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Seasonal Variation of Thermal Sweating

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Abstract: Although seasonal change in sweat response; the higher sweat rate, the shorter latent period for sweating, and the lower salt concentration in sweat in summer than in winter has been reported, the findings have hardly been led by accurate methods of measuring sweat rate. In order to confirm seasonal variation of sweating, sweat tests were carried out in summer and in winter for each subject. Local sweat rate was recorded before, during and after heat load by using capacitance hygrometer-sweat capture capsule method, which enabled the determination of local sweat rate highly sensitively and continuously. Sweat-onset time and local sweat volume were compared between both seasons. Sweat-onset time was 10.82±1.21 min (chest), 11.85±1.26 min (abdomen) in summer. It was 16.33±1.95 min (chest), 16.42±1.91 min (abdomen) in winter, $P<0.005$ (chest) and $P<0.05$ (abdomen) between both seasons. Local sweat volume was 121.23±20.90 mg/capsule (chest), 48.46±10.83 mg/capsule (abdomen) in summer. It was 36.59±10.83 mg/capsule (chest), 19.20±5.88 mg/capsule (abdomen) in winter, $P<0.01$ (chest) and $P<0.05$ (abdomen) between both seasons. Seasonal variation of thermal sweating was reconfirmed by the more accurate method in this study. Furthermore, no changes in threshold for sweating in oral temperature was observed. It is suggested that the mechanism of seasonal acclimatization is different from that of artificial heat acclimation.

Key words: Seasonal variation, Thermal sweating, Sweat-onset time, Heat acclimation, Threshold temperature for sweating

INTRODUCTION

Sweating is the main mechanism of heat dissipation for humans in a hot environment. It is known that sweating response to heat is influenced by climatic conditions. In an area where there is a distinct seasonal fluctuation of ambient temperature such as Japan, various physiological responses may change season by season. The basal metabolism is highest in winter and lowest in summer (Sasaki, 1954; Shimaoka *et al.*, 1987). Seasonal change of sweat responses; the higher sweat rate, shorter latent period for sweat onset

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and lower salt concentration in sweat in summer than in winter have been reported (Kuno, 1956; Yoshimura, 1960; Ohara, 1966; Hori *et al.*, 1974, 1976). However, the methods used in those reports, like the body weight balance or filter paper method, for the measurement of sweat rate are not so accurate nowadays. The measurement of latent period for sweat onset is especially very rough. In the present investigation, therefore, by using capacitance hygrometer-sweat capture capsule method which enabled the determination of local sweat rate continuously and more precisely (Sugenoya and Ogawa, 1985; Fan, 1987), seasonal variation of thermal sweating between summer and winter was confirmed.

MATERIALS AND METHODS

Six healthy men, 20−37 years old , who had been living in Nagasaki city for at least 10 years volunteered for this study. Four of them were college students belonging to sports clubs and two were laboratory staff.

As shown in Fig. 1, it was coldest (6.2℃) in January and hotest (27.5℃) in August at Nagasaki. The difference of ambient temperature in a year was 21.1℃. Sweat tests were performed in winter (January to March) and in summer (July to September) for each subject. Mean ambient temperature of the experimental period was 7.9℃ and 26.1℃, respectively.

On the experimental day, the subject came to our laboratory at 13:00 after lunch, wore shorts only and the sweat test was started at 14:00. In the environmentally controlled room set at 25℃ and 60% of relative humidity, after equilibration to the condition for at least 30 min, the lower legs were immersed to the hot water bath (43℃) for 30 min. 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). In briefly, dry N_2 gas flowed into the capsule (10.18 cm^2) attached on the skin with

