

## Study on Mechanisms of Heat Acclimatization Due to Thermal Sweating

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

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**Abstract:** Heat tolerance and sweat response to heat load of tropical subjects in Chiang Mai and temperate subjects in Nagasaki were compared under identical conditions. Male students in Chiang Mai (n=10) and in Nagasaki (n=10) volunteered for this study. The Thai subjects were a little shorter and slightly leaner than the Japanese. Heat load was applied on the legs by immersion into hot water (43°C) for 30 min in the room at 26.6°C and 33%rh. Sublingual (oral) temperature was measured with a thermistor probe and local sweat rate was measured by the capacitance hygrometer-sweat capsule method. Change in oral temperature, sweat onset time and local sweat volume were compared between Japanese and Thai. Initial oral temperatures ( $36.76 \pm 0.11^\circ\text{C}$  in Japanese,  $36.71 \pm 0.23^\circ\text{C}$  in Thai) were identical, and no sweat was observed before heat load. Mean sweat onset time ( $9.3 \pm 2.1$  min chest in Japanese,  $16.6 \pm 5.6$  min chest in Thai) were significantly longer and local sweat volume ( $10.19 \pm 5.00$  mg/cm<sup>2</sup>, chest in Japanese,  $1.39 \pm 0.91$  mg/cm<sup>2</sup>, chest in Thai) was significantly smaller in Thai subjects than Japanese, however, oral temperature ( $37.18 \pm 0.32^\circ\text{C}$ ) of Thai subjects was kept slightly lower than oral temperature ( $37.42 \pm 0.10^\circ\text{C}$ ) of Japanese even under a 30 min heat load. Sweat volume on the abdomen was larger than on the chest in 9 of 10 Thai subjects. On the contrary, sweat volume on the chest was larger than that on the abdomen in 7 of 10 Japanese subjects. These results suggest that heat tolerance of tropical subjects is due to a more efficient evaporative ability due to a greater heat loss brought about by their long term exposure to heat. Furthermore, the habituation phenomenon related to the reduction of thermoregulatory effector mechanisms were also considered so as to clarify the mechanisms of thermal acclimatization.

*Key words:* Heat-acclimatization, Heat tolerance, Tropical subjects, Thermoregulation, Thermal sweating

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## INTRODUCTION

Temperature regulation of the human body is affected in different ways by climatic environments such as air temperature, humidity and air velocity. 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 has been intensively investigated by many researchers. Up to now, it is generally accepted that tropical natives begin to sweat more slowly 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; Matsumoto *et al.*, 1991). We have studied sweat responses to heat load in Japanese and Thai subjects under identical, thermo-neutral conditions, obtaining the preliminary results, which support the previous findings. It was speculated that the slow rise in oral temperature in tropical subjects might be attributed to a lower sweat rate and an increase of dry heat loss through conduction and convection. (Matsumoto *et al.*, 1991). As far as the autonomic nervous control of reduction of thermoregulatory effector gain (Kosaka *et al.*, 1988, 1989; Ohwatari *et al.*, 1992) is concerned, most theories consider that central and peripheral temperature signals interact at the level of the preoptic area and the anterior hypothalamic in the diencephalon (PO/AH), of which the effector mechanism of thermoregulation indicated little or no increase of cerebral blood flow in thermally acclimated animals (habituation phenomenon). In this paper, therefore, precise measurement and analysis of sweat onset time as well as sweat volume due to heat load were carried out by the mechanism of long term heat acclimatization.

## MATERIALS AND METHODS

Twenty healthy male students, 18-21 years old, 10 Japanese from Nagasaki (32° 44' N, 129° 52' E), Japan and 10 Thai from Chiang Mai (18° 47' N, 98° 59' E), Thailand volunteered for this study (Fig. 1, Table 1). Nagasaki is located in a temperate zone, with hot summers and cold winters, while Chiang Mai is located in a tropical zone, with dry-and wet-seasons. Mean annual ambient temperature is 16.6°C and 25.9°C in Nagasaki and Chiang Mai, respectively. The experiments for Thai subjects were carried out from January to February in 1991 in Chiang Mai, and those for the Japanese subjects from January to February in 1992 in Nagasaki. All experiments were performed between 02:00-04:00 p.m. to avoid the influence of circadian variation. Experimental procedures were almost the same as the previous paper described by Matsumoto *et al.* (1991). Namely, each subject wore only shorts and was submitted to sit quietly on a chair in the experimental room. The air temperature and relative humidity in the experimental room in Chiang Mai were  $26.6 \pm 2.0^\circ\text{C}$  and  $33.0 \pm 5.1\%$ , respectively. In Nagasaki, the same experimental conditions as in Chiang Mai were simulated in an environmentally-controlled chamber. After stauomg 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°C) for 30 min. After cessation of the heat load, the subject was allowed to sit in the same condition for a further 30 min.



