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PHYSIOLOGICAL REACTION OF MEN UNDER EXERCISE TO RADIANT HEAT

BY

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ABSTRACT

To investigate the effect of the radiant heat on the human body in a hot environment, the subjects exposed their nude back to a radiant heat of 1.3 and 2.6 cal/cm². min, using the exsiccating infrared illuminators under a hot ambient condition of a temperature 31°C, with a relative humidity of 55% and a 0.5 m/sec air flow. The 8 subjects were healthy male college students aged 20 to 25.

The following results were obtained by estimating the physiological reactions to different degrees of radiant heat at rest for 60 minutes and during exercise for 30 minutes on a bicycle ergometer by 272 kg. m/min (or 600 kp. m/min).

1) The mean skin temperature, heart rate, respiration rate and body weight loss rate increased at rest in parallel with the degree of the radiant heat, and during exercise the mean skin temperature, heart rate, respiration rate, body weight loss rate and respiratory volume increased, but the Na^+ loss rate decreased. The regression equation was obtained to show the quantitative relationship between the degree of the radiant heat and the physiological body reactions.

2) By computing the Heat Tolerance Index by Inoue *et al.*, it was clarified that the higher the degree of the radiant heat was, the smaller was the index. And as there was a close correlation between the indices both at rest and during exercise, it was suggested that for the evaluation of heat tolerance, the radiant heat by the infrared illuminators is applicable as additional heat loading besides hot water bathing or staying in a hot chamber.

INTRODUCTION

Several kinds of physiological reactions of the human body were observed during exercise or working under a hot environment by being exposed to the radiant heat in the summer season, and many investigators have been studying the effects of the different kinds of ambient conditions[1–5] on the human body.

The ambient thermal environment depends upon several physical factors, such as temperature, relative humidity, air flow and radiant heat, and these factors act as a whole. But, for outdoor labour, especially in the summer, the effects of solar radiant heat plays an important role. The effects of temperature, relative humidity, and air flow, as the factors affecting the hot environment, have been studied by many investigators, but only a few studied the physiological effect of radiant heat in the hot emvironment. The solar radiant that is composed mainly of infrared rays. When the body surface is exposed to the infrared rays from the sun, i.e. rays of wave lengths shorter than 3000 nm, 80~90% of them are absorbed by the body.

Absorbed infrared rays may reach the subcutaneous tissue, though most of them are

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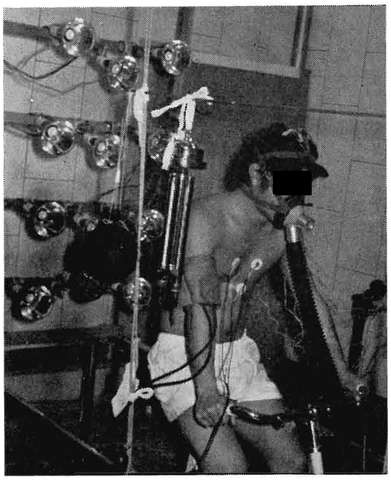


Fig. 1. Exercise under radiant heat.

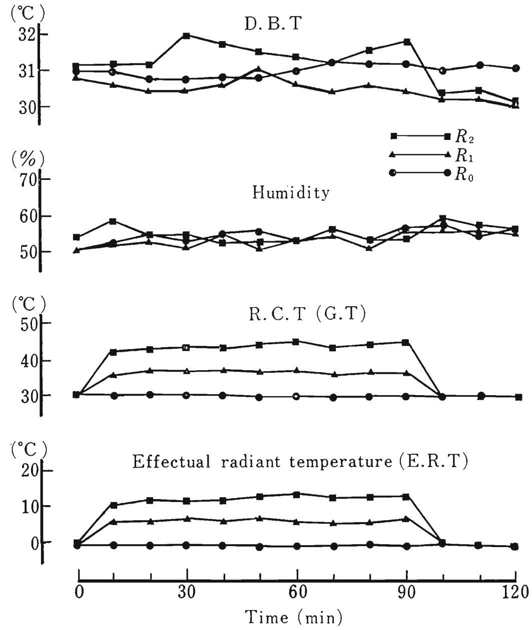


Fig. 2. Environmental conditions during the experiments.

absorbed by the skin tissue, i.e. 1% of them penetrate into the deeper tissue[6]. Therefore, the effects of the infrared rays on the body are quite different from those of the ultraviolet rays which are totally absorbed by the superficial layer of the skin.

Among the studies on radiant heat there are the reports on physiological reactions[10-13], including the change of the heat balance by infrared radiation[7-9]. But almost all of these authors studied the effects of the long waves of the infrared ray longer than 3000 nm. Presently, the authors attempted to clarify the physiological reactions of the human body under a hot environment exposed to the infrared rays of short wave lengths i.e. rays from exsiccating infrared lamp (2500°K, wave length's: 400∼3000 nm, peak intensity at 1200 nm). As emphasis was placed to examine their patterns and to evaluate the merit of using radiant heat in testing the for heat tolerance.

Methods

This study was carried out in April, 1974, in a climate chamber of a size of 2 m × 3 m × 2.3 m (13.8 m^3). In this chamber, the room temperature was controlled at 31° ± 1 °C., similar to the average of the maximum outdoor temperature in August in Tokyo; the relative humidity of 55 ± 5%, which is the average value at noon during this season[14], and the air flow was controlled continuously at 0.5 m/sec.