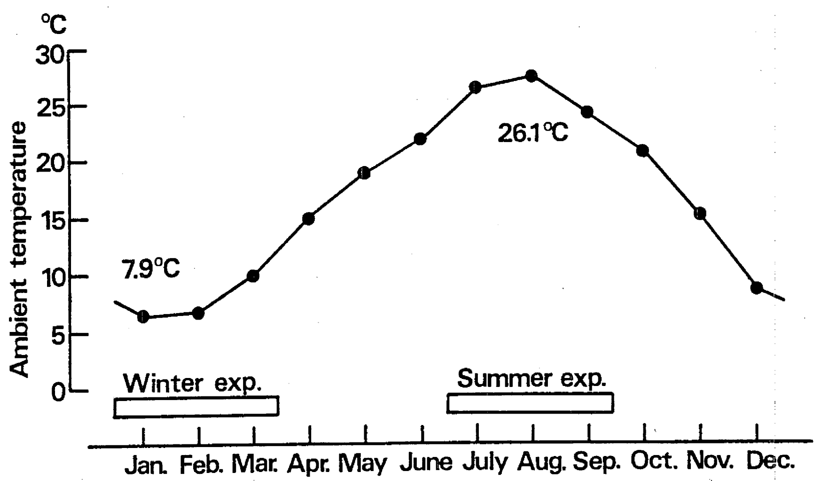

Fig. 1. Monthly mean ambient temperature in Nagasaki. Mean ambient temperature of the experimental period is 7.9℃ in winter (January to March) and 26.1℃ in summer (July to September).

a constant flow rate of 1 l/min, and the changes of the humidity of effluent gas were detected by hygrometer (H211 TAKARA Instruments Co.) connected to DC-pen-recorder. For the calibration of sweat volume, a certain amount of 0.45% NaCl solution was dropped into the capsule through a small hole on the top of the capsule with the micropipette, and local sweat rate was expressed in $mg/cm^2/min$. Oral (sublingual) temperature and skin temperatures on the chest, abdomen and forearm were measured by thermistors (K923 TAKARA Instruments Co.) connected to the personal computer (PC−8801 NEC), and mean skin temperature (average of three determined regions) was calculated. Local sweat volume induced by 30 min heat load and sweat-onset time (latent period for sweating) were calculated and compared between winter and summer.

Statistical significance was assessed by paired Student's t−test at 0.05 level and the values are presented as mean±SE.

RESULTS

Typical recordings of subject K. O. in summer and in winter were shown in Fig. 2. Small rises in oral temperature and skin temperatures by heat load were observed at first and then sweat occured. In summer, sweat-onset time was 10.9 min on the chest, 13.4 min on the abdomen, and local sweat volume induced by 30 min heat load was 122.88 mg/capsule on the chest. 22.53 mg/capsule on the abdomen (Fig. 2a). In winter, sweat−onset time was 16.0 min on the chest, 16.5 min on the abdomen, and local sweat volume was 26.57 mg/capsule on the chest, 15.30 mg/capsule on the abdomen (Fig. 2b). Sweat occured after the shorter latent period and sweat rate was greater in summer than in winter.

Sweat-onset time and local sweat volume were summarized (Fig. 3 and Fig. 4) and compared between summer and winter. Mean sweat onset-time was 10.82±1.21 min on the chest and 11.85±1.26 min on the abdomen in summer. It was 16.33±1.95 min on the chest and 16.42±1.91 min on the abdomen in winter. There was a significant difference between summer and winter, $P<0.005$ on the chest and $P<0.05$ on the abdomen respectively (Fig. 3).

Mean local sweat volume induced by 30 min heat load, was 121.23±20.90 mg/capsule on the chest and 48.46±10.83 mg/capsule on the abdomen in summer. It was 36.59±11.26 mg/capsule on the chest and 19.20±5.88 mg/capsule on the abdomen in winter. There was a significant difference between summer and winter, $P<0.01$ on the chest and $P<0.05$ on the abdomen respectively (Fig. 4).

Oral temperature and mean skin temperature were summarized (Table 1). Mean oral temperature at the equilibration to the climatic condition before heat load was 36.67±0.20℃ in summer and 36.77±0.05℃ in winter with no significant difference. Mean threshold in oral temperature for sweating of 36.83±0.20℃ in summer and 36.87±0.08℃ in winter were insignificant. Mean skin temperature before heat load of 33.23±0.20℃ in summer and 33.41±0.14℃ in winter were also not significant as much as the threshold in mean skin temperature of 33.16±0.13℃ in summer and 33.24±0.13℃ in winter were insignificant.

