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Effect of Fine Alteration in Ambient Temperature on Thermal Sweating at Rest and during Exercise under Thermo-neutral Conditions

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Abstract: In order to clarify the influence of ambient temperature on thermal sweating, especially within thermo-neutral temperature, sweat response during resting and exercise were examined by using capacitance hygrometer-sweat capture capsule method. In the resting series, at 25℃ and 28℃, local heat load (43℃ water bath) was applied on the lower legs for 30 min. In the exercise series, at 20℃ and 28℃, 50% of $\dot{V}O_2max$ bicycle ergometer exercise was carried out for 30 min. Mean skin temperatures before heat load or exercise were 31.68℃, 33.07℃ and 34.09℃ at ambient temperatures of 20℃, 25℃ and 28℃, respectively. Oral temperature at 20℃ was slightly but significantly lower than that at 28℃ ($p<0.01$). In the resting series, sweat-onset time after heat load was 11.8 min at 25℃ and 4.1 min at 28℃ ($p<0.01$). Local sweat volume on the chest was 10.26 mg/cm^2 at 25℃ and 22.91 mg/cm^2 at 28℃. In the exercise series, sweat-onset time after the beginning of exercise was 8.5 min at 20℃ and 3.4 min at 28℃ ($p<0.01$). Local sweat volume on the chest was 33.06 mg/cm^2 at 20℃ and 47.98 mg/cm^2 at 28℃. The study shows that fine displacement of ambient temperature within thermo-neutral temperature significantly affects thermal sweating in thermo-regulation. Significant negative correlations between initial mean skin temperature and sweat-onset time were observed not only during resting but also during exercise. The slope of the regression line during exercise was less steep than that during resting. This indicates that during exercise, non-thermal factors may play an important role on the onset of sweating.

Key words: Ambient temperature, Sweat-onset time, Local sweat volume, Heat load, Physical exercise.

INTRODUCTION

Ambient temperature is one of the most important factors to study the sweating responese during rest or exercise. Up to now, although a lot of authors have reported the

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sweating responses at various ambient conditions, little attention has been paid to the influence of fine alteration in ambient temperature within thermo-neutrality on thermal sweating. It is important to study sweating responses under relatively thermo-neutral condition because this is favourable not only to the physiology of everyday work but also to the physiology of exercise such as marathon run since exercise performance is largely dependent on the ambient condition. Therefore, in the present investigation the affect of small changes of ambient temperature within thermo-neutrality to sweating responses during rest and exercise was studied by means of capacitance hygrometer-sweat capture capsule method which can determene the fine fluctuation of local sweating rate (Sugenoya and Ogawa, 1985; Fan, 1987).

MATERIALS AND METHODS

Two series of experiments were carriend out to investigate sweating responses during rest and exercise. All experiments were performed between 2 pm.−5 pm. from May to October in 1988.

The resting series: Five male subjects, (5−9) as shown in Table 1 volunteered for this series of experiments. In a controlled climatic chamber which was set at 25℃ or 28℃ and 60% rh, the subject wore shorts only and sat on a chair quietly for 30 min to equilibrate to the environmental condition. Heat load was then applied by immersing the legs in the water (43℃) for 30 min.

The exercise series: Ten subjects, 5 male and 5 female, (1−5 and 10−14) shown in Table 1, volunteered for this series of experiments. After the equilibration to the

Table 1. Subjects characteristics

Subject	Sex	Age (year)	Height (cm)	Weight (kg)	$\dot{V}o^2$max (ml/kg·min)
1	M	20	170	60.6	58.3
2	M	21	180	69.0	49.8
3	M	19	170	72.0	63.7
4	M	22	177	76.0	51.8
5	M	23	177	70.4	49.9
6	M	22	165	68.0	
7	M	21	177	77.9	
8	M	21	175	67.0	
9	M	28	165	62.9	
10	F	21	156	50.0	46.5
11	F	21	157	51.9	53.5
12	F	20	156	46.9	70.2
13	F	19	158	58.0	42.5
14	F	21	158	52.5	52.8

Subjects 5−9 participated in the resting series, and subjects 1−5 and 10−14 participated in the exercise series.

environment (at least 30 min), the subject (the males wore shorts, while the females wore shorts and thin sleeveless shirts) worked bicycle ergometer exercise (50% of $\dot{V}o_2max$) for 30 min in a controlled climatic chamber set at 20℃ or 28℃ and 60% rh.