Fig. 1. A map of Chiang Mai where locates 18° 47' N and 98° 39' E. (Nagasaki 32° 44' N and 129° 52' E). Mean annual ambient temperature is 26.6°C and 16.6°C in Chiang Mai and Nagasaki, respectively.

Table 1. Physical characteristics of the subjects

	n	Age. years	Height. cm	Weight. kg
Japanese in Nagasaki	10	20.3±0.6	174.2±4.0	63.7±6.3
Thai in Chiang Mai	10	20.8±0.9	169.7±3.9	58.1±5.9

Values are mean±SD. There was no significant difference between two groups, except for weight. ( $P < 0.05$ )

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

In Nagasaki, oral and tympanic temperatures as well as skin temperatures on the chest, forearm, thigh and lower leg were measured by thermistor probes (K923, TAKARA Instruments Co.) connected to a 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, 1991). Briefly, dry nitrogen gas flowed into the capsule (10.18 cm<sup>2</sup>) attached to the skin with a constant flow rate of 1 l/min, and the change of relative humidity of effluent gas was detected by a 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  $\pm$  SE or mean  $\pm$  SD.

## RESULTS

The physical characteristics of the subjects were well matched as shown in Table 1. Mean values of age, height and weight in the Japanese subjects were slightly different compared to those in the Thai subjects, however, the differences were not significant except for weight ( $p < 0.05$ ). 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 subjects had a slightly lower basal metabolism per unit body surface reported by Matsumoto *et al.* (1991).

Comparison of changes in oral temperature during and after heat load in Japanese and Thai subjects were demonstrated in Table 2. Mean initial oral temperature at ambient temperature of 26.6°C and 33% of relative humidity before heat load was  $36.76 \pm 0.11$ °C (mean  $\pm$  SD) in the Japanese and  $36.71 \pm 0.23$ °C in the Thai subjects (NS). After 30 min application of heat load, oral temperature rose and reached  $37.42 \pm 0.10$ °C in the Japanese and  $37.18 \pm 0.32$ °C in the Thai subjects (NS). However oral temperature of Thai subjects

Table 2. Oral temperature before and after heat load

	before	at 30 min
Japanese (Nagasaki)	$36.76 \pm 0.1$	$37.42 \pm 0.10$ ( $0.70 \pm 0.15$ )
Thai (Chiang Mai)	$36.71 \pm 0.23$	$37.18 \pm 0.32$ ( $0.47 \pm 0.31$ )
	N.S.	N.S.

(Mean  $\pm$  SD)

were kept slightly lower than oral temperature of Japanese. No significant difference in the oral temperature was found between the two groups throughout the whole experiment. Threshold oral temperatures (including temperature differences from the initial oral temperature) for sweating were summarized in the Table 3. Both at the chest and abdomen, threshold temperatures for sweating in Chiang Mai subjects were higher than those of Japanese subjects which indicate stronger heat tolerance in Thai subjects compared to Japanese subjects.

A typical recording of a Japanese subject in Nagasaki is shown in Fig. 2. At 26.6°C and 33% of relative humidity no sweating was observed. Tympanic temperature followed oral temperature well, although tympanic temperature was slightly higher than oral temperature