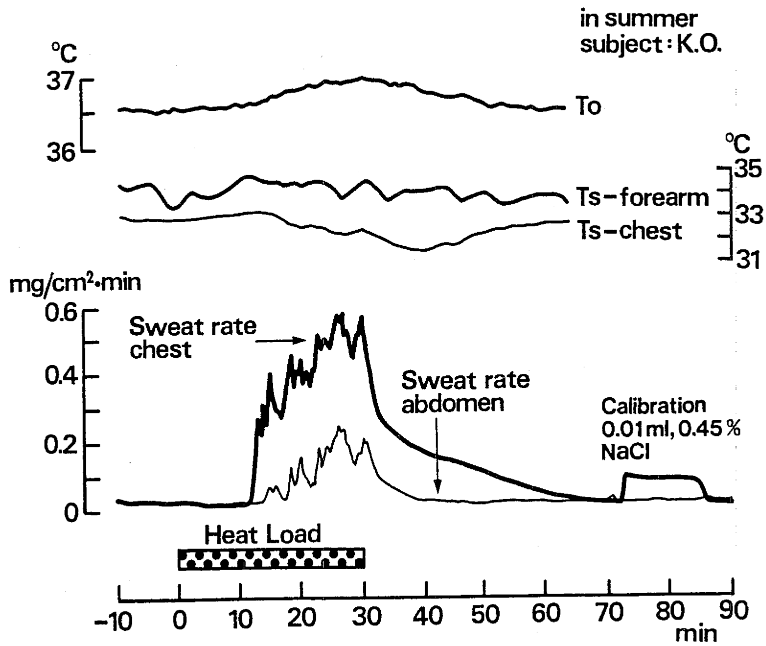

Fig. 2a.

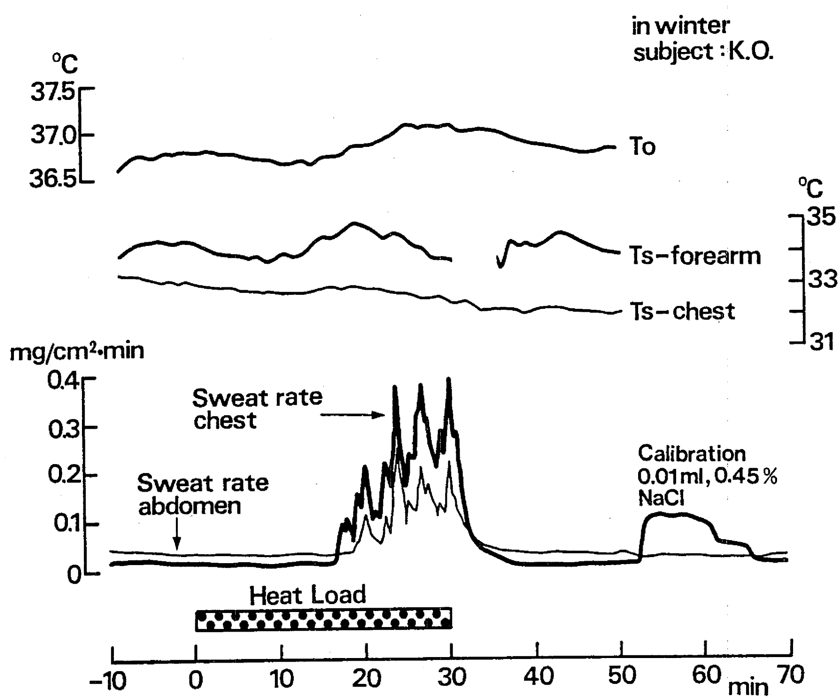

Fig. 2b.

