Analysis of Heat-Exercise Cross Adaptation in Hot Dry Sauna

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Abstract: A tropical resident (non-sportsman) and a Japanese sportsman (sprinter) were the subjects in this study. The changes in metabolic rate, respiratory rate, pulse rate, blood pressure, skin temperature and body weight during 30 minutes sauna heat load (60-70℃) were measured after 30 minutes resting in the climate chamber (28℃, 60% r.h.). The mean increase of pulse rate and metabolic rate in the tropical subject were small compared to those of the Japanese sportsman (in both subjects, n=4 period of experiments). But considerable increase of respiratory rate and in a few case the rapid and shallow breathing similar to thermal panting were observed in the tropical subject. The results obtained from the tropical subject may be closely related to his inherent constitutional characteristic and his acquired heat tolerance, and those of the Japanese sportsman may be due to the enhanced ability of heat production and effective heat loss response owing to larger cross adaptability by co-operation of heat and exercise load.

Key words: Tropical resident, Heat-exercise cross adaptation, Metabolic rate, Human thermal panting

INTRODUCTION

It is well known that tropical residents have some tolerance to heat. Such characteristics seem to be not only hereditary but also acquired one. Furthermore, it is said that their physical status, basal metabolism and some other physiological characteristics are influenced by the climate in which they were born and raised (Adolph, 1946; Dill *et al.*, 1938; Kuno 1934, 1956). On the other hand, physical training enhances the sweating capacity to heat load (Hori *et al.*, 1976, 1977; Hale, 1970; Glaser, 1953; Nadel *et al.*, 1974).

Therefore, we designed the present investigation in order to clarify the mechanisms of cross adaptation between heat load and physical training.

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MATERIALS AND METHODS

Two healthy male volunteers were the subjects of this experiment. One is a tropical resident who works in the office and has almost no athletic activities. He was born and bred in Tanzania and arrived in Japan last winter. The other is a Japanese sportsman (sprinter). Mean atmospheric temperature is 25.7℃ at Dar es Salaam in Tanzania and 16.6℃ at Nagasaki in Japan. The physilogical characteristics of these two subjects are shown in Table 1. The experiments commenced mid-summer and were carried out in controlled climatic chamber (temperature 28℃, relative hummidity 60%).

Table 1. Comparison of the physical characteristics in the tropical subject and the Japanese sportsman.

Ht:Hight(cm), Wt:Weight(kg), BSA:Body surface area(m^2)

Subject	Age	Ht (cm)	Wt (kg)	BSA (m^2)	Resident
Tropical subject	37	160	54.59	1.57	Tanzania
Japanese sportsman	33	167	68.74	1.79	Japan

On the experimental days the subjects dressed in sporting shorts only were instructed to sit in the controlled climatic chamber for 30 minutes to obtain thermal equilibrium. Their pulse rate and blood pressure were measured with digital haemodynamometer (UA-535) and body weight were measured with human balance (FW-100K, Japan). Their oxygen consumptions were measured by a 9 ℓ drum Benedict-Roth's respirometer.

Thereafter the subject had body attachments of four skin thermisters at the upper chest, upper arm, lateral aspect of thigh and calf by fixing with a single layer hospital grade plaster. Then the subject entered a pre-heated sauna box (Arubi-As 1300SD, Japan) at 60-70℃. The sauna temperature was thermostatically controlled. Two thermisters inside the sauna box were like the skin thermisters connected to computer printer assembly and minute to minute skin temperature and sauna temperature were recorded. The subject had to sit quietly in the sauna box. The respirometer mouth tubing was advanced through a small opening on the door of the sauna box. The nose of the subject was clipped and a haemodynamometer cuff was applied to the right arm.

The subject started breathing oxygen continuously for 30 minutes. Blood pressure and pulse rate were recorded every five minutes. At the end of the 30 minutes the subject moved out of the sauna box and skin attachments were removed and he sat on a chair and oxygen consumption measurement was repeated for 15 minutes. After this experiment the subject took bath, dried up well and was not allowed to pass out urine or drink. He wore similar sporting shorts and re-weighed himself.

These time course events were analysed and compared between individuals. Four

such experiments were repeatedly done by each subject between 9 and 11 a.m. over a period of three weeks.

