sleep	2.9	4.4	3.4
Constipation	0.5	0.4	0.5
Miscellaneous	6.9	8.6	7.6
None	6.9	8.6	7.6
Unable to evaluate	6.7	4.1	5.7
Unanswered	4.5	5.3	4.8

[a] Plural answeres are included

sleep but also showed polysomnographically a prolonged duration of stage 3+4 sleep after use of the mattress embedded with radiator disks. Consequently, it is suggested that far-infrared radiation is more effective to patients when accompanying self-realized insomnia than to normal healthy persons who are unaware of sleep disorders.

This suggestion is substantiated by statistical analysis of the questionnaires to users of either the futon or the mattress (see Fig. 1) in which the far-infrared radiator disks were embedded (Jpn Res Lab Sleep Sci 1988). Subjective evaluations of the bedclothes were collected from 542 users (343 females and 199 males) after several weeks of use. The users were primarily interested in the popular belief that far-infrared rays have a health-improving effect, and were highly motivated to use the bedclothes. Approximately two-thirds of them were older than 40 years of age (see Table 1 for the age distributions).

As summarized in Table 2, the majority of the users obtained satisfactory sleep with the radiator disk-embedded futon and mattress, and subjectively evaluated that the bedclothes had improved the state of their health. Such improvements included the disappearance or reduction of the feeling of coldness, stiffness of muscles in the shoulders, loins and legs, and disordered sleep. The effects seem to be non-specific, since they are largely based on a relaxed and comfortable sleep. Thus, if sleepers have a special complaint of their physical state, the far-infrared irradiation is likely to exert a psychophysiological health-improving effect.

Acceleration of skin blood flow in humans

Ise et al. (1987) detected an enhancement of peripheral blood circulation after acute exposure to the far-infrared rays. They measured changes in the blood flow of forearm skin in nine male and female healthy young volunteers. Nine ceramic radiator disks were arranged in series on a ribbon. A similar ribbon either with or without nine plastic disks of the same size and shape was used for control. The ribbon was placed on the left forearm to contact directly with the skin. By use of mercury-in-rubber strain gauge plethysmography, the blood flow of the forearm was recorded 20 min after placing each ribbon out of the three different types in sequence. Ambient temperature was maintained at $24 \pm 1°$ C.

A 20-min exposure to far-infrared radiation increased forearm skin blood flow in the majority of the subjects. The radiative ceramic disks brought about a significantly higher blood flow rate than the plastic disks in 6 out of the 9 subjects and the ribbon without disks in 8 of the subjects. It is assumed that the far-infrared radiation may increase skin temperature which eventually affects cutaneous blood vessels to induce an elevated blood flow. The study of Shimura (1988) seems to substantiate this assumption (see below).

Warming-up activity in relation to body temperature in humans

Shimura (1988) analyzed a warming effect of far-infrared rays on inner human tissues by a model system. An agar block (110 × 103 × 10 mm at 20° C) was regarded as a substitute for body tissues. The agar block was heated via a water bath at a distance of 10 mm, with the water temperature controlled at either 40° or 50° C. For the far-infrared irradiation, a radiator disk was placed at the bottom of the water bath. Spot temperatures inside the agar block were detected at 2-mm intervals from the upper surface to the bottom and averaged.

The agar blocks exposed to the far-infrared radiation showed a quicker rise in inner temperatures than the non-exposed control blocks. Higher values of the inner temperatures were observed over a period of up to ca. 60 min after heating; no further difference was detected beween the irradiated and non-irradiated blocks thereafter. For example, at 20 min after heating with the water bath at 40° and 50° C, the inner temperature was 1.4° and 1.7° C higher, respectively, in the irradiated agar blocks than in the unirradiated ones; at 40 min after heating the respective inner temperatures were 1.1° and 2.5° C higher. Thus, it is speculated that the far-infrared radiation may acutely accelerate a temperature rise inside human tissue.

On the contrary, in their study of chronic far-infrared exposure of healthy young subjects, Kotorii et al. (1988) failed to detect any change in rectal temperature (see above). Recording continuously over 48 h, no differences were detected between subjects sleeping on the radiator disk-embedded mattress and those sleeping on the control ones.

Underlying mechanisms

The biological activities described above of far-infrared radiation are so diverse that no direct interrelationship could be found. It appears likely that all these activities were non-specifically induced via an integration of subtle changes in the bodily state, which may result in an improvement or a normalization of the organism as a whole. At present, no information is available to explain the physiological mechanisms involved in the phenomena.

However, the tissue-warming activity of far-infrared radiation may be regarded as a possible common background. This activity must induce an accelerated blood circulation at peripheral tissues, eventually triggering an improved state of metabolism, improved transfer of chemical messengers, and so forth.

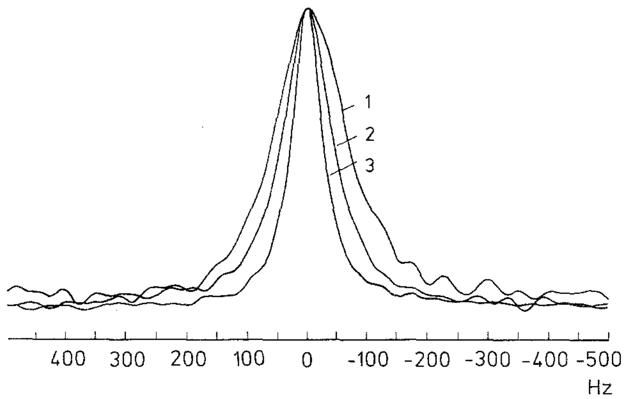

Fig. 4. ^{17}O-NMR spectra of distilled water. The half peak width of 138 Hz under no treatment (1) was reduced to 78 Hz (57% of the control) and 48 Hz (35%) after 20-min (2) and 4 days (3) of exposure, respectively, to far-infrared rays

On the other hand, Fuse and Taki (1987) suggested a possible involvement of nonthermogenic effects of far-infrared radiation on biochemical processes. However, they failed to demonstrate that irradiation with 100 μm laser pulses could activate oxygen consumption in rat liver mitochondria in vitro.

In this connection, it must be mentioned here that the molecular structure of water is greatly modified by far-infrared radiation. NMR studies have recently revealed that water clusters become much smaller in size after an exposure to far-infrared rays (Matsushita 1988). Figure 4 shows a reduced peak width in ^{17}O-NMR spectra of water kept around far-infrared radiator disks (Kabaya, unpublished). Such a change means that the motility of water molecules is highly activated by the far-infrared radiation. Hence, it might be speculated that far-infrared radiation stimulates the penetration of water molecules into various sites inside the body tissue and also modulates dynamic functions of humoral factors in the body fluid.

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