Fig. 2. Sweating tests of subject K. O. in summer (Fig. 2a) and in winter (Fig. 2b). After equilibration to the experimental condition for at least 30 min, lower legs were immersed into the hot water bath (43℃) for 30 min. Local sweat rate on the chest and the abdomen, oral temperature and skin temperatures were continuously recorded. Sweat occured following slight rises in oral and skin temperatures. Sweat—onset time was 10.9 min (chest), 13.4 min (abdomen) and local sweat volume was 122.88 mg/capsule (chest), 22.58 mg/capsule (abdomen), in summer (Fig. 2a). Sweat-onset time was 16.0 min (chest), 16.5 min (abdomen) and local sweat volume was 26.57 mg/capsule (chest), 15.30 mg/capsule (abdomen) in winter (Fig. 2b).

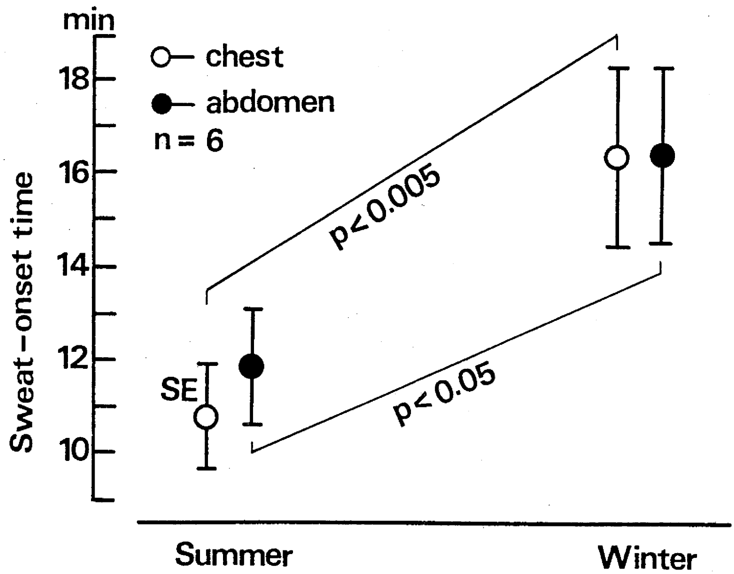

Fig. 3. Comparison of sweat-onset time between summer and winter. Sweat-onset time in summer was significantly short compared to that in winter ($P<0.005$ on the chest, $P<0.05$ on the abdomen).

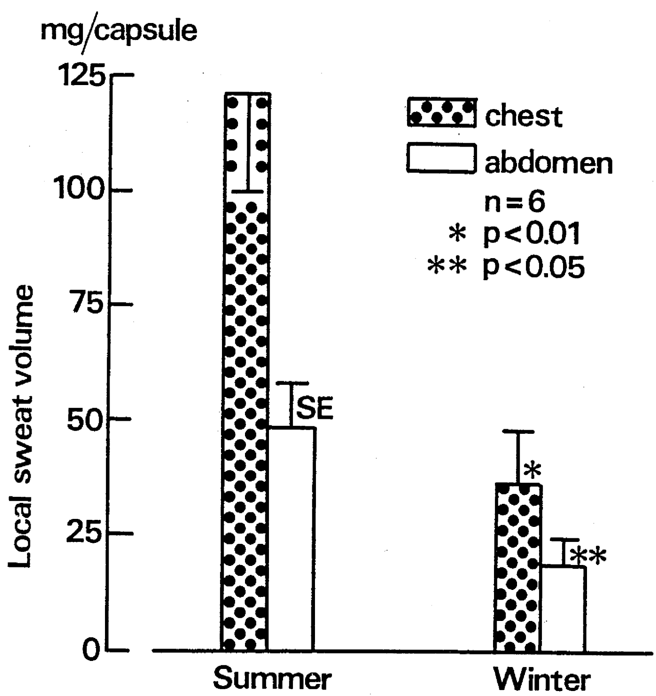

Fig. 4. Comparison of local sweat volume between summer and winter. Local sweat volume in summer was significantly large compared to that in winter ($P<0.01$ on the chest, $P<0.05$ on the abdomen).