Local sweat volume and sweat-onset time on the chest and the abdomen were determined by capacitance hygrometer-sweat capture capsule method (Fan, 1987; Matsumoto *et al.,* 1988). Oral temperature (To) at sublingual space and skin temperatures were simultaneously measured with thermistors. Mean skin temperature ($\bar{T}s$) was calculated from four temperatures measured on the chest (T_1), forearm (T_2), thigh (T_3) and lower leg (T_4), according to the equation of Ramanathan (1964):

$$\bar{T}s=0.3\ (T_1\ +\ T_2)+0.2\ (T_3\ +\ T_4)$$

Mean body temperature ($\bar{T}b$) was calculated from To and $\bar{T}s$ according to

$$\bar{T}b=0.9\ To\ +\ 0.1\ \bar{T}s$$

Sweat-onset time and local sweat volume obtained at two ambient temperatures were compared in the resting series and the exercise series, respectively. The relationships between sweat-onset time (or local sweat volume) and the following three parameters: initial $\bar{T}s$, initial $\bar{T}b$, $\dot{V}o_2max$, were determined.

Values are presented as means ± SD. Statistical differences were assessed by the paired Students' t-test at 0.05 level.

RESULTS

The resting series: Sweat-onset time after heat load was 11.8 ± 2.5 min on the chest, 13.0 ± 2.0 min on the abdomen at 25℃, and 4.1 ± 2.9 min on the chest, 3.9 ± 2.9 min on the abdomen at 28℃ (Fig. 1). Sweat-onset time at 28℃ was significantly short compared to that at 25℃, $p<0.01$ on both regions. A very little rise in ambient temperature, 3℃, shortened sweat-onset time to one third. Local sweat volume induced by heat load was 10.26 ± 4.16 mg/cm^2 on the chest, 3.76 ± 1.64 mg/cm^2 on the abdomen at 25℃, and 22.91 ± 18.71 mg/cm^2 on the cheat, 10.40 ± 9.91 mg/cm^2 on the abdomen at 28℃ (Fig. 2). Though the significance was not found in the differences, twice as much amount of sweat was observed at 28℃ compared to 25℃.

Changes in To, $\bar{T}s$ and $\bar{T}b$ during heat load at rest are shown in Table 2. Before heat load, $\bar{T}s$ was significantly higher at 28℃ than at 25℃, $p<0.01$. Threshold in $\bar{T}s$ for sweat-onset at 28℃ was higher than that at 25℃ ($p<0.01$), however there were no differences in the thresholds of To and $\bar{T}b$ for sweat-onset between 25℃ and 28℃.

The exercise series: A slightly shorter sweat-onset time and a slightly larger sweat volume were observed in males than females, but no statistical significance in the differences was detected. Therefore the data from male and female subjects were analysed together. Sweat-onset time after the beginning of exercise was 8.5 ± 2.2 min on the chest, 8.4 ± 2.5 min on the abdomen at 20℃, and 3.4 ± 0.8 min on the chest, 3.1 ± 1.1 min on the abdomen at 28℃ (Fig. 3). 8℃ rise in ambient temperature shortened sweat-onset time to one third. Sweat-onset time at 28℃ was significantly short compared to that at 20℃, $p<0.01$, on both determined regions. Local sweat volume induced by

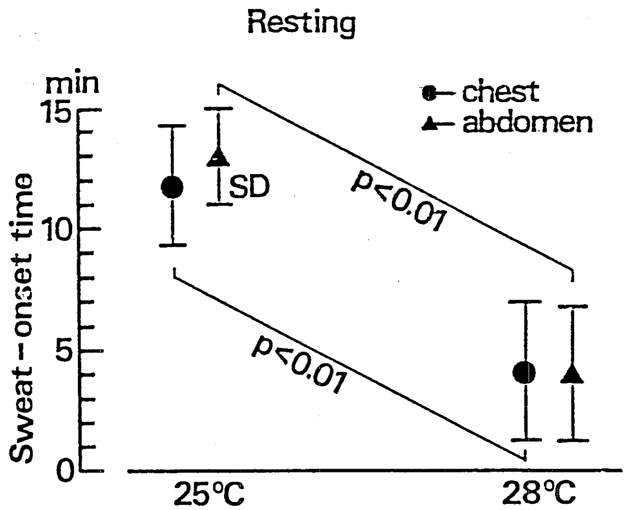

Fig. 1. Sweat-onset time after heat load at rest.