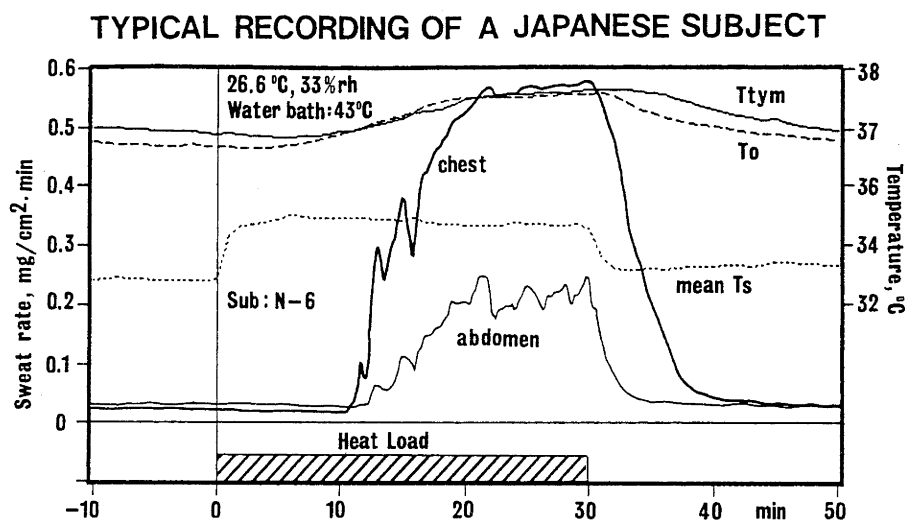


Fig. 2. A typical recording of a Japanese subject in Nagasaki, oral and tympanic temperatures as well as mean skin temperature colmulated by a personal computer and local sweat rates on the chest and abdomen were recorded before during and after heat load by immersion of the lower legs in a hot water bath (43°C). Sub: N-6. No. 6 subject in Nagasaki Ttym: tympanic temperature, To: mean oral temperature Ts: mean skin temperature calculated, of the chest, forearm, thigh and leg, after Ramamathan 1964

Table 3. Threshold oral temperature for sweating

	on the chest	on the abdomen
Japanese	36.84±0.09	36.9±0.09
(Nagasaki)	( $\Delta T=0.12\pm0.06$ )	( $\Delta T=0.17\pm0.06$ )
Thai	25.87±0.27	36.92±0.27
(Chiang Mai)	( $\Delta T=0.27\pm0.29$ )*	( $\Delta T=0.21\pm0.31$ )*
	N.S. P<0.05*	N.S. N.S.*

(Mean±SD)

before and after the application of heat load on the legs. In the previous paper, 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 in 9 of 10 Japanese subjects (Matsumoto *et al.*, 1991). However, the transient suppression of sweating by heat load was not induced in this

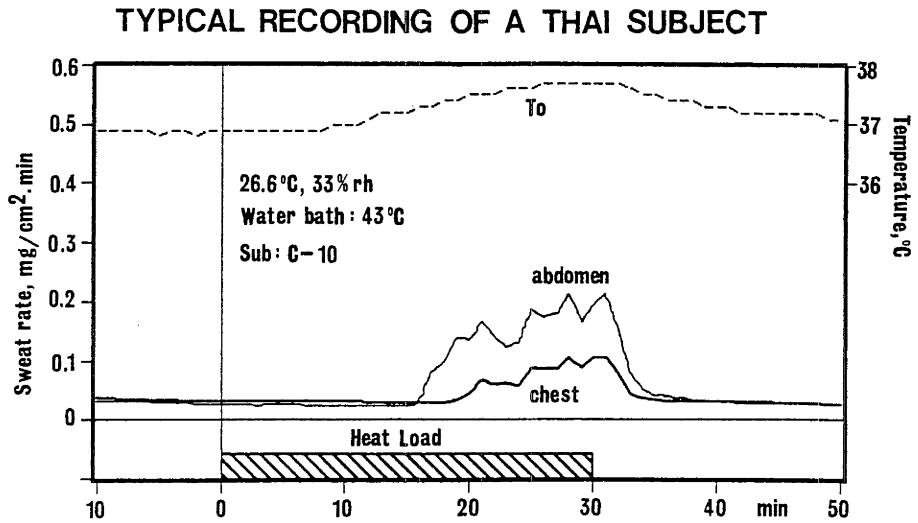


Fig. 3. A typical recording of a Thai subject in Chiang Mai. Oral temperature and local sweat rate on the chest and abdomen were recorded before, during and after heat load by immersion of the lower legs in a hot water bath (43°C).  
 Sub C-10: No. 10 Subject in Chiang Mai  
 To: oral temperature

