Physiological Responses of Men and Women during Exercise in Hot Environments with Equivalent WBGT

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Abstract. Eight Japanese men and women participated in this study. They were randomly exposed to two environments: hot-dry; HD ($T_a=40^\circ\text{C}$, rh 30%, wet bulb globe temperature (WBGT)= 32°C) and hot-wet; HW ($T_a=31^\circ\text{C}$, rh=80%, WBGT= 32°C) for 110 min. During the exposure, they rested on a bicycle ergometer for 