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Analysis of the Mechanisms of Heat Acclimatization

−Comparison of Heat-tolerance between Japanese and Thai Subjects−

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Abstract: In order to clarify the mechanisms of heat acclimatization to tropical climates by permanent residence, changes in oral temperature due to heat load were compared in 10 male subjects in Chiang Mai, Thailand (tropical region) and 10 male subjects in Nagasaki, Japan (temperate region). Mean annual ambient temperature is 16.6℃ in Nagasaki and 25.9℃ in Chiang Mai. The experiments for the Thai subjects were performed in Chiang Mai and those for the Japanese subjects in Nagasaki during each region's hottest months. The constitutional characteristics of the Thai subjects were a little shorter and slightly leaner than the Japanese. After staying at rest in the experimental room at 32℃ and 35% of relative humidity for at least 30 min, the lower legs were immersed into a hot water bath of 43℃ for 30 min. Mean initial oral temperature was 37.06±0.07℃ in Japanese and 37.12±0.05℃ in Thai subjects ($P>0.05$). Oral temperature rose after heat load and reached to 37.54±0.06℃ and 37.59±0.06℃ in Japanese and Thai subjects ($P>0.05$), respectively. Although the inhabitants in Chiang Mai were expected to be more acclimatized to heat compared to those in Nagasaki, no significant difference in the oral temperature was found between two groups throughout the experiment. It is speculated that the same rise in oral temperature in both groups of subjects is attributed to a lower sweat rate and an increase of dry heat loss in Thai subjects. In future studies, not only core temperature but also skin temperatures (dry heat loss) and sweat rate (evaporative heat loss) should be measured and analyzed.

Key words: Heat-acclimatization, Tropical natives, Thermo-regulation, Sweating, Dry heat loss

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Introduction

Temperature regulation of human body is affected in different ways by climatic environments such as air temperature and humidity. In "Human Perspiration", Kuno (1956) described that adaptation to temporary exposure to heat and acclimatization to a tropical climate by permanent residence were distinguishable from each other. Transitory heat acclimation by repeated exposure to heat with or without physical exercise has been intensively investigated by many researchers. It is well-known that unacclimatized subjects tend to sweat more profusely with a shorter latent period after repeated exposure to heat. Also, salt concentration in the sweat becomes lower (Kuno, 1956; Yoshimura, 1960).

Up to now, there have been very few studies concerned with long-term heat acclimatization to tropical climates. Therefore, in order to clarify the mechanisms of heat acclimatization, changes in oral temperature due to heat load in tropical residents were compared to those in residents of temperate zone in the present study.

Materials and Methods

Twenty healthy male students, 18–21 years old, 10 Japanese in Nagasaki (32°44'N, 129°52'E), Japan and 10 Thai in Chiang Mai (18°47'N, 98°59'E), Thailand volunteered for this study. Mean monthly ambient temperatures in Nagasaki and in Chiang Mai are shown in Fig. 1. Nagasaki is located in a temperate zone, with hot summers and cold winters, while Chiang Mai is located in a tropical zone, with long hot summers. Mean annual ambient temperature is 16.6℃ and 25.9℃ in Nagasaki and Chiang Mai, respectively. The experiments for Thai subjects were carried out from March to April in 1990 in Chiang Mai, and those

