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Seasonal Variations of Physiological Responses to Heat of Subtropical and Temperate Natives

by

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ABSTRACT. – In an attempt to compare the physiological responses of subtropical natives to heat with those of temperate natives, seasonal variations in physiological responses to heat were observed in young male residents of Okinawa who were born and raised in Okinawa, subtropical zone (group O) and young male residents of Okinawa who were born and raised on the Japan mainland, temperate zone, but moved to Okinawa in less than two years (group M). In both seasons, group O showed less sweat loss, lower Na concentration in sweat, lower rise in rectal temperature and less increase in heart rate during heat exposure than group M. In both groups, greater sweat loss, lower Na concentration in sweat and lower rise in rectal temperature in summer than in winter were observed. Seasonal differences in Na concentration in sweat, rise in rectal temperature and increase in heart rate for group O were smaller than those for group M. It was assumed the efficiency of sweat for cooling the body for group O was better than that for group M, and heat tolerance for group O was superior to that for group M.

INTRODUCTION

It is known that the primary feature of short-term heat acclimatization of unacclimatized individuals is a more profuse sweating with lower salt concentration and less rise in core temperature at a given heat load (Dill, Hall and Edwards, 1938, Adolph, 1946; Hori, Ihzuka and Nakamura, 1976). However, these adaptive changes in sweating responses observed during short-term heat acclimatization gradually disappear over several weeks after the cessation of heat exposure (Williams, Wyndham and Morrison, 1967). On the contrary, fully acclimatized individuals such as tropical natives, as well as Japanese born and raised in the tropical zone, tend to sweat less than unacclimatized individuals (Kuno, 1956). Okinawa (subtropical zone) has hot and long summers and temperate winters; whereas, the Japan mainland (temperate zone) has short summers and cold winters. Residents who were born and raised in Okinawa, subtropical natives, are expected to be more acclimatized to heat than temperate natives. We then attempt to compare physio-

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logical responses of subtropical natives to heat with special reference to sweating reaction with those of migrants from the Japan mainland to Okinawa in summer and winter to study differences in physiological responses to heat and the effects of subtropical climate on sweating reaction between subtropical and temperate natives.

MATERIALS AND METHODS

The young male residents of Okinawa who were born and raised in Okinawa (group O) and young male residents of Okinawa who were born and raised on the Japan mainland but move to Okinawa in less than two years (group M) were selected as subjects. Observations of physiological responses to heat were made on 42 subjects in group O, 44 subjects in group M in summer and 40 subjects in group O, 41 subjects in group M in winter. Experiments were performed at around 15:00 h in summer. Subjects were instructed to fast and remain at rest after lunch. After staying at rest in a climatic chamber maintained at 30 C of Ta with about 70% R.H., the subjects, dressed in shorts only, immersed their legs just up to the knees into a stirred water bath of 42 C and stayed there for 60 min. Rectal temperature was recorded continuously by a copper-constantan thermocouple. Body weight was measured before and immediately after heat exposure, using a platform balance with an accuracy of ± 5 g, and net body weight was obtained by subtracting the weight of shorts. Local sweat samples from the chest and back were collected successively at 15 min intervals by the filter paper method (Ohara, 1966). Na in sweat was eluted from the filter paper and its content was determined by flame photometry. The average value of mean Na concentration of sweat on the chest and back, and body weight loss without correction of body weight loss through respiration were used in calculation of the salt loss in sweat. Heat tolerance was assessed by our numerical heat tolerance indices. The heat tolerance indices and their components were calculated as follows (Hori, Inouye and Ihzuka, 1974):

$$I = (A^2 + B^2 + C^2)^{0.5}, S = B / (A^2 + C^2)^{0.5}$$

where $A = \Delta W / 0.07 \times W$, $B = \Delta Tre / (40.6 - Tre)$, $C = \Delta S / 0.75 \times W$

and W = Body weight before the experiment (Kg)
ΔW = Weight loss at the end of heat exposure (Kg)
Tre = Rectal temperature before the experiment (°C)
ΔTre = Rise in rectal temperature at the end of heat exposure (°C)
ΔS = Salt loss estimated from mean Na concentration and body weight loss (g)

RESULTS

The physical characteristics of subjects in the two groups and the length of residence of subjects born and raised on the Japan mainland are given in Table 1. Group O showed smaller mean values of height, body weight and body surface area than group M. These differences were statistically significant except the difference in height in winter. Thus it can be said that physical characteristics of subjects in group O was less height and a more slender body shape than in group M.