Results and Discussion

1. Changes in skin temperature.

The changes of mean skin temperature were almost parallel with those of sauna temperature in both subjects.

2. Changes in pulse rate and blood pressure.

Before entering the sauna box, the initial value of pulse rate in the tropical subject was higher than that of the Japanese sportsman (Fig. 1, 2). Probably the finding suggests that the pulse rate of the Japanese sportsman is parasympathetically suppressed, because of an increased cardiac output due to daily physical training of the subject. On the contrary, the increase of pulse rate during heat load was low in the tropical subject compared to that of the Japanese sportsman. It seems to be due to small increase of metabolism to the same amount of heat load. In both subject no significant changes in blood pressure were observed.

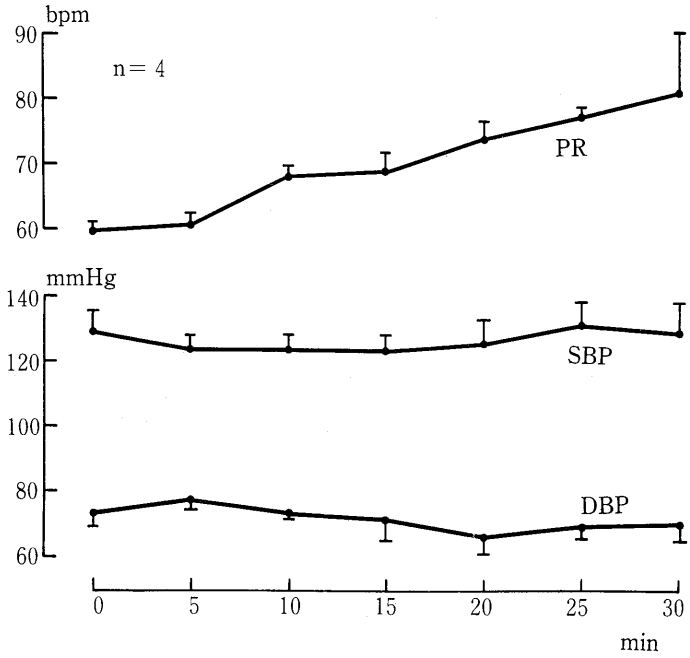

Fig. 1. The time course of pulse rate and blood pressure in the Japanese sportsman during heat exposure in the sauna box.
PR: Pulse rate (bpm), SBP: Systolic blood pressure (mmHg), DBP: Diastolic blood pressure (mmHg)

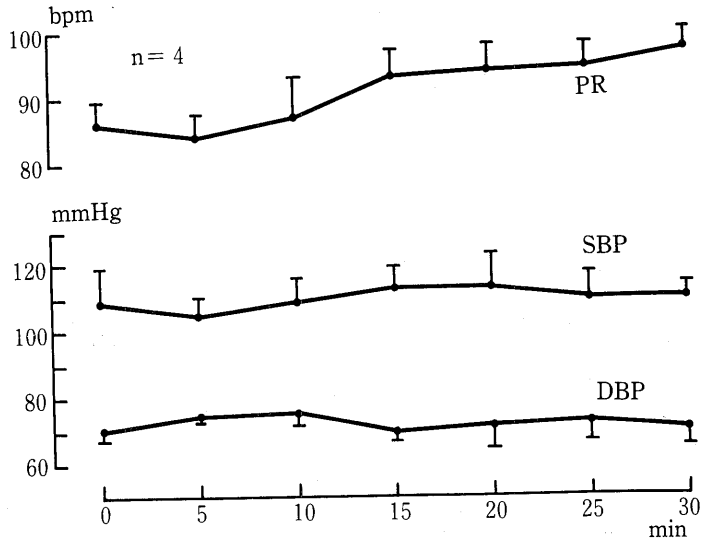

Fig. 2. The time course of pulse rate and blood pressure in the tropical subject during heat exposure in the sauna box.
PR: Pulse rate (bpm), SBP: Systolic blood pressure (mmHg), DBP: Diastolic blood pressure (mmHg)