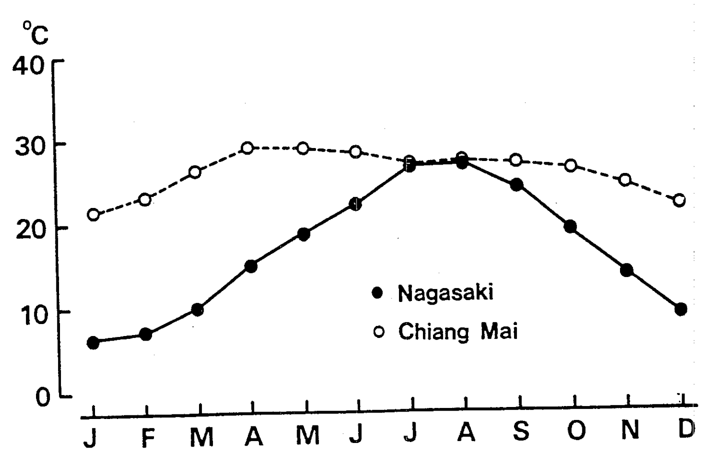

Fig. 1. Mean monthly ambient temperatures in Nagasaki (32°44'N, 129°52'E, Japan) and in Chiang Mai (18°47'N, 98°59'E, Thailand). The experiments were carried out in the hottest months in both places, from August to September in Nagasaki and from March to April in Chiang Mai.

for the Japanese subjects from August to September in 1990 in Nagasaki. All experiments were performed between 02:00−04:00 p.m. to avoid the influence of circadian variation.

Each subject wore only shorts and was allowed to sit quietly on a chair in the experimental room. The air temperature and relative humidity in the experimental room in Chiang Mai were 32±2℃ and 35±5%, respectively. In Nagasaki, the same experimental conditions as in Chiang Mai were simulated in an environmentally-controlled chamber. After staying at rest in the experimental room for at least 30 min, heat load was applied by immersing the lower legs in a hot water bath (43℃) for 30 min. After cessation of the heat load, the subject was allowed to sit in the same condition for a further 30 min.

Oral temperature was measured with a thermistor probe (Model 2100, YSI), placed into sublingual space before, during and after heat load every 5 min in Chiang Mai.

In Nagasaki, oral, tympanic and rectal temperatures as well as skin temperatures on the chest, forearm, thigh and lower leg were measured by thermistors (K923, TAKARA Instruments Co.) connected to the personal computer (PC−8801, NEC). Mean skin temperature was calculated according to Ramanathan's formula (Ramanathan, 1964). Furthermore, local sweat rates on the chest and the abdomen were continuously recorded by capacitance hygrometer-sweat capture capsule method (Fan, 1987; Matsumoto *et al.*, 1988, 1989). Briefly, dry N_2 gas flowed into the capsule (10.18 cm^2) attached to the skin with a constant flow rate of 1 ℓ/min, and the change of the relative humidity of effluent gas was detected by hygrometer (H211, TAKARA Instruments Co.) connected to a DC-pen-recorder.

Statistical significance was assessed by Student's *t*-test at 0.05 level and the values were presented as mean±SE.

RESULTS

The physical characteristics of the subjects were well matched as shown in Table 1. Mean values of height and weight in the Japanese subjects were slightly higher than those in the Thai subjects; however, the differences were not significant. These results are in agreement with Hori *et al.* (1977), who measured physical characteristics and basal metabolism in 30 young male Thai and 20 young male Japanese, and reported that Thai subjects were a little shorter and more slender (a smaller skinfold thickness) than Japanese. Also, Thai sub-

Table 1. Physical characteristics of the subjects

	n	Age. years	Height, cm	Weight, kg
Japanese in Nagasaki	10	19.1±0.9	170.7±6.1	64.2±12.0
Thai in Chiang Mai	10	19.3±0.7	170.0±5.9	59.4±5.5

Values are mean±SD. There was no significant difference between two groups.

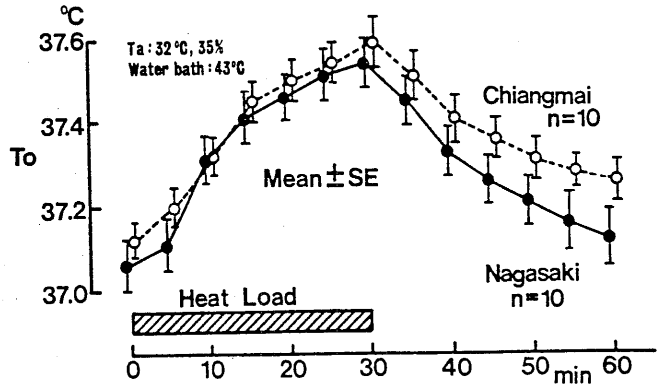

Fig. 2. Comparison of oral temperatures during and after heat load between Thai and Japanese subjects. After staying at rest under the experimental condition (32±2℃, 35±5% of relative humidity) for at least 30 min, heat load was then applied by bilateral immersing the lower legs to hot water bath (43℃) for 30 min.