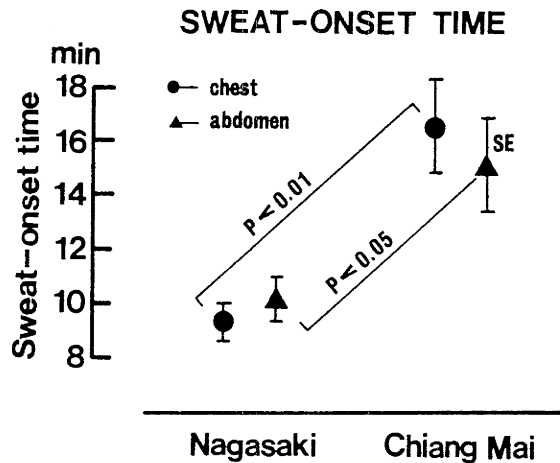


Fig. 4. Comparison of sweat-onset time between Nagasaki and Chiang Mai subjects. (Mean ± SE)

case. generally, sweat volume on the chest was larger than that on the abdomen in 7 of 10 Japanese subjects. An another typical recording of a Thai subject in Chiang Mai is demonstrated in Fig. 3. Mean sweat onset time ( $9.3 \pm 2.1$  min at the chest) in Japanese was significantly different compared to the value of  $16.6 \pm 5.6$  min at the chest in Thai as shown in Fig. 4. Mean sweat onset time ( $16.6 \pm 5.6$  min at the chest) in Thai was significantly

Table 4. Sweat onset time

	chest	abdomen
Japanese (Nagasaki)	$9.3 \pm 2.1$	$10.2 \pm 2.4$
Thai (Chiang Mai)	$16.6 \pm 5.6$	$15.1 \pm 5.7$ (min)
	$P < 0.01$	$P < 0.05$

(Mean  $\pm$  SD)

Table 5. Local sweat volume

	chest	abdomen
Japanese (Nagasaki)	$10.19 \pm 5.00$	$6.86 \pm 4.16$
Thai (Chiang Mai)	$1.39 \pm 0.91$	$2.37 \pm 1.22$ (mg/cm <sup>2</sup> )
	$P < 0.01$	$P < 0.01$

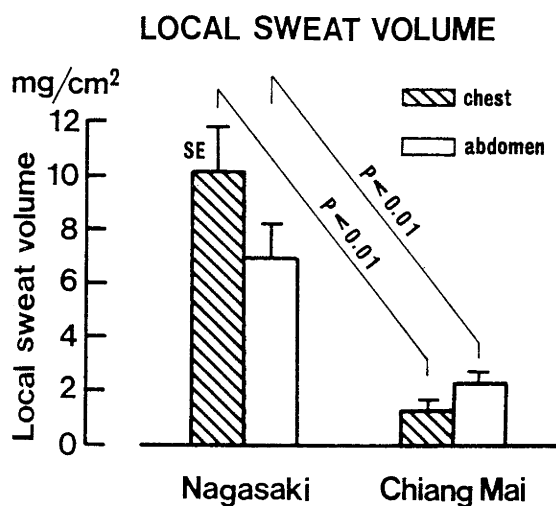
(Mean  $\pm$  SD)

Fig. 5. Comparison of local sweat volume between Nagasaki and Chiang Mai subjects. (Mean  $\pm$  SE)