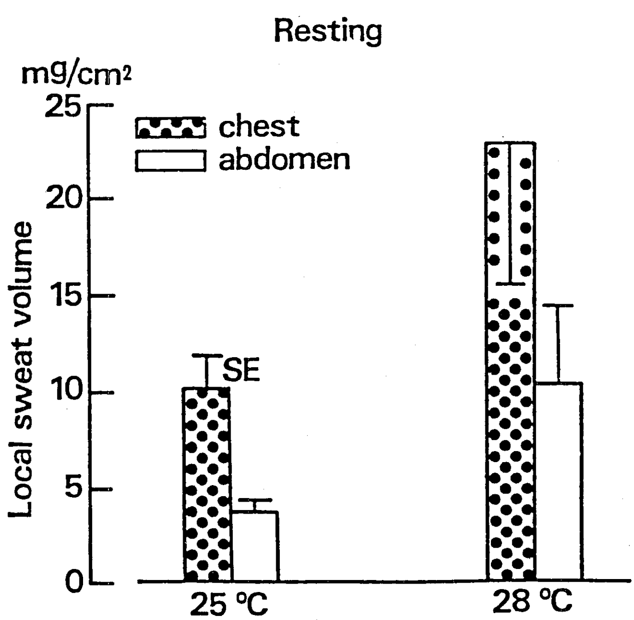

Fig. 2. Local sweat volume induced by heat load at rest.

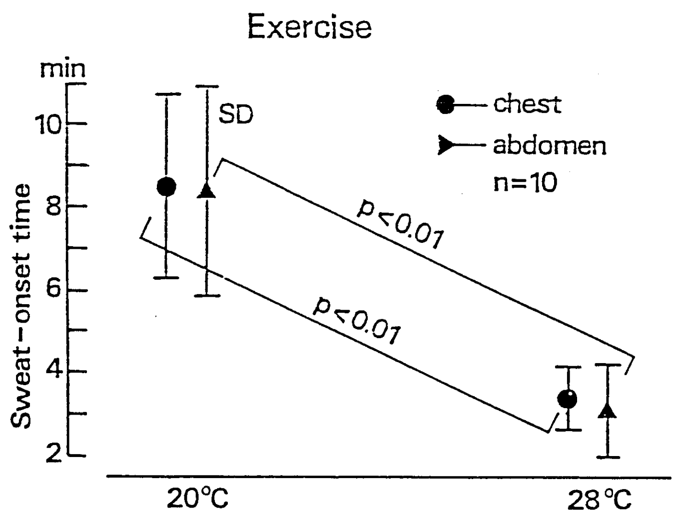

Fig. 3. Sweat-onset time after the beginning of exercise.

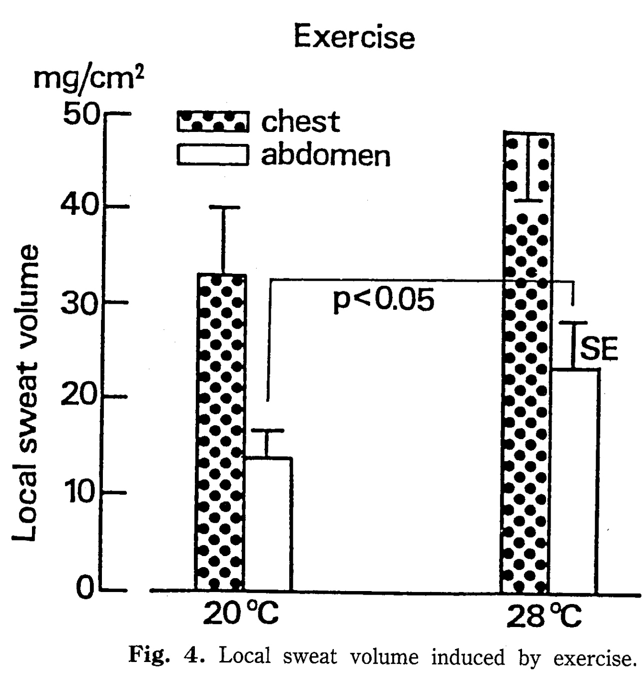

Fig. 4. Local sweat volume induced by exercise.

Table 2. Changes in oral temperature (To), mean skin temperature ($\bar{T}s$), and mean body temperature ($\bar{T}b$) during heat load in the resting series.