Table 2 represents body weight loss, mean Na concentration in local sweat, rise in

Table 1. Characteristics of subjects (X±SD)

Season	Group	Number	Age (yr)	Height (cm)	Weight (Kg)	Area (m^2)	Stay in Okinawa (yr)
Summer	Okinawa	42	22.3 ±1.9	166.3* ±4.6	57.6** ±6.1	1.65** ±0.10	
	Mainland	44	22.1 ±1.5	168.9 ±4.7	61.7 ±5.8	1.71 ±0.10	1.16 ±0.54
Winter	Okinawa	40	23.8 ±3.7	166.2 ±5.0	58.2* ±7.1	1.66** ±0.11	
	Mainland	41	23.3 ±3.8	168.3 ±5.4	61.8 ±8.0	. 1.71 ±0.12	1.51 ±0.76

* Difference between two groups in the same season.
* P<0.05, **P<0.01

Table 2. Body weight loss, mean Na concentration in sweat, rise in rectal temperature and increase in heart rate (X±SD).

Season	Group	ΔW (Kg)	C (mEq/L)	ΔTre (°C)	ΔH (beats/min)
Summer	Okinawa	0.39**s ±0.12	. 34.8**s ±11.7	0.42**s ±0.17	13.6 ±6.4
	Mainland	0.46**s ±0.13	39.7**s ±11.8	. 0.48*s ±0.18	15.3 ±6.6
Winter	Okinawa	0.31** ±0.09	50.9** ±13.2	0.56* ±0.20	13.5 ±7.7
	Mainland	0.37 ±0.10	62.8 ±13.6	0.67 ±0.24	16.6 ±8.1

ΔW: Body weight loss, C: Mean Na concentration, ΔTre: Rise in rectal temperature, ΔH: Increase in heart rate.
* Difference between two groups in the same season.
*s Difference between two seasons in the same group.
* P<0.05, ** P<0.01

rectal temperature and increase in heart rate at the end of the sweating test. Group O showed significantly smaller mean values of body weight loss in both seasons, mean Na concentration in local sweat in winter and rise in rectal temperature in winter than group M. The mean values of mean Na concentration in local sweat in summer, rise in rectal temperature in summer and increase in heart rate in both seasons for group O were considerably smaller than those for group M. Consequently, the magnitude of physiological reactions induced by heat exposure for group O was smaller than that for group M. In both groups, mean value of body weight loss was greater in summer than in winter, while mean values of mean Na concentration in local sweat and rise in rectal temperature were smaller in summer than in winter. All these differences were statistically significant. Seasonal variations in mean Na concentration in local sweat and rise in rectal temperature for group O were smaller than those for group M.

Table 3 represents values of heat tolerance indices I and S, relative water loss (A), relative rise in core temperature (B) and relative salt loss (C). All the mean values of I, S, A, B, and C for group O were smaller than those for group M. Among these differences, differences in the value of I in summer and all the values except S in winter were statistically significant. These results indicate magnitude of physiological strain induced by heat load was smaller in group O than in group M. In both groups, all the mean values of heat tolerance indices and their components, except value of A, were significantly smaller in summer than in winter. The value of A in summer was greater than in winter in both groups. Seasonal differences in values of heat tolerance indices and their components, except that of A, were smaller in group O than group M.

DISCUSSION

It has been known that adaptive changes in physiological responses to heat occur when unacclimatized individuals are repeatedly exposed to a hot environment (Adolph, 1946; Dill, Hall and Edwards, 1938). It is known that changes in sweating reaction and circulatory function are the main physiological responses to heat and relative importance of heat dissipation by evaporation increases as the ambient temperature rises (Robinson, 1949; Belding and Hertig, 1962). In short-term heat acclimatization, unacclimatized subjects tend to sweat more profusely, the salt concentration in sweat decreases, and rise in core temperature during heat exposure diminishes (Adolph, 1946; Eichna et al., 1950; Robinson et al., 1953). However, these adaptive changes in physiological responses to heat are gradually lost after the cessation of heat exposure (Williams, Wyndham and Morrison, 1967). In long-term heat acclimatization, fully heat acclimatized individuals, sweat loss and salt concentration in sweat are lower (Christensen, 1946; Kuno, 1956; Wyndham et al., 1964).