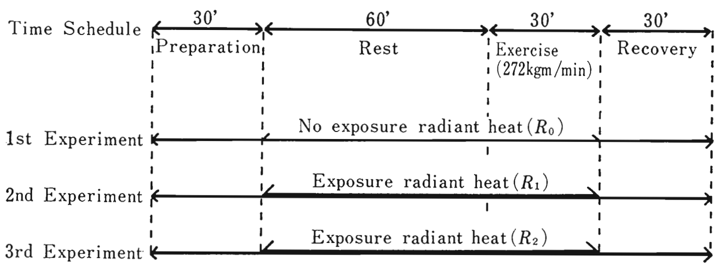
Twelve infrared exsiccating bulbs (100 V, 250 W) were placed in a wooden box (90 × 120 cm) in 3 rows, 4 in each row, and with the nude back of the subjects exposed to hot radiation at the distance of 1.3 m from the source (Fig. 1). To simulate the total solar radiant heat value at noon in August in Tokyo, a radiation intensity of 1.3 cal/cm^2. min was used as the standard condition (using 6 bulbs) and the double value, 2.6 cal/cm^2. min was also used for comparison (using 12 bulbs). The radiant heat value was measured by a thermopile radiometer (EKO Co.) and the effective radiant temperature (E.R.T.) was calculated from the readings on the glove thermometer (diameter of 6

Table 1. Physical characteristics of subjects

Subject	Age (yrs.)	Height (cm)	Weight (kg)	Chest girth (cm)	Skinfold* thickness (mm)	Rohrer's index	Surface** area (m^2)	Basal metabolism (Cal/h)
A	25	170.8	58.1	83.5	5.5	116.6	1.63	59.82
B	21	169.0	61.9	85.5	14.0	128.2	1.66	61.09
C	21	163.4	60.4	84.4	18.5	138.5	1.61	59.25
D	21	170.2	58.4	85.5	6.0	118.3	1.63	59.98
E	22	163.4	56.0	83.5	12.0	128.4	1.56	57.41
F	20	163.1	52.2	86.0	6.0	120.3	1.51	55.57
G	25	167.6	60.2	84.5	6.5	127.9	1.61	59.09
H	25	163.8	60.5	85.5	22.0	137.7	1.56	57.25
Mean	22.5	166.4	58.5	84.9	11.3	127.0	1.60	58.68
S.D.	2.14	3.33	3.12	1.12	6.40	8.28	0.049	1.798

* Measured on the right umbilical area (Skinfold caliper)
** Surface area $= W^{0.44} \times H^{0.663} \times 88.83$

Table 2. Procedure of experiments.



inches) and on the dry bulb thermometer placed near the back of the subject and the E.R.T. for 1.3 cal/cm². min was 7°C and that for 2.6 cm/cm². min was 14°C. Fig. 2 shows the thermal conditions during experiments. Exercise on the bicycle ergometer (by Monark Co. Sweden) was carried at the rate of 272 kg.m/min for 30 minutes.

The physical characterics of eight subjects are shown in Table 1, and the reactions of each subject to the radiant that (0, 1.3 and 2.6 cal/cm². min) were tested every four days (Table 2). The following items were measured: skin temperature, rectal temperature, heart rate, blood pressure (systolic and diastolic), respiration rate, respiratory volume, O_2 and CO_2 content of the expired gas and O_2 consumption, respiratory quotient, heat production, energy metabolism, body weight loss rate, loss rate of Na^+ and K^+ content in the sweat and change of excretion of adrenalin and noradrenalin in the urine.

For the measurement of the skin temperature, eleven points were chosen over the body surface, as Kurata suggested in his report[15] (Fig. 3.). Thermisters were used for this purpose and the temperature at these 11 points were registered by a plotting recorder. The mean skin temperature was calculated by the Mean Skin Temperature.

$$\frac{4.3A+3.1B+2.4C+16.6D+8.1E+8.1F+8.2G+6.1H+5.3I+17.2J+20.6K}{100}$$

(A～K: Skin temperature at each point)

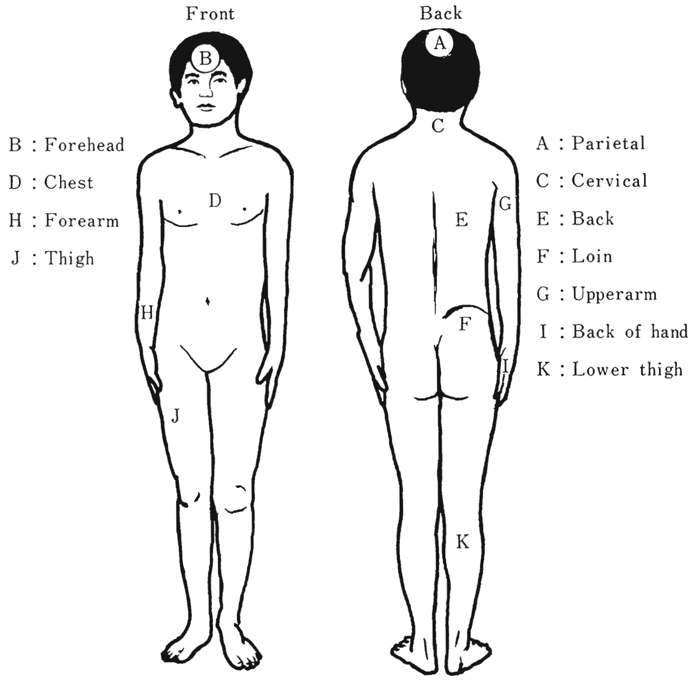


Fig. 3. Measuring points of skin temperatures (A ~ K).