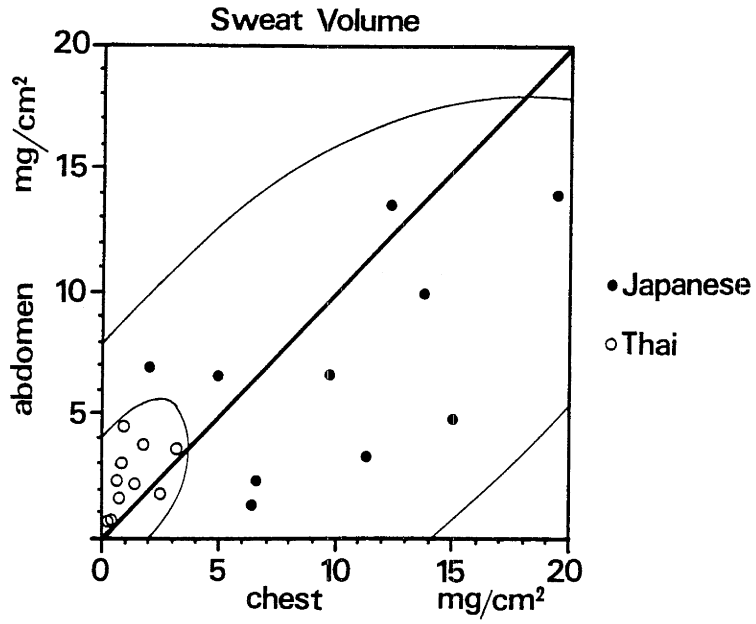


Fig. 6. Correlation of sweat volume between chest and abdomen, and dissociation of sweat volume between Japanese and Thai.

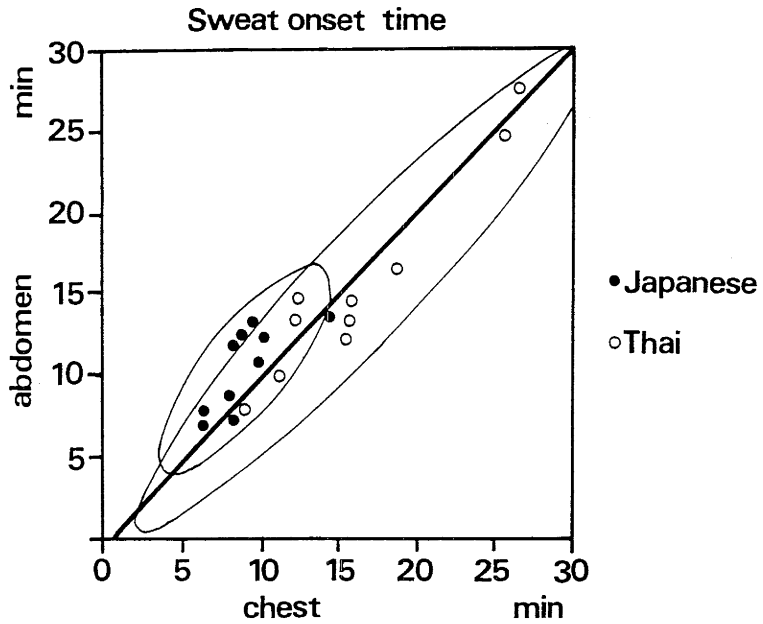


Fig. 7. Correlation of sweat onset time between the chest and abdomen and dissociation of sweat onset time between Japanese and Thai.



longer than the value ( $9.3 \pm 2.1$  min) in Japanese as shown in Table 4. Local sweat volume ( $1.39 \pm 0.91$  mg/cm<sup>2</sup>, at the chest) in Thai was significantly less than the value ( $10.19 \pm 5.00$  mg/cm<sup>2</sup> at the chest) in Japanese, as shown in Table 5. and Fig. 5.

Although sweat volume both on the chest and abdomen in Chiang Mai subjects were less than those in Japanese subjects, sweat volume on the abdomen was larger than sweat volume on the chest in 9 of 10 Thai subjects as shown in Fig. 6. The central and peripheral mechanism of sweat volume dissociation between the chest and abdomen observed in Chiang Mai subjects (Fig. 6) is precisely explained in some portion of the discussion of this paper. Sweat onset time between chest and abdomen was well corrected for both Japanese and Thai subjects, however, the longer sweat onset time of Thai subjects compared to Japanese subjects and distribution difference of sweat onset time between Japanese and Thai (Fig. 7) is also discussed at somewhere in this paper.

## DISCUSSION

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 Chiang Mai, mean monthly ambient temperatures are above 20°C throughout the year, and mean annual ambient temperature is 25.9°C. In order to clarify the mechanisms of long term heat acclimatization to tropical climates, in the present investigation, changes in oral temperature due to 30 min heat load on the legs were compared between the subjects in Chiang Mai ( $37.18 \pm 0.32$ °C) and those in Nagasaki ( $37.42 \pm 0.10$ °C). However, contrary to expectation, no significant difference was statistically observed at least in the oral temperature between the two groups of subjects.