Table 1. Comparison of oral and mean skin temperature between summer and winter

	Before heat load		Threshold for sweating	
	To	mTs	To	mTs
Summer	36.67±0.20	33.23±0.20	36.83±0.20	33.16±0.13
Winter	36.77±0.05	33.41±0.14	36.87±0.08	33.24±0.13

Values are Mean±SE ℃. To: oral temperature, mTs: mean skin temperature (average of three determined regions). Not any significant differences were observed between summer and winter.

Discussion

Although it has been generally recognized that sweat rate is higher, the latent period for sweating is shorter and salt concentration in the sweat is lower in summer than in winter (Kuno, 1956; Yoshimura, 1960; Ohara, 1966; Hori *et al.*, 1974, 1976), this was not based on precise data because filter paper method or whole body weighing was used for measuring of sweat rate. Capacitance hygrometer-sweat capture capsule method used in our study enabled the determination on local sweat rate highly sensitively and continuously (Sugenoya and Ogawa, 1985; Fan, 1987).

Local Sweat volume induced by the same heat load in the same thermal environmental condition was significantly larger in summer than in winter on both of the two determined regions (Fig. 2). These results are in agreement with previous reports using filter paper method or whole body weighing (Kuno, 1956; Yoshimura, 1960; Ohara, 1966; Hori *et al.*, 1974).

In this study, sweat-onset time after heat load was accurately determined, unlike in the previous reports. It was clearly demonstrated that sweat onset-time in summer was significantly shorter than that in winter (Fig. 3). Seasonal variation of sweat response to heat; the shorter latent period and the larger amount of sweat were also clearly demonstrated and reconfirmed by the more accurate method.

A similar phenomenon to seasonal variation, the enhancement of sweating, is known to be induced by short-term artificial heat acclimation (Henane and Valatx, 1973; Henane and Bittel, 1975; Sugenoya *et al.*, 1986), physical training (Piwonka *et al.*, 1965; Nadel *et al.*, 1974; Henana *et al.*, 1977; Roberts *et al.*, 1977; Hessemer and Brück, 1983; Buono and Sjoholm, 1988) and local skin heating (MacIntyre *et al.*, 1968; Ogawa *et al.*, 1982). Henane and Bittel (1975) reported that increased sensitivity of sweating with marked quickening of sweat onset was obtained after 9 days passive heat acclimation. Basal rectal temperature equilibrated to the ambient temperature of 30℃ and the threshold rectal temperature for sweating were also significantly decreased after acclimation. However, no decrease in basal level or in threshold of oral temperature was observed in this study (Table 1). Hori *et al.* (1974) also reported that initial level of rectal temperature was the same between both seasons. These results indicate that seasonal variation of thermal sweating is not mainly attributed to the shift of threshold core temperature for sweating. There may be some differences between the mechanisms of seasonal acclimatization and artificial heat acclimation.

Seasonal change in central sudomotor neural activity was reported by means of determination of the frequency of sweat expulsions. It was suggested that seasonal acclimatization involved changes in the central sudomotor activity as well as peripheral conditions, since the regression line relating the frequency of sweat expulsions to ambient temperature was steeper in slope in summer than in winter (Ogawa, 1975; Ogawa and Asayama, 1978).

The mechanisms of seasonal acclimatization are not fully solved. However, it is considered that repeated heat exposure or elevation of body temperature in daily life modulate the central sudomotor activity and/or secretory capacity of sweat glands. Recent development of air-conditioning systems may be inducing the reduction in the level of seasonal variation of various physiological responses in humans. Nevertheless, seasonal variation of thermal sweating was observed in this study. Four of the 6 subjects in this study were college students who were regulary exposed to outdoor environment in their daily lives. This may be the reason for the observation of distinct seasonal variation of thermal sweating in this investigation.

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REFERENCES

1) Bouno, M. J. & Sjoholm, N. T. (1988): Effect of physical training on peripheral sweat production. J. Appl. Physiol., 65(2), 811−814.

2) Fan, Yu−Jen (1987): Determination of acclimatization by capacitance hygrometer−sweat capture capsule method. Trop. Med., 29(2), 107−121.