Rectal temperature was measured by a stick thermister inserted into the rectum 8 cm from the anus and recorded on another recorder simultaneously with the skin temperature. The heart rate was recorded by the chest lead of ECG, and the blood pressure with Riva-Rocci's sphygmomanometer, and the respiration rate, respiratory volume and O_2 and CO_2 content of the expired gas with the "Respilyzer" (Fukuda Co., RM-10).

The measurement of the body weight was made before, during and after the experiment with a 100-kg scale balance of an accuracy of ± 2g (Kobe Balance Co.), and the weight loss rate was calculated by the formula:

$$\frac{\text{weight loss}}{\text{weight before the experiment}} \times 100(\%)$$

For collecting the weat, a new method was developed, in which a plastic capsule of a diameter of 3 cm was used. A piece of foam rubber and a celluloid plate and several pieces of filter paper were placed in the capsule and the filter paper was pressed tight by over the skin of the right subscapular region to absorb the sweat during the ex-

A B C D E

A: A sponge rubber plate for the plastic capsule to place tightly over the skin, with a plaster.
B: A plastic capsule of a diameter of 3 cm, inside the foamrubber, the celluloid plate and several pieces of filter papers.
C: A filter papers.
D: A celluloid plate dividing the foamrubber the filter papers.
E: A piece of foamrubber to press the filter paper discs in the capsule with a constant pressure against the skin.

Fig. 4. Capsule for sampling sweat.

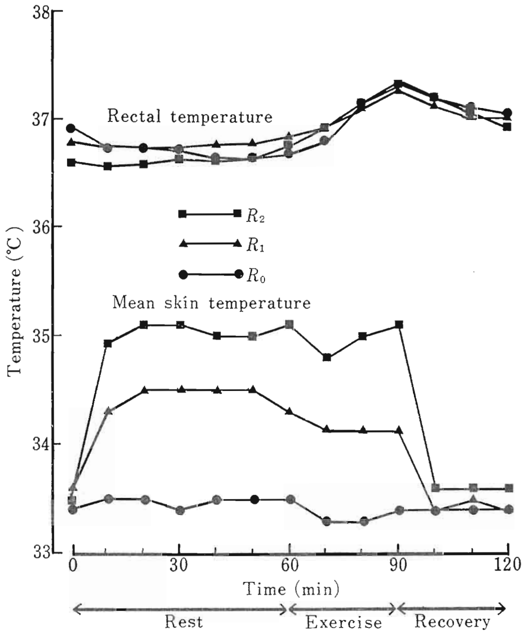


Fig. 5. Change of mean skin temperature and rectal temperature.

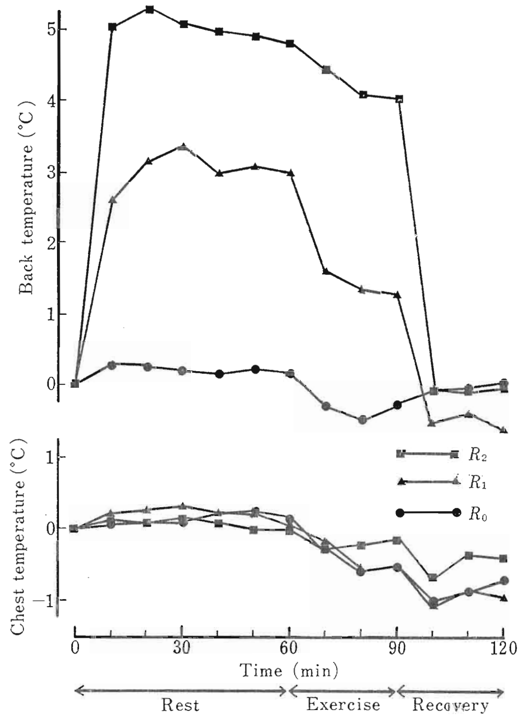


Fig. 6. Comparison of skin temperature of exposed and unexposed region to radiant heat.

periments (Fig. 4). The sweat was extracted with a 100 ml of distilled water, and the Na^+, K^+ concentration was measured with a flame photometer (Evance Co.)[16]. The adrenalin and noradrenalin content in the urine before and after the experiments were measured by a fluorophotomater (Turner Co.)[16].