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 the rise of core temperature between residents in a subtropical zone and those in a temperate zone. Mean oral temperature measured under basal conditions (at 28°C) in 30 Thai subjects was identical to that in 20 Japanese subjects (Hori *et al.*, 1977). Those results were in agreement with our results obtained in the previous study (Matsumoto *et al.*, 1991)

On the other hand, Wyndham *et al.* (1964) reported conflicting results stating that rectal temperatures before and during heat load in Bantu were lower than those in Caucasians which is not strongly but partially agreeable to the present result (see Table 2). They carried out the experiments in winter, while the previous experiments were performed during the hottest month of the year (Matsumoto *et al.*, 1991). 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, 1991). Hori *et al.* (1976) reported smaller seasonal variation of sweat rate in subtropical residents compared to temperate residents. Therefore, in the present study, experiments were performed from January to February, but we cannot fully explain the discrepancy between our results and Wyndham's however this may be one of the possible explanations.

In the present study, we selected (NS: statistically not significant) about 20 year old subjects. Kuno (1956) suggested that the natives in the torrid zones have the capacity to sweat but they have acquired the ability to avoid excessive sweating by acclimatization. For settlers of less than 3 years, the sweat reflex is similar to that of newcomers. It has been suggested that more than 6 years of residence in the tropics is necessary to acquire the same capacity as the natives (Morimoto, 1978).

Hori *et al.* (1977) reported the anthropometric data, body temperature and basal metabolic rate in Thai subjects compared to Japanese people and had concluded that the body shape in Thai people is considered to be more convenient for heat dissipation in hot environment. There is no doubt that the functional, behavioural and anthropometric characteristics of tropical people are attuned to an increase in their capacity of homeostasis in hot environment.

Regarding the longer sweating onset time of Thai subjects (see Fig. 4, Table 4) as compared to Japanese subjects, though there exist some differences between Japanese sportsmen and sedentary Japanese. The following explanations are possible: a) a shift of the threshold core temperature of sweating onset time, b) a setting of the core temperature to a lower level, and c) a decline of the resing curve of the core temperature during heat load. The factors which determine the set-point of body temperature are lower basal metabolism related to heat production in the physical constitution related to heat dissipation of tropical inhabitants (Hammel *et al.*, 1963).

The universal outbreak of sweating (Kuno, 1953) was confirmed not only on the chest and abdominal skin but also on the face, neck, back and extremities surface areas of present subjects. However, the phenomenon of sweat volume dissociation between the chest and abdomen was observed in the present experiment (see Figs. 2, 3, 6). Although the origin and thermoregulatory mechanism of sweat dissociation between the chest and abdomen is not clear, among others the following factors have to be considered: a) regional differentiation of sympathetic efferents on the chest and abdominal skin blood flow during thermal stimulation (Iriki, 1983), b) active vasoconstriction of abdominal skin vessel, c) differences in amount as by subcutaneous fatty layers between the chest and abdomen, d) the effect of skin pressure reflex caused by sitting position (Takagi and Sakurai, 1950), e) difference of concentration and distribution of active sweat glands between the chest and abdominal skin, f) air flow of the environmental control chamber, g) the phenomenon of hydromeiosis due to exhaustion of sweat gland activity (Brown and Sargent, 1965; Ogawa, 1987), h) after heat load off, an increase in evaporative heat loss capacity due to the decrease of sweat rate on the abdominal skin.

So far as the mechanism of reduction of thermoregulatory effector gain is concerned, central and peripheral temperature signals interact at the level of the anterior hypothalamus where effector mechanisms of temperature regulation actually exert in thermally acclimated animals. (Kosaka *et al.*, 1988, 1989; Ohwatari *et al.*, 1992)

In conclusion, the various levels at which the acclimatization process takes place may be summarized as follows; (1) central, together with numerous input/output; (2) neuro-

glandular junction (with attendant modification); (3) and at the end-organ level, particularly the sweat glands and skin.