3) Henane, R. & Valatx, J. L. (1973): Thermoregulatory changes induced during heat acclimatization by controlled hyperthermia in man. J. Physiol., 230, 255−271.

4) Henane, R. & Bittel, J. (1975): Changes of thermal balance induced by passive heating in resting man. J. Appl. Physiol., 38(2), 294−299.

5) Henane, R., Flandrois, R. & Charbonnier, J. P. (1977): Increase in sweating sensitivity by endurance conditioning in man. J. Appl. Physiol., 43(5), 822−828.

6) Hessemer, V. & Brück, K. (1983): Thermally−controlled exercixe−adaptive effects on thermoregulation in man. J. Therm. Biol., 8, 171−173.

7) Hori, S., Ihzuka, H & Yamada, T. (1974): Study on seasonal variation of heat tolerance in young Japanese males and effects of physical training thereon. Jap. J. Physiol., 24, 463−474.

8) 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.

9) Kuno, Y. (1956): Human Perspiration. Charles C. Thomas, Springfield.

10) MacIntyre, B. A., Bullard, R. B., Banerjee, M. & Elizondo, R. (1968): Mechanism of enhancement of eccrine sweating by localized heating. J. Appl. Physiol., 25(3), 255−260.

11) Matsumoto, T., Kosaka, M., Yamauchi, M., Ohwatari, N., Yang, G. J., Nakamura, K., Yamashita, S., Izumi, M. & Nagataki, S. (1988): Effect of thyroid hormone on thermal sweating. Trop. Med., 30(3), 255−231.

12) 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.

13) Nadel, E. R., Pandolf, K. B., Roberts, M. F. & Stolwijk, J. A. J. (1974): Mechanisms of thermal acclimation to exercise and heat. J. Appl. Physiol., 37(4), 515−520.

14) Ogawa, T. (1975): Seasonal variation of sudomotor activities, as evidenced by the frequency of sweat expulsions. J. Physiol. Soc. Japan, 37, 107−109.

15) Ogawa, T. & Asayama, M. (1978): Frequency of sweat expulsion, as indicator of sudomotor neural activity. pp. 105−107. *In* Houdas, Y. & Guieu, J. P. (ed.). New Trends in Thermal Physiology. Masson, Paris.

16) Ogawa, T., Asayama, M. & Miyagawa, T. (1982): Effects of sweat gland training by repeated local heating. Jap. J. Physiol., 32, 971−981.

17) Ohara, K. (1966): Chloride concentration in sweat; Its individual, regional, seasonal and some other variations, and interrelationships between them. Jap. J. Physiol., 16, 274−290.

18) Piwonka, R. W., Robinson, S., Gay, V. L. & Manalis, R. S. (1965): Preacclimatization of man to heat by training. J. Appl. Physiol., 20(3), 379−384.

19) Roberts, M. F., Wenger, C. B., Stolwijk, J. A. J. & Nadel E. R. (1977): Skin blood flow and sweating changes following exercise training and heat acclimation. J. Appl. Physiol., 43(1), 133−137.

20) Sasaki, T. (1954): Seasonal variation in basal metabolism and resting metabolism, with particular reference to a climatic element of temperature. Report of Institute of Constitutional Medicine, Kumamoto University, 4, 439−452. (in Japanese with English abstract)

21) Shimaoka, A., Machida, K., Kumae, T., Sugawara, K., Kurakake, S., Okamura, N. & Suemune, J. (1987) Seasonal variation of basal metabolism. Jpn. J. Biometeor., 24(1), 3−8. (in Japanese with English abstract)

22) Sugenoya, J. & Ogawa, T. (1985): Characteristics of central sudomotor mechanism estimated by frequency of sweat expulsions. Jap. J. Physiol., 35, 783−794.

23) Sugenoya, J., Ogawa, T., Asayama, M., Miyagawa, T., Yamashita, Y. & Ohnishi, N. (1986): Involvement of the central sudomotor mechanism in an increased sweating capacity following the heat acclimation. J. Aichi Med. Univ. Assoc., 14(4), 653−661. (in Japanese with English abstract)

24) 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.