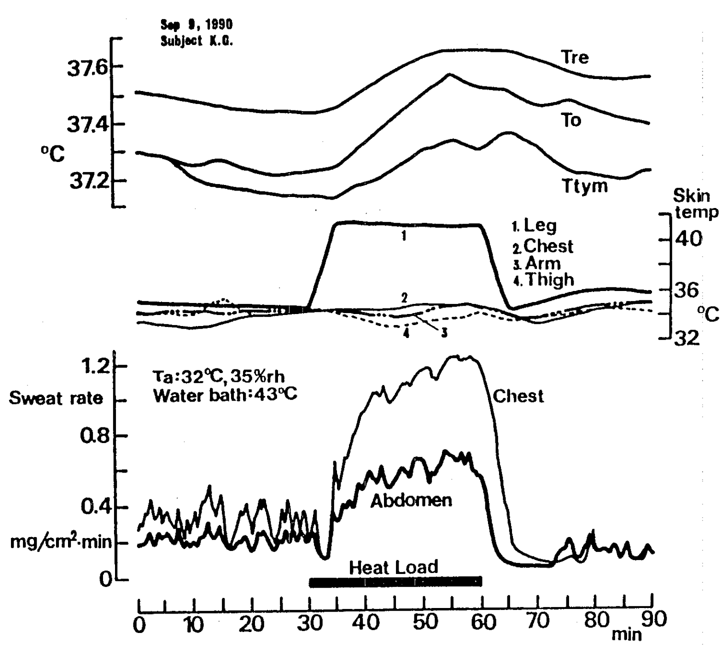

Fig. 3. A typical recording of a Japanese subject at Nagasaki. Oral, rectal and tympanic temperatures and skin temperatures on the chest, forearm, thigh and leg as well as local sweat rates on the chest and abdomen were recorded before, during and after heat load by immersion of the lower legs in a hot water bath (43℃). Mild sweating on the chest and the abdomen was observed before heat load. Local sweat rate was transiently suppressed by the application of heat load and then markedly increased. Tre: rectal temperature, To: oral temperature, Ttym: tympanic temperature.

jects had a slightly lower basal metabolism per unit body surface.

Changes in oral temperature during and after heat load in Japanese and Thai subjects were shown and compared in Fig. 2. Mean initial oral temperature under the condition of 32℃ and 35% of relative humidity before heat load was 37.06±0.07℃ (mean±SE) in the Japanese and 37.12±0.05℃ in the Thai subjects ($P>0.05$). After the application of heat load, oral temperature rose and reached 37.54±0.06℃ in the Japanese and 37.59±0.06℃ in the Thai subjects ($P>0.05$), and gradually decreased after the cessation of heat load. No significant difference in the oral temperature was found between two groups throughout the whole experiment.

A typical recording of a Japanese subject in Nagasaki is shown in Fig. 3. Averages in rectal, oral, tympanic and mean skin temperature among 10 Japanese subjects in Nagasaki are shown in Fig. 4. At 32℃ and 35% of relative humidity, before the application of heat load on the legs, rectal temperature was the highest among three kinds of core temperatures: rectal, tympanic and oral. Tympanic temperature was almost identical to oral temperature. Mild to moderate sweating was observed at 32℃ and 35% of relative humidity before heat load. Response to heat load was the sharpest in oral temperature, while that of rectal temperature was fairly dull and lagged far behind. Tympanic temperature well followed oral temperature. Local sweat rates on the chest and the abdomen were transiently suppressed by the application of heat load on the legs, and then markedly increased. This transient suppression of sweating by heat load was observed in 9 of 10 Japanese subjects.