Results

1) Body temperature and radiant heat value

The changes in the mean skin temperature (Ts) and the rectal temperature (T_R) are shown in Fig. 5. Without the radiant heat (R_0), Ts showed no change during the time of resting, exercise and recovery. But when the radiant heat of 1.3 cal/cm^2. min (R_1) or 2.6 cal/cm^2. min (R_2), was applied at rest, the skin temperature increased and showed the maximum with the equilibrium appearing at about 20 minutes later, and the skin temperature during exercise was a little lower than at rest. During recovery, as there was no heat loading, the skin temperature decreased rapidly to the level at the beginning of the experiment. The decrease of the skin temperature during exercise may be due to the increase of the air flow caused by the exercise and evaporatory heat loss by sweating. T_R was not influenced by radiant heat at rest and during exercise while the rectal temperature increased gradually during the exercise. The decrease of T_R during recovery was slow, not being complete within 30 minutes. Fig. 6 shows the difference in the change of the skin temperature between the regions of the back exposed to the radiant heat and that of the chest not exposed. The skin temperature of the exposed regions increased roughly in proportion to the radiation intensity, but no

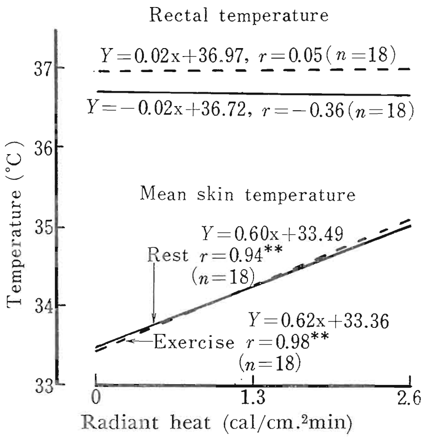


Fig. 7. Correlation between radiant heat and change of mean skin temperature and rectal temperature.

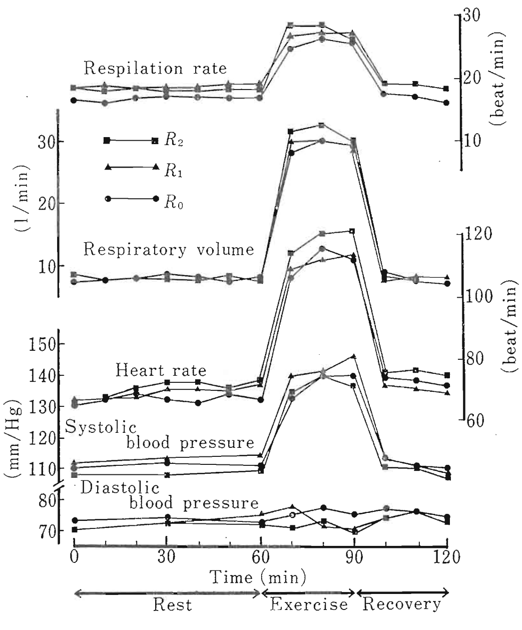


Fig. 8. Change of circulatory and respiratory function.

change in the skin temperature was observed in the unexposed regions of the chest.

The relationship between the intensity of the radiant heat and T_S and T_R is shown in Fig. 7. T_S showed a close correlation with radiation during rest (r=0.94) and during exercise (r=0.98) but no significant correlation was found between radiation and T_R.

2) Radiant heat and respiratory and circulatory function

The time course of change in the heart rate, blood pressure, respiration rate and respiratory volume are shown in Fig. 8. The heart rate increased by heat radiation at rest, but more markedly during exercise with an increase of 40~46 beats per minute. The rate decreased rapidly after the end of exercise and soon returned to the rate at rest. This increase during exercise seemed to be caused by the added effects of exercise and radiant heat loading, and the change in the heart rate by R_2 showed a clear difference from that by R_0, but there was no clear difference between the rate by R_1 and that by R_0. The systolic blood pressure increased during exercise but the effect of radiant heat loading was not clear. The diastolic blood pressure did not show any change by exercise and radiant heat loading. The respiration rate and respiratory volume were increased by the added effect of exercise and radiant heat loading, similar to the heart rate. The influence of the increase of radiant heat on the heart rate, systolic blood pressure, pulse pressure, respiration rate and respiratory volume is shown in Fig. 9. There was a significant correlation between the increase in the heart rate and the level of radiant heat at rest and during exercise, but there was no correlation between the systolic, diastolic and pulse pressure and the level of the radiant heat. Respiration rate increased significantly not only during exercise but also at rest under heat radiation, but in regard to the respiratory volume, there was a significant correlation only during exercise.

3) Radiant heat and gas and water metabolism

The change in the oxygen consumption

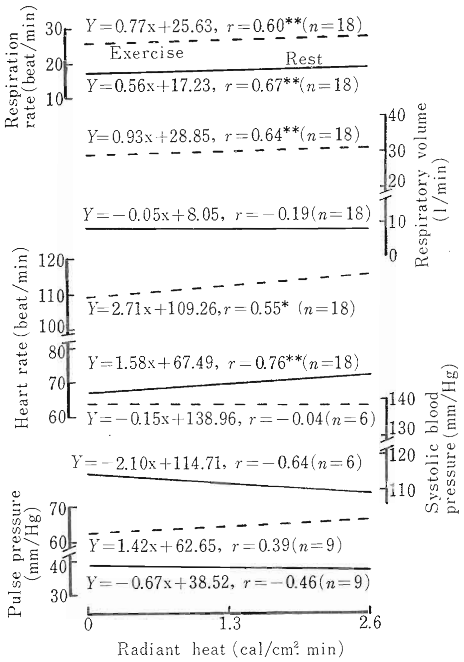


Fig. 9. Correlation between the levels of radiant heat and change of circulatory and respiratory function.