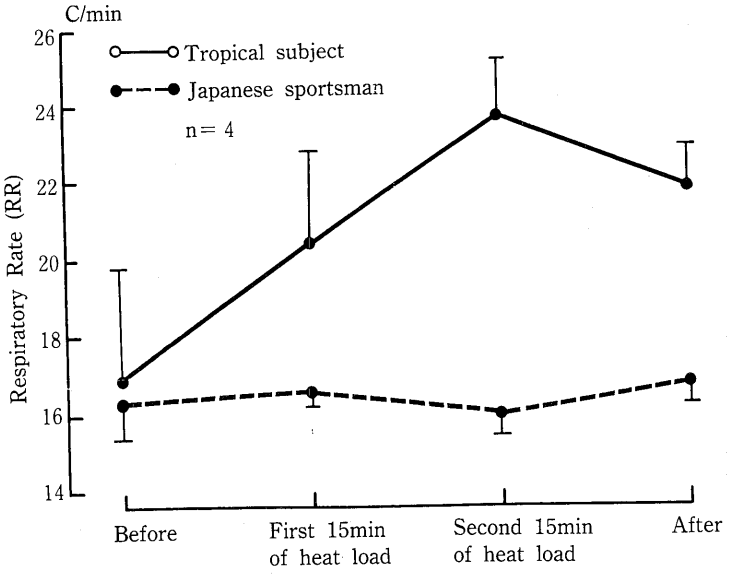

Fig. 3. Comparison of the changes in respiratory rate induced by sauna heat exposure in the tropical subject and the Japanese sportsman. RR: Respiratory rate (c/min)

3. Changes in respiratory rate.

In the Japanese sportsman almost no changes in respiratory rate were observed during heat load (Fig. 3). This finding agrees with that of the previous report (Gaudio *et al.*, 1968). In general, it is considerable that an increase of oxygen uptake during heat load does not depend on the change of respiratory rate but on the increase of the tidal volume. However, considerable increase of respiratory rate was observed in the tropical subject. In addition to this finding, in one case of a series of experiments of the tropical subject at the end period of 30 min heat load, the rapid and shallow breathing similar to the so-called panting phenomenon was observed after a single deep breathing. Maximam respiratory rate was 34 cycle/min (Fig. 4). The rapid and shallow respiration (thermal panting) is markedly effective to evaporative heat loss and further thermal panting is well activated by efferent neural drive of the preoptic area and anterior hypothalamus (PO/AH) as well as by direct warming the respiratory center with warm blood. The thermal panting characterized by rapid and shallow respiration does not play an important role on gaseous exchange of metabolic and circulatory function, therefore, respiratory alkalosis does not occur. Gaudio *et al.* reported the markedly high respiratory rate (36 breaths/min) during strenuous heat load observed in a man of his race undescribed whether tropical subject or not.