	Before			Sweat−onset			End of heat load			Sweat−onset			End of heat load		
	To	$\bar{T}s$	$\bar{T}b$	To	$\bar{T}s$	$\bar{T}b$	To	$\bar{T}s$	$\bar{T}b$	dTo	d$\bar{T}s$	d$\bar{T}b$	dTo	d$\bar{T}s$	d$\bar{T}b$
25 ℃	36.60	33.07	36.25	36.80	35.24	36.64	37.28	34.68	37.02	0.20	2.17	0.40	0.68	0.61	0.77
	(0.55)	(0.52)	(0.54)	(0.53)	(0.41)	(0.51)	(0.35)	(0.47)	(0.33)	(0.07)	(0.26)	(0.07)	(0.31)	(0.28)	(0.29)
28 ℃	36.86	34.09**	36.59	36.91	35.95**	36.82	37.35	35.94*	37.21	0.05*	1.86*	0.23**	0.49	1.85	0.63
	(0.12)	(0.11)	(0.11)	(0.16)	(0.10)	(0.14)	(0.12)	(0.54)	(0.15)	(0.05)	(0.05)	(0.05)	(0.12)	(0.60)	(0.14)

℃. Values in parentheses are SD. *$p<0.05$, **$p<0.01$ compared to the value at 25℃

Table 3. Changes in oral temperature (To), mean skin temperature ($\bar{T}s$), and mean body temperature ($\bar{T}b$) during exercise.

	Before			Sweat−onset			End of exercise			Sweat−onset			End of exercise		
	To	$\bar{T}s$	$\bar{T}b$	To	$\bar{T}s$	$\bar{T}b$	To	$\bar{T}s$	$\bar{T}b$	dTo	d$\bar{T}s$	d$\bar{T}b$	dTo	d$\bar{T}s$	d$\bar{T}b$
20 ℃	36.65	31.68	36.14	36.65	31.41	36.18	37.19	31.85	36.14	−0.01	−0.27	0.00	0.53	0.17	0.52
	(0.19)	(0.89)	(0.14)	(0.18)	(1.05)	(0.16)	(0.24)	(1.06)	(0.28)	(0.15)	(0.29)	(0.15)	(0.23)	(0.53)	(0.29)
28 ℃	36.78*	34.51**	36.53**	36.84**	34.44**	36.67**	37.39	34.47**	36.82**	0.04	−0.06	0.03	0.62	0.32	0.56
	(0.24)	(0.38)	(0.12)	(0.27)	(0.40)	(0.22)	(0.33)	(0.64)	(0.26)	(0.06)	(0.07)	(0.07)	(0.17)	(0.86)	(0.25)

℃. Values in parentheses are SD. *$p<0.05$, **$p<0.01$ compared to the value at 20℃

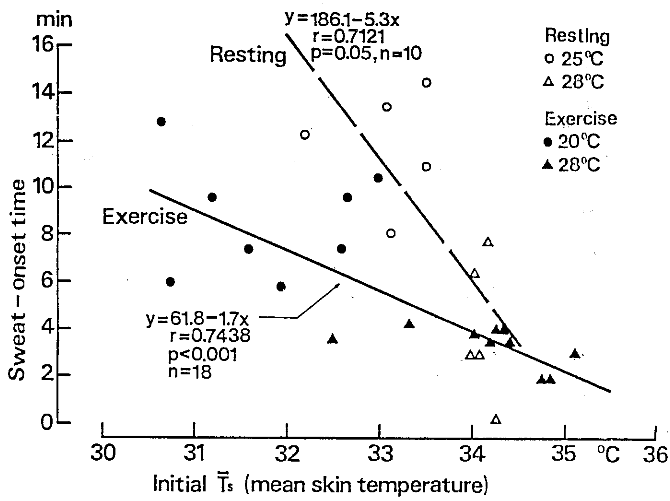

Fig. 5. Relationship between sweat-onset time and initial mean skin temperature ($\bar{T}s$).

exercise (50% of $\dot{V}O_2max$) on the cheat was 33.06 ± 21.69 mg/cm^2 at 20℃, 47.98 ± 20.74 mg/cm^2 at 28℃ (not significant). Local sweat volume at the abdomen was 13.85 ± 8.80 mg/cm^2 at 20℃, 23.31 ± 15.04 mg/cm^2 at 28℃, $p<0.05$ (Fig. 4).