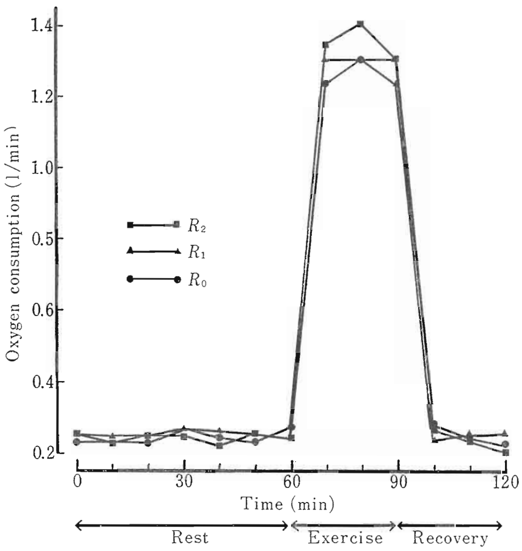


Fig. 10. Change of oxygen consumption.

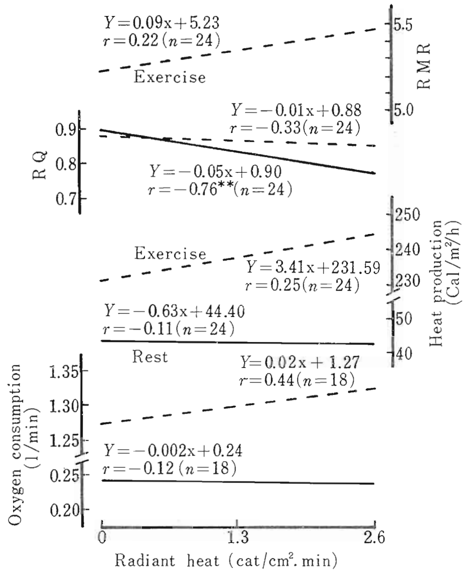


Fig. 11. Correlation between radiant heat and changes of the factors concerning energy metabolism.

from the beginning to the end of radiation is shown in Fig. 10. The changes in the O_2 consumption, heat production, respiratory quotient (RQ) and relative metabolic rate (R.M.R.) in relation to the increasing levels of radiant heat are shown in Fig. 11. At rest, the O_2 consumption, heat production and RQ decreased with the increase of the radiant heat, especially the RQ showed a clear negative correlation (r=−0.76) with the radiant heat. During exercise however, O_2 consumption, heat production and RMR showed a positive correlation while the RQ showed a negative correlation. Fig. 12 shows the relationship between the body weight loss rate and the increase of the radiant heat at rest, during exercise and before and after the tests. As shown in Fig. 13, sweating increased as the radiant heat increased, and in each period of the experiment, the body weight loss rate showed a positive correlation in relation to the radiant heat levels. The correlation between the change in the Na^+, K^+ content in the sweat and the increase of the radiant heat is shown in Fig. 13. The Na^+ loss rate decreased while the radiant heat increased, and the K^+ loss rate

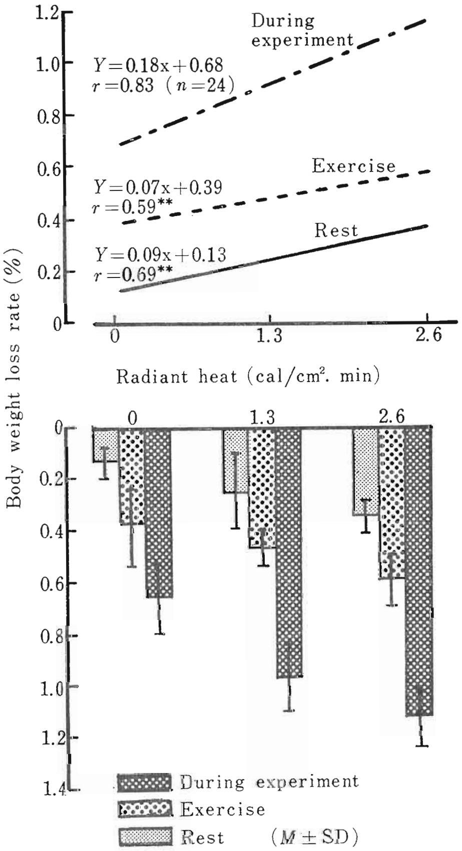


Fig. 12. Correlation between radiant heat and body weight loss rate.

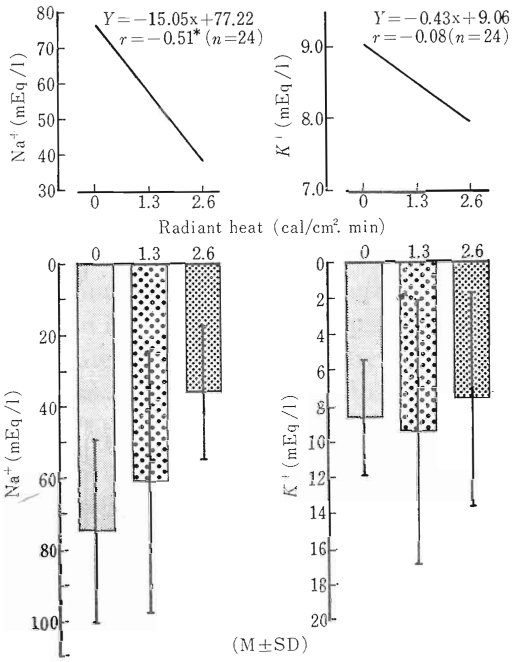


Fig. 13. Correlation between radiant heat and Na^+, K^+ loss rate in the sweat.

did not show any correlation with radiation. The adrenalin and noradrenalin content in the urine before and after the experiments is shown in Fig. 14. Excretion of adrenalin increased by R_2, but showed lower values by R_0 and R_1. Noradrenalin increased under all conditions of radiant heat. There was no significant correlation between the excretion of adrenalin and noradrenalin and radiant heat.