Table 3. Indices for the assessment of heat tolerance and their components

Season	Group	I	S	A	B	C
Summer	Okinawa	s 0.158‡* ±0.040	1.26**s ±0.59	0.098**s ±0.027	0.125**s ±0.044	*s0.019‡* ±0.003
	Mainland	0.179*s ±0.034	1.33**s ±0.49	0.106**s ±0.028	0.141**s ±0.038	0.023**s ±0.003
Winter	Okinawa	0.174* ±0.046	2.02 0.77	0.76* ±0.020	0.151* ±0.044	0.0022** ±0.003
	Mainland	0.201 ±0.051	2.27 ±1.27	0.086 ±0.022	0.177 ±0.057	0.029 ±0.088

I: Heat tolerance index, S: Effectiveness of sweating,
A: Relative water loss, B: Relative rise in rectal temperature,
C: Relative salt loss.
*: Difference between two groups in the same season.
*s: Difference between two seasons in the same group.
* $P<0.05$, ** $P<0.01$

As shown in Table 2, the mean values of body weight loss and mean Na concentration in local sweat for group O were smaller than those for group M in both seasons. Consequently, it can be said that sweating reaction for subtropical natives showed the same pattern as that for fully heat acclimatized individuals. Less rise in rectal temperature and less increase in heart rate during heat exposure for group O in both seasons than those for group M are shown in Table 2. These observations are in good agreement with other reports concerning heat acclimatization (Adolph, 1946; Robinson et al., 1943; Bass, 1963). The amount of sweat from the skin surface is in proportion to the degree of wetness of the skin surface and the difference in vapor pressure between the skin surface and the surrounding air. The increase of sweat represents only dripping sweat not used for heat dissipation after wetness of the overall skin has taken place, and a higher concentration of salt in sweat decreases the difference in vapor pressure between the skin surface and the surrounding air. From the above account, it is presumed that subjects in group O have better efficiency of sweating for heat dissipation than those in group M. The better efficiency of sweating for cooling the body of subjects in group O might be one reason for less rise in rectal temperature despite smaller sweat volume. And it is known that rectal temperature is a dominant factor in determining sweat volume and heart rate.

As shown in Table 2, there were seasonal differences in rise in rectal temperature during heat exposure, body weight loss and increase in heart rate in both groups, except heart rate in group O. Correlations between increase in heart rate, ratio of body weight loss (sweat volume) to body weight and rise in rectal temperature were shown in Fig. 1.

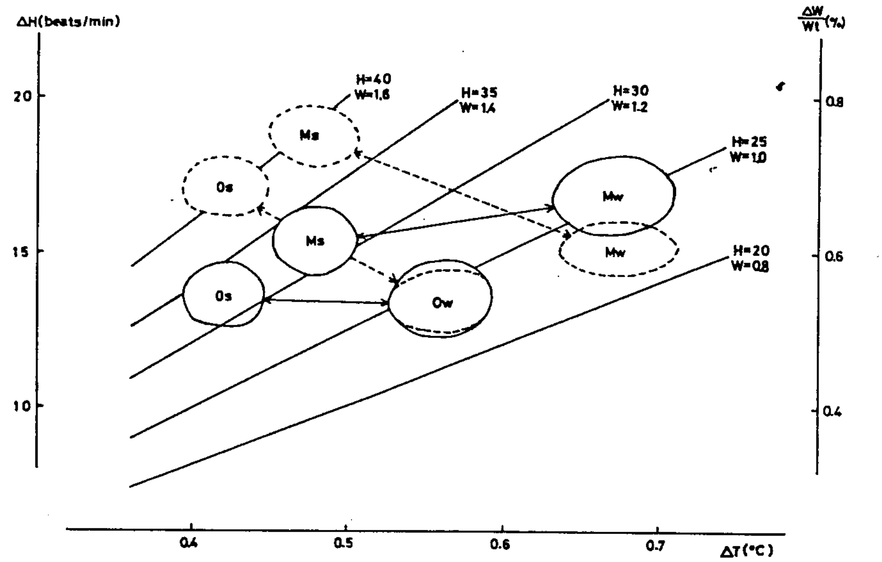

Fig. 1 Correlation between increase in heart rate, body weight loss per body weight and rise in rectal temperature.

ΔH: Increase in heart rate, ΔW: Body weight loss, Wt: Body weight,
ΔT: Rise in rectal temperature, H: ΔH/ΔT, W: ΔH/W.ΔT,
O: Okinawa group, M: Mainland group, S: Summer, W: Winter,
O: Correlation between ΔH and ΔT, O: Correlation between ΔW/W and ΔT, circles: Drawn around the means with radii of standard errors, Arrows indicate direction of seasonal change.