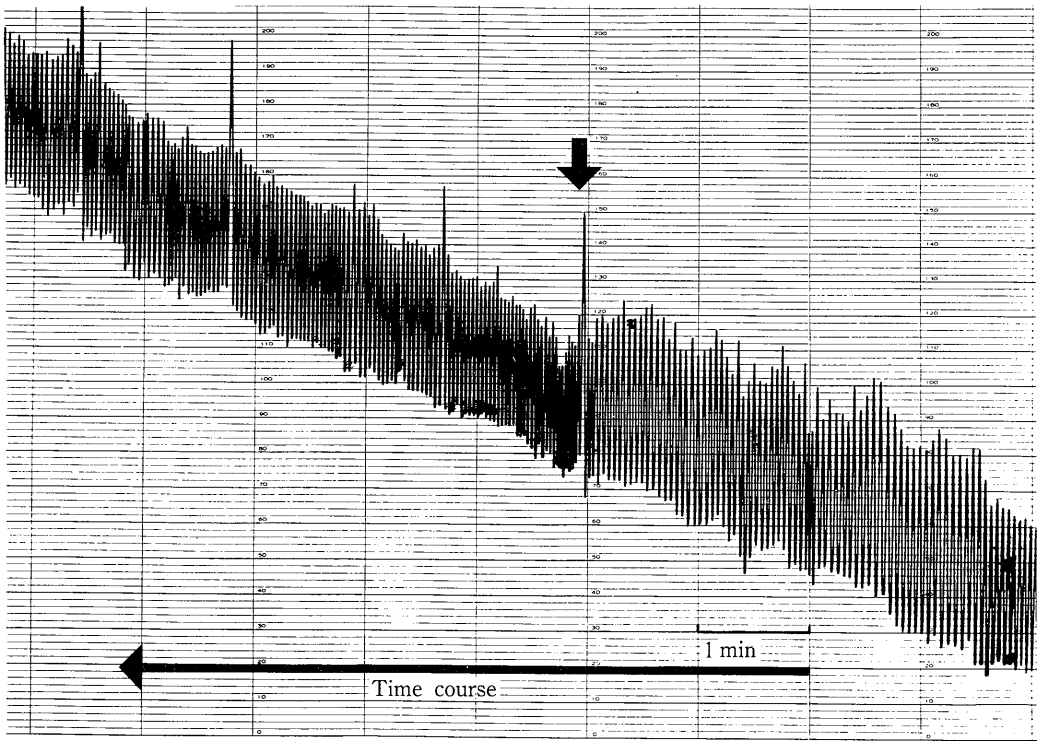

Fig. 4. A typical recording of the rapid and shallow breathing similar to thermal panting during sauna heat load in the tropical subject. (For details see text)

4. Changes in metabolic rate.

It is well known that metabolic rate of tropical residents is low compared to non-heat acclimatized residents. As shown in Fig. 5, the initial metabolic rate in the tropical subject was lower than that of the Japanese subject. The increase in metabolic rate due to heat load in tropical subject was significantly small compared to that of the Japanese sportsman (Fig. 5). These results suggest that the metabolic rate in tropical resident may be suppressed against heat load by his inherent constitutional characteristic as well as by acquired heat tolerance. On the other hand, large increase of metabolic rate in the Japanese sportsman may be attributed to the large ability of heat production and energy expenditure due to cross adaptation between heat load and physical training in his mode of daily life (Hori *et al.*, 1976, 1977; Hale, 1970; Glaser, 1953; Nadel *et al.*, 1974).

In both subjects, however, the initial rise of metabolic rate during the first 15 min heat load was sharp compared to that of the second one.

In Fig. 6, mean pulse rate during the first and second 15 min heat load were demonstrated to compare the results of metabolic rate shown in Fig. 5. It is attractive that the pulse rate in the tropical subject was higher than that of the Japanese sportsman, while the metabolic rate in the tropical subject was conversely lower. But the increase rate in pulse rate and metabolic rate during heat load in the tropical subject was low compared to that of the Japanese subject.

From these results the following two comments are drawn: the first is that the pulse rate and metabolic rate during heat load changed in parallel in both subjects, and the second is that the stable and smaller change rate of metabolism during heat load observed in the tropical subject sugests the habituation due to a raised threshold of heat sensitivity.

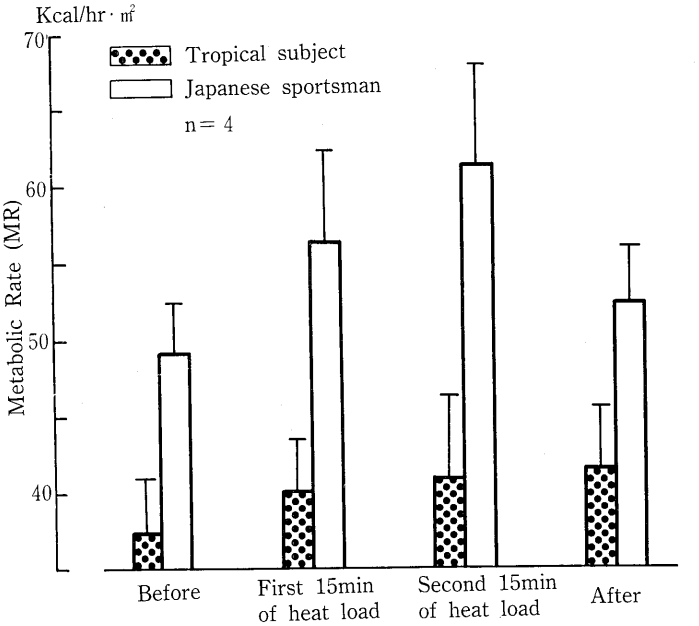

Fig. 5. Comparison of the changes in metabolic rate by sauna heat exposure in the tropical subject and the Japanese sportsman. MR: Metabolic rate (Kcal/hr•m^2)