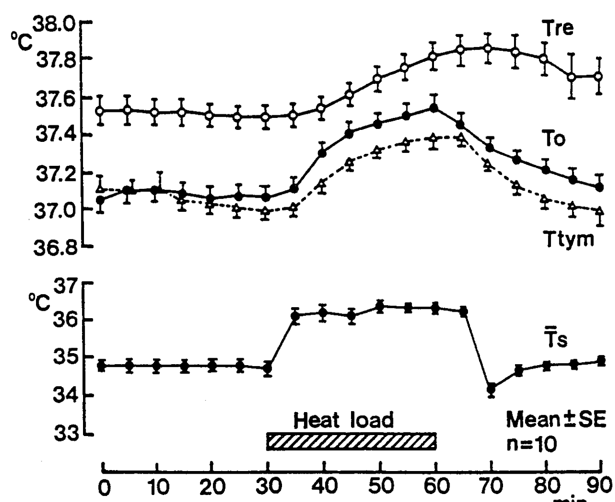

Fig. 4. Changes in rectal, oral, tympanic and mean skin temperatures due to heat load in Japanese subjects at Nagasaki. Rectal temperature was higher than oral and tympanic temperatures throughout the experiment. Response to heat load in oral temperature was the sharpest and that in rectal temperature was fairly dull and fur lagged. Tre: rectal temperature, To: oral temperature, Ttym: tympanic temperature, T̄s: mean skin temperature.

Discussion

It is well known that temperature regulation of human body is influenced by climatic conditions. Chiang Mai is located in a tropical zone. Mean monthly ambient temperatures are above 20℃ throughout the year , and mean annual ambient temperature is 25.9℃. The inhabitants in Chiang Mai are expected to be more acclimatized to heat compared to those in Nagasaki, which is located in a temperate zone. In order to clarify the mechanisms of long-term heat acclimatization to tropical climates, in the present investigation, changes in oral temperature due to heat load on the legs were compared between the residents in Chiang Mai and those in Nagasaki. However, contrary to expectation, no significant difference was observed at least in the oral temperature between the two groups.

Hori *et al.* (1976) and Sasaki and Tsuzuki (1984) studied sweat responses to heat load on the legs in residents of Okinawa (subtropical zone) and reported no significant difference in rise of core temperature between residents in a subtropical zone and those in a temperate zone. Mean oral temperature measured under basal condition (at 28℃) in 30 Thai subjects was identical to that in 20 Japanese subjects (Hori *et al.,* 1977). Those results are in agreement with our results obtained in the present study.

On the other hand, Wyndham *et al.* (1964) reported a conflicting result that rectal temperatures before and during heat load in Bantu were lower than those in Caucasians. They carried out the experiments in winter, while our experiments were performed in the hottest months during the year. Since we have fairly hot summers in Nagasaki, the Japanese subjects in this study are considered to be acclimatized to heat (Matsumoto *et al.,* 1990). Hori *et al.,* 1976) reported smaller seasonal variation of sweat rate in the subtropical residents than temperate residents. We can not fully explain the discrepancy between our results and Wyndham's; however this may be one of the possible explanations.

It is generally accepted that tropical natives sweat less and slower than temperate natives and the salt concentration in sweat in the former is much lower than in the latter (Kuno, 1956; Yoshimura, 1960; Hori *et al.,* 1976; Ohwatari *et al.,* 1983; Sasaki and Tsuzuki, 1984; Fan, 1987). In fact, we studied sweat reponses to heat load in Japanese and Thai subjects under thermo-neutral conditions, obtaining the preliminary results, which support previous findings (unpublished data). It is speculated that the same rise in oral temperature in both groups of subjects is attributed to a lower sweat rate and an increase of dry heat loss, through conduction and convection, in the Thai subjects. Further studies should be carried out to clarify the mechanisms of heat acclimatization, in which not only core temperature but also skin temperatures (indicator of dry heat loss) and sweat rate (indicator of wet heat loss) are determined and analyzed.

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