Discussion

1) Skin temperature

Skin temperature rises as the blood flow increases by the dilatation of the blood vessels in the skin surface, being caused by exposure to the hot environment[17]. It is recognized that the skin temperature rises in the regions exposed to radiant heat. In this study, the exposed regions showed a high skin temperature, and there was a difference in the rise of the skin temperature according to the radiant heat value, but there was no difference in the unexposed skin regions. Skin temperature on the back, as the example of the exposed regions, and that on the chest, as the example of the unexposed region, is shown in Fig. 6.

The change of the skin temperature by the radiant heat exposure shows many aspects. Tanaka[8] reported that the changes of the skin temperature are different between the body trunk and peripheral regions, and the latter are influenced easily by the environmental conditions. Nakagawa[12] reported that radiant heat naturally raises the skin temperature in the exposed skin regions, but the skin temperature in the unexposed regions depends on the am-

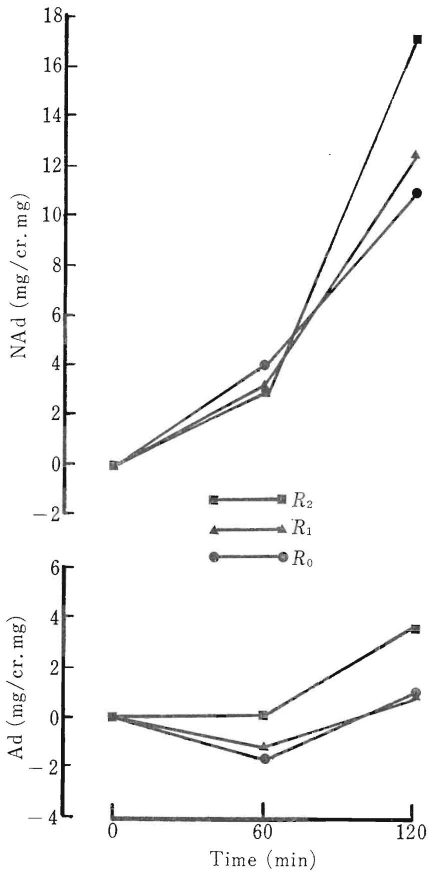


Fig. 14. Change of adrenalin and noradrenalin in the urine.

bient temperature. Also, according to Miura *et al.*[10], the radiant heat exposure over a wide area evokes nerve reflexes which cause the reaction of the whole body. The Committee on Physiological Reaction to Climatic Seasonal Change[18] reported that the distribution of the skin temperature or the mean skin temperature obtained from it will be useful as an index showing the various aspects of heat metabolism. In studying the effect of exposure, therefore, the mean skin temperature, can be considered as an index which shows the pattern of the heat metabolism of the body reaction. Hence, the authors, in this study, investigated the change in the skin temperature by the mean skin temperature. It is reported by Suzuki[19] that under an ambient temperature (T_E) of 25°C∼47°C, the skin temperature can be represented by an equation, $T_S=23.59+0.38\ T_E$. The authors obtained the following equations under an ambient temperature of 31°C, for radiant heat of 0∼2.6 cal/cm². min.

$$T_S=33.49+0.60\ R_H \text{ (at rest)}$$
$$T_S=33.36+0.62\ R_H \text{ (during exercise)}$$

where: T_S: mean skin temperature
R_H: radiant heat.

Comparing the above equations without considering radiant heat, the skin temperature obtained by Suzuki's equation is a little larger than the author's. This is probably because Suzuki's equation was derived by the tests performed in September, while the authors' was in April, that is under a different seasonal condition. The rise of the rectal temperature, as reported by Suzuki[20] is slower than that of the skin temperature. In this study, however the rectal temperature was not influenced by exposure to the radiant heat. Suzuki obtained[20] an equation of $T_R=33.38+0.11\ T_E$, under the ambient condition of 25°C∼47°C, but we could not find such an equation between T_R and R_H.

2) Cardiovascular function

The effect of the hot environment on the cardiovascular function is evident by the fact the cardiovascular system often does not function normally under an extremely hot emvironment. A normal cardiovascular function enables us to continue exercise or working. Therefore, the increase of the heart rate is used generally to show the degree of loading. Miura[21] suggested that a heart rate of 150 per minute should be considered as the limit for heat loading. In this study, the heart rate at rest was 68∼72 per minute and it increased to 111∼118 per minute during exercise. Since the R.M.R. of the load used was only about 5.2, this heart rate, was below the limit of Miura in all subjects. But there was a positive correlation between the increase of the heart rate and the value of the radiant heat, that is r=0.76 at rest and r=0.55 during exercise. And it is clear that the radiant heat affects the heart rate. The relationship between the heart rate and the value of the radiant heat, under the condition of an ambient temperature of 31°C, the exercise loading of 5.0~5.3 of R.M.R., 0~2.6 cal/cm². min of radiant heat, is shown by the following equation:

At rest $H_R=67.49+1.58\ R_H$

During exercise $H_R=109.26+2.71\ R_H$

where H_R=is the heart rate

R_H=is the radiant heat

Between the increase of the heart rate and the rise of the mean skin temperature there exists a significant correlation both at rest (r=0.77) and during exercise (r=0.62).