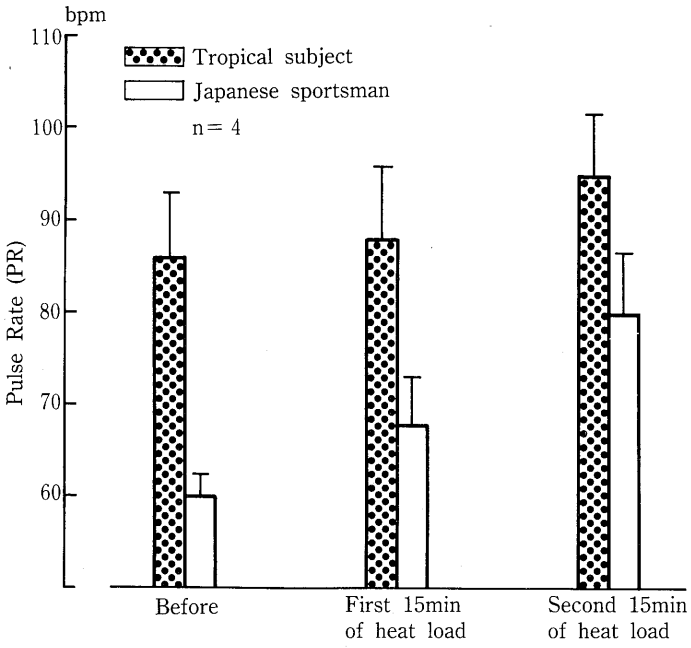

Fig. 6. Comparison of the changes in pulse rate by sauna heat exposure in the tropical subject and the Japanese sportsman. PR: Pusle rate

5. Changes in body weight.

In order to determine the effective heat loss capability in both subjects, body weight loss was calculated as an indicator of thermal sweating. The results of body weight loss in the tropical and Japanese subjects were 0.67% and 0.97%, respectively (Table 2). The small amount of sweat observed in the tropical subject may suggest an eventual feature of the long term heat acclimatization. The larger amount of sweat in the sportsman is considered to be the result of a highly developed heat loss capability acquired by his daily physical training.

Table 2. Comparison of body weight loss in the tropical subject and the Japanese sportsman.

Subject (n=4)	Body Weight Loss (kg)	Body Weight Loss Rate (%)
Tropical subject	0.37±0.11	0.67±0.21
Japanese sportsman	0.67±0.07	0.97±0.21

(mean ± SD)

6. Changes in oral temperature.

The results of the changes in oral temperature previously reported were shown in Table 3 (Riwa *et al.*, 1987). No significant difference of the initial values of oral temperature was observed in both subjects. However, the mean rectal temperature of Bantu was significantly lower than that of Caucasians in unacclimatized state (Wyndham *et al.*, 1964).

The increase in oral temperature during heat load in the tropical subject was smaller than that of the Japanese sportsman, which agrees with the results reported by Wyndham *et al.*.

Table 3. Comparison of the changes of oral temperature in the tropical subject and the Japanese subject.

Subject	before (℃)	after (℃)
Tropical subject	36.57±0.27	38.11±0.30
Japanese sportsman	36.55±0.19	38.33±0.37

(mean ± SD)

Although the comparison between one tropical resident and one Japanese sportsman, the results obtained in the present investigation may be utilized for the further development of research not only on the central and peripheral mechanisms of temperature regulation but also the mechanisms of cross adaptation related to heat and physical training.

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低温サウナによる暑熱−運動負荷の交叉適応の解析

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熱帯地非スポーツマン（タンザニア）と日本人スポーツマン（短距離走者）を環境制御実験装置（気温28℃，湿度60％）に安静にさせた後，低温サウナ（60−70℃）で30分間暑熱負荷を加え（n＝4　period），体重，皮膚温，心拍数，血圧，呼吸数，代謝量の変化を連続記録解析した．暑熱負荷中の熱帯地非スポーツマンの心拍数・代謝量の増加率は日本人スポーツマンの増加率より低かった．しかし熱帯地非スポーツマンでは，かなりの呼吸数増加が観察され，特に深呼吸後に見られた浅速呼吸は，ヒトに熱放散現象であるパンディング現象の残存が示唆された．この熱帯地非スポーツマンから得られた結果は遺伝的に獲得された熱耐性であり，日本人スポーツマンのそれは暑熱と運動の協調による体温調節反応量の増加によると考えられる．

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