Table 3 Shows that, To, $\bar{T}s$ and $\bar{T}b$ before exercise were high at 28℃ compared to those at 20℃, $p<0.05$ in To, $p<0.01$ in $\bar{T}s$ and $\bar{T}b$. The thresholds in To, $\bar{T}s$ and $\bar{T}b$ for sweat-onset were also high at 28℃ compared to those at 20℃, $p<0.01$. During exercise sweating was initiated without any rise in To or $\bar{T}b$ at both ambient temperatures.

In order to investigate the difference between sweating mechanisms at rest and during exercise, the relationships between sweat-onset time or local sweat volume and $\bar{T}s$, $\bar{T}b$ before load or $\dot{V}o_2max$ were determined. In the resting subjects, there was a significant correlation between sweat-onset time and initial $\bar{T}s$, namely,

$Y=186.1-5.3\ X,\ r=0.7121,\ p<0.05,\ n=10$

where, Y: sweat-onset time, X: initial $\bar{T}s$

but not in others. During exercise, there were significant correlations of sweat-onset time to initial $\bar{T}s$ and initial $\bar{T}b$, and of sweat volume to initial $\bar{T}b$, namely,

$Y=61.8-1.7\ X,\ r=0.7438,\ p<0.001,\ n=18$

where, Y: sweat-onset time, X: initial $\bar{T}s$

and

$Y=265.7-7.2\ X,\ r=0.6613,\ p<0.01,\ n=19$

where, Y: sweat-onset time, X: initial $\bar{T}b$

and

$Y=50.0\ X-1779.4,\ r=0.6184,\ p<0.001,\ n=18$

where, Y: local sweat volume, X: initial $\bar{T}b$

but not in others. The slope of the regression line between sweat-onset time and initial $\bar{T}s$ during exercise is less steep compared to that during resting (Fig. 5). There was no significant relationship between sweat-onset time or sweat volume and maximum aerobic power ($\dot{V}O_2max$).

Discussion

The ambient temperatures, 20℃, 25℃ and 28℃, tested in this study are considered to be thermo-neutral condition for human. In fact no sweating was observed in any subjects before heat or exercise load. However, higher body temperature such as To, $\bar{T}s$ and $\bar{T}b$ was observed at 28℃ compared to 20℃ or 25℃. These findings indicate that the higher heat content and the higher activity of dry heat loss response exists at relatively high ambient temperature within thermo-neutrality.

The sweating delay is inversely related to the external heat load (Colin and Houdas, 1965; Saltin *et al.,* 1970; Davies, 1980). Sweating can be initiated in a few seconds in a pre-heated subject (Van Beaumont and Bullard, 1963), but is often delayed when the subject is at or below thermo-neutrality (Hardy and Stolwijk, 1966; Davies, 1980; Mairiaux and Libert, 1987). The present study showed that sweat-onset time was shortened to one third by a little rese in ambient temperature, 3℃ or 8℃ , within thermo-neutrality (Fig. 1,3). The initial $\bar{T}s$ was higher at 28℃ than at 20℃ or 25℃ (Table 2,3). There was a negative relationship between sweat-onset time and initial $\bar{T}s$ during resting and exercese (Fig. 5). From these results, it is supposed that fine ambient temperature rise causes elevation of $\bar{T}s$ and the shortening of sweating delay is attributed to high $\bar{T}s$. Peripheral thermal input from the skin is a major factor in the variations in sweating delay, as shown previously (Nadel *et al.,* 1971; Libert *et al.,* 1978; Mairiaux and Libert, 1987). The influence of core temperature, $\bar{T}b$ and heat content on sweating delay also must be considered. Mairiaux and Libert (1987) showed that the sweating delay was influenced by the initial $\bar{T}b$ and by the body heat content prior to exposure, however, onset of sweating was not related to a critical level of heat storage.

During exercise, sweat occured without any elevation in To, $\bar{T}s$ and $\bar{T}b$ at both ambient temperatures (Table 3.). Negative relationship between sweat-onset time and initial $\bar{T}s$ was observed at rest and during exercise, and the slope of the regression line was less steep during exercese compared to that at rest (Fig. 5). These results indicate that non-thermal factors may play an important role on the onset of sweating during exercise.

In conclusion, this study confirms that fine alteration of ambient temperature within thermo-neutrality greatly affects thermal sweating, especially on sweat-onset time, not only at rest but also during exercise.

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