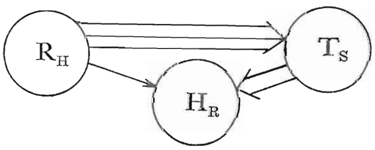
The following is the correlation between the two factors among to the radiant heat, mean skin temperature and heart rate.

R_H and T_S (r=0.94 at rest, r=0.98 during exercise)

R_H and H_R (r=0.76 at rest, r=0.55 during exercise)

H_R and T_S (r=0.77 at rest, r=0.62 during exercise)

The correlation between R_H and Ts is the highest, and the following figure will show these correlations.



Change of heart rate and degree of radiant heat show a parallel relationship as mentioned above. But, compared to exercise loading, the heart rate increases slightly, being only 2~4 beats per minute. There was a similar relationship between the value of the radiant heat and respiration rate or respiratory volume.

3) Water and salt metabolism

Generally, the water loss rate in the human body, loaded by exercise in a hot environment, increases by sweating[22].

In this study, the body weight loss rate increased according to the increase of the value of the radiant heat, both at rest and during exercise, and there is a significant correlation between the value of the radiant heat and body weight loss rate (Y%) before and after the tests (r=0.83).

The following equation was obtained:

$$Y(\%)=0.68+0.18\ R_H$$

This shows the relationship between the intensity of the radiant heat and the body weight loss rate.

In the summer season, the radiant heat value of sunshine will be 1.3 cal/cm². min at the temperature of 31°C and the body weight loss rate can be calculated by the above equation is 0.234%. For instance, in a person weighing 60 kg the body weight loss is 140 g. This shows that the radiant heat loading influences body weight loss greatly.

Yasukawa[13] reported that the Na^+ content in the sweat usually increases in parallel with the amount of the sweat. But in this study, the quantity of the sweat increased in proportion to the increase of the value of the radiant heat while the Na^+ excretion decreased. When sweating is continuous, the Na^+ content in the sweat is reported to increase, decrease or does not change according to the different authors, but Ohara[23] from the quantity of the sweat and salt excretion, made four criteria to obtain information on the type of heat tolerance.

Type I: High sweat rate, high electrolyte content

Table 3. Correlation between radiant heat and physiological finding and regression equations

Physiological finding	N	Rest		Exercise	
		r	Y=Ax+B	r	Y=Ax+B
Mean skin temperatuer	18	0.94**	0.60x+33.49	0.98**	0.62x+33.36
Rectal temperature	18	−0.36	−0.02x+36.72	0.05	0.02x+36.97
Heart rate	18	0.76**	1.58x+67.49	0.55*	2.71x+109.26
Blood pressure (systolic)	6	−0.64	−2.10x+114.71	−0.04	−0.15x+138.96
Pulse pressure	9	−0.46	−0.67x+38.52	0.39	1.42x+ 62.65
Respiration rate	18	0.67**	0.56x+17.23	0.60**	0.77x+25.63
Respiratory volume	18	−0.19	−0.05x+ 8.05	0.64**	0.93x+28.85
Oxygen consumption	18	−0.12	−0.002x+0.24	0.44	0.02x+ 1.27
Heat production	24	−0.11	−0.63x+44.40	0.25	3.41x+231.59
R Q	24	−0.76**	−0.05x+ 0.90	−0.33	−0.01x+ 0.88
R M R	24		—	0.22	0.09x+ 5.23
Weight loss rate (during experiments)	24		—	0.83**	0.18x+ 0.68
Weight loss rate	24	0.69**	0.09x+ 0.13	0.59**	0.07x+ 0.39
Na^+ loss rate	24		—	−0.51*	−15.05x+77.22
K^+ loss rate	24		—	−0.08	−0.43x+ 9.06
Ad volume	24		—	0.04	0.12x+ 2.04
NAd volume	24		—	0.14	1.10x+11.60
$I_1=\sqrt{A^2+B^2+C^2}$	24	−0.45*	−0.07x+ 0.41	−0.51*	−0.09x+ 0.49
$I_2=\sqrt{A^2+B^2+D^2}$	24	0.41*	0.02x+ 0.06	0.07	0.01x+ 0.42
$I_3=\sqrt{A^2+B^2+C^2+D^2}$	24	−0.43*	−0.07x+ 0.41	−0.14	−0.02x+ 0.58

**: Significant at 1% level
*: Significant at 5% level
Y=Ax+B Y: Physiological reaction
x: Radiant heat

Table 4. Change produced by radiant heat only (%)

Physiological finding	Rest	Exercise
Mean skin temperature	2.3	2.4
Heart rate	3.1	3.2
Respiratory rate	4.3	3.9
Tidal volume	—	4.3
Weight loss rate (during experiments)	34.98	
Weight loss rate	86.0	24.0
Na^+ loss rate	25.3	

Rate (%) of contribution of the radiant heat to the physiological effects produced by a sun effect of high amient temperature and radiant heat.