As shown in this figure, there were differences in features of correlation between heart rate and rise in rectal temperature and those between ratio of body weight loss to body weight and rise in rectal temperature. The ratio of body weight loss to body weight increased in summer and increase in heart rate rather declined in summer. Seasonal variation in the ratio of body weight loss per body weight to rise in rectal temperature in both groups was greater than the ratio of increase in heart rate to rise in rectal temperature though all the values of these ratios in both groups were essentially the same in the same season. The results described above indicate the sweat center becomes more sensitive during heat acclimatization than the center regulating heart rate. It is obvious from Fig. 1 that the circles representing group O are in the left lower region and the absolute values of their seasonal changes are smaller when compared with those for group M. Thus it is assumed that physiological changes induced by heat exposure for group O were smaller and more stable than those for group M. These characteristics of physiological responses of subjects in group O to heat might be caused by their long-term residence in a subtropical zone. Heat tolerance of group O was compared with that of group M.

As shown in Table 3, the values of heat tolerance index I for group O were significantly smaller than those for group M in both seasons. Since the value of heat tolerance index I represents the magnitude of strain induced in the body by heat exposure, a smaller value of the index I indicates superior heat tolerance (Hori, Inouye and Ihzuka, 1974). Consequently, heat tolerance of subjects in group O was superior to that of subjects in group M. Significantly smaller values of index I in summer than in winter in both groups indicates heat tolerance of subjects in both groups was improved in summer by repeated exposure to heat. Superior heat tolerance of subjects in group O might be induced by long residence in a subtropical climate from childhood. The value of index S represents the ratio of relative rise in rectal temperature to relative water loss and relative salt loss.

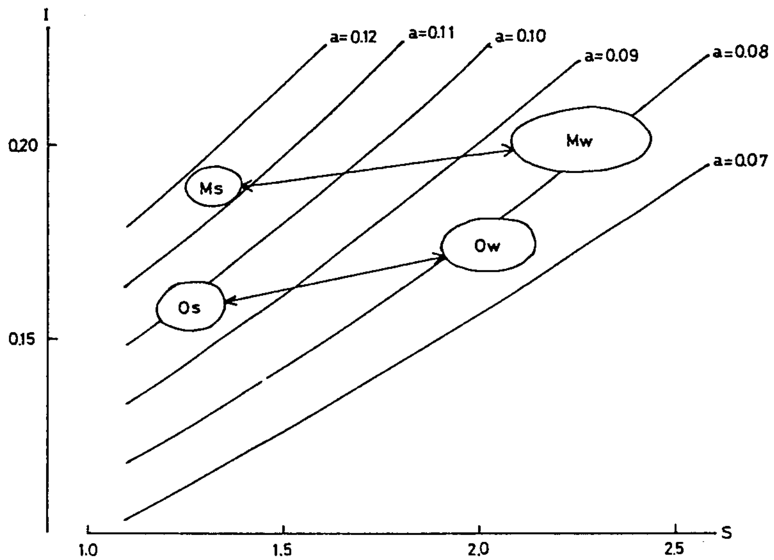

Fig. 2 Seasonal differences in relationship between indices I and S.
O, M, S, W: The same as in Fig. 1.
a: Parameter indicating various levels of iso-sweating line.
Arrows indicate direction of seasonal change.

Fig. 2 represents the relationship between values of index I and those of index S. In Fig. 2, iso-sweating lines are drawn by connecting the points of the same value of parameter 'a', $A(1 + C^2/A^2)^{1/2}$ (Hori, Inouye and Ihzaka, 1974). The circles drawn around the means with radii of standard errors for group O are located in the left lower region, and the value of parameter 'a' for group O is smaller than that for group M. The smaller value of 'a' with smaller value of index I for group O might reflect better efficiency of sweat for cooling the body than those in group M. The smaller seasonal change in value of 'a' for group O indicates smaller seasonal change in pattern of strain induced by heat exposure; i.e., pattern of strain of subtropical natives is less affected by climatic change.

From these results, it may be concluded that physiological strain in terms of core temperature, water-electrolyte metabolism and cardiovascular function of subtropical natives induced by heat exposure was smaller and more stable than that of migrants of temperate natives from the Japan mainland to the subtropical zone.

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