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#### REFERENCES

- 1) Brown, W.K. & Sargent, F. (1965): Hidromeiosis. *Arch. Environ. Health.*, 11, 442–453.
- 2) Fan, Y.J. (1987): Determination of heat acclimatization by capacitance hygrometer sweat capture capsule method. *Trop. Med.*, 29 (2), 107–121.
- 3) Hammel, H.T., Jackson, D.C., Stolwijk, J.A.J., Hardy, J.D. & Stromme, S.B. (1963): Temperature regulation by hypothalamic proportional control with adjustable set temperature. *J. Appl. Physiol.*, 18, 1146–1154.
- 4) Hori, S., Ihzuka, H. & Nakamura, M. (1976): Studies on physiological responses of residents in Okinawa to a hot environment. *Jap. J. Physiol.*, 26, 235–244.
- 5) Hori, S., Ohnaka, M., Shiraki, K., Tsujita, J., Yoshimura, H., Saito, N. & Panata, M. (1977): Comparison of physical characteristics, body temperature and basal metabolism between Thai and Japanese in a neutral temperature zone. *Jap. J. Physiol.*, 27, 525–538.
- 6) Iriki, M. (1983): Regional differentiation of sympathetic efferents during thermal stimulation. *J. Therm. Biol.*, 8, 225–228.
- 7) Kosaka, M., Ohwatari, N., Matsumoto, T. & Yang, G.J. (1988): Changes in hypothalamic blood flow due to thermal acclimation. *Trop. Med.*, 30 (2), 163–174.
- 8) Kosaka, M., Ohwatari, N., Tsuchiya, K. & Matsumoto, T. (1989): Cerebral blood flow change due to thermal acclimation. *Thermal physiology 1989*, Ed. by J. B. Mercer. Elsevier Science Publishers B.V. pp. 463–468.
- 9) Kuno, Y. (1956): *Human Perspiration*. Charles C. Thomas, Springfield.
- 10) Matsumoto, T., Yamauchi, M., Kosaka, M. & Nakamura, K. (1989): Effect of fine alteration in ambient temperature on thermal sweating at rest and during exercise under thermo-neutral conditions. *Trop. Med.*, 31 (3), 131–139.
- 11) Matsumoto, T., Kosaka, M., Yamauchi, M., Nakamura, K., Yang, G.J., Lee, J.M., Tsuchiya, K., Amador Velazquez J.J. (1990): Seasonal variation of thermal sweating. *Trop. Med.*, 32 (2), 73–80.
- 12) Matsumoto, T., Kosaka, M., Yamauchi, M., Yang, G.J., Lee, J.M., Tsuchiya, K., Amador Velazquez J.J., Praputpittaya, C., Yongsiri, A. & Boonayathap, U. (1991): Analysis of the mechanisms of heat acclimatization –Comparison of heat-tolerance between Japanese and Thai subjects–. *Trop. Med.*, 33 (4), 127–133.
- 13) Ohwatari, N., Fujiwara, M., Iwamoto, J., Fan, Y.J., Tsuchiya, K. & Kosaka, M. (1983): Studies on heat adaptation. –Measurement of the sweating reaction of a tropical inhabitant–. *Trop. Med.*, 25 (4), 235–241.

- 14) Ohwatari, N., Kosaka, M. & Matsumoto, T. (1992): Effect of thermal acclimation on change in cerebral blood flow during LPS-pyrogen fever in rabbits. *Trop. Med.*, 34 (1), 29–38.
- 15) Ramanathan, N.L.A. (1964): A new weighing system for the mean surface temperature of the human body. *J. Appl. Physiol.*, 19, 531–533.
- 16) Sasaki, T. & Tsuzuki, S. (1984): Changes in tolerance to heat and cold after migration from subtropic to temperate zone. pp. 479–482. *In* Hales, J.R.S. (ed.). *Thermal Physiology*. Raven Press, New York.
- 17) Takagi, K. & Sakurai, T. (1950): A sweat reflex due to pressure on the body surface. *Jap. J. Physiol.*, 1, 22.
- 18) Wyndham, C.H., Strydom, N.B., Morrison, J.F., Williams, C.G., Bredell, G.A.G., Von Rahden, M.J.E., Van Rensburg, A.J. & Munro, A. (1964): Heat reactions of Caucasians and Bantu in South Africa. *J. Appl. Physiol.*, 19 (4), 598–606.
- 19) Yoshimura, H. (1960): Acclimatization to heat and cold. pp. 61–106. *In*: Yoshimura, H., Ogata, K. & Itoh, S. (ed.). *Essential Problem in Climatic Physiology*. Nankodo. Tokyo.