Type II: High sweat rate, low electrolyte content
Type III: Low sweat rate, high electrolyte content
Type IV: Low sweat rate, low electrolyte content

In this study, all subjects showed an increase in the sweat rate according to the increase of the radiant value, while there was a decrease of the excretion of Na^+. These could belong to Type II or high sweat rate, low electrolyte content, and the subjects of this group can be considered as less tolerant to heat loading.

Physiological reactions observed in the present study under the condition of an ambient temperature of 31°C with radiant heat loading were listed in Table 3 with regression equations. Table 4 shows the contributive rates (%) of the radiant heat to the physiological effects produced by a high ambient temperature (31°C) and radiant heat as a whole. Among the changes by the radiant heat of 3 grades of intensity, the body weight loss rate (35%) and electrolyte loss rate (25%) are relatively of large values. The respiration rate, heart rate, mean skin temperature, and respiratory volume during exercise show the effect of radiant heat on them (2.3%~4.3%).

4) Relation to heat tolerance index (H.T.I.)

Inoue *et al.*[24] showed the following heat tolerance index:

$$I_1 = \sqrt{A^2 + B^2 + C^2}$$
$$I_2 = \sqrt{A^2 + B^2 + D^2}$$
$$I_3 = \sqrt{A^2 + B^2 + C^2 + D^2}$$

where:

A: water loss, $\Delta W/0.07W$,

ΔW: water loss measured at the end of the test.

W: control values of body weight (kg) observed prior to loading.

B: Body temperature rise, $\Delta T/(40.6-To)$,

ΔT: increase of rectal temperature measured at the end of the test.

To: control values of rectal temperature (°C) observed prior to loading.

C: electrolyte loss, $\Delta S/0.75W$,

S: the salt loss by sweating (gr), estimated as $\Delta S = \Delta W \times \bar{C}$,

D: heart rate increase, $\Delta H/(200-Ho)$,

ΔH: increase in the heart rate at measured end of the test.

Ho: control values of heart rate (beam/min) observed prior to loading.

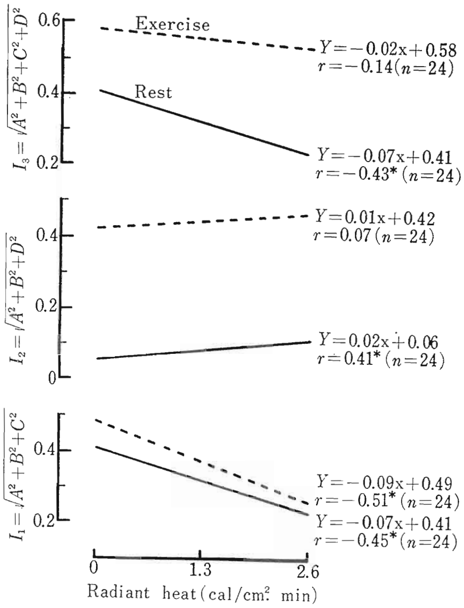


Fig. 15. Correlation between radiant heat and H.T.I (Inoue, A.)

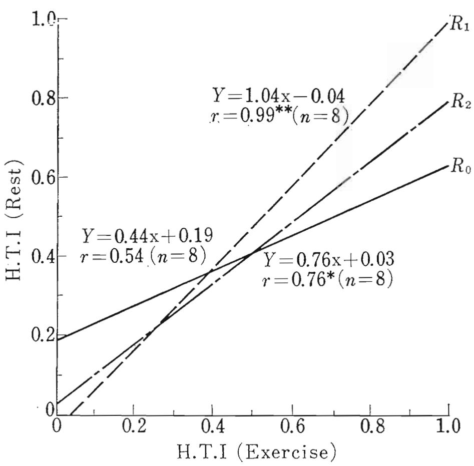


Fig. 16. Correlation between H.T.I at rest and H.T.I during exercise in I_1.

I_1, I_2 and I_3 were calculated from the data obtained in the present study, and relationship of these indices with the intensity of the radiant heat is shown in Fig. 15. I_1 decrease according to the increase of the radiant heat at rest and during exercise with a significant negative correlation. There is a significant correlation in the two indices, I_2 and I_3, with the intensity of radiant heat at rest, positive in I_2 and negative in I_3, but no correlation during exercise.

Also, Fig. 16 shows the correlation between the values of index I_1 at rest and during exercise, I_1 and I_3 show a significant positive correlation to the increase of radiant heat but I_2 does not. Therefore, it can be suggested that index I_1 is most useful in evaluating the heat tolerance by exposure to the radiant heat.

Conclusion

To learn about the physiological reactions of the human body under direct sunshine exposure, a series of simulating experiments were carried out and the following results were obtained:

1) Equations were obtained to quantitatively indicate the change in the rate of the physiological reactions caused by the radiant heat (Table 3).

2) The body weight loss rate and Na^+ loss rate were most markely influenced by radiation at rest and during exercise, followed by the respiration rate and heart rate. The respiratory volume showed a significant correlation with radiation only during exercise.

3) Heat tolerance index based on change of the rectal temperature, body weight loss rate and electrolyte loss rate, gave a useful clue in studying the heat tolerance under radiant heat exposure.

4) Rectal temperature, heart rate, systolic blood pressure, respiration rate, respiratory volume, O_2 consumption, heat production and body weight loss rate showed differences between at rest and exercise under a hot environment, regardless of the intensity of the radiant heat. The effect of radiant heat on mean skin temperature, diastolic blood pressure and RQ did not differ between at rest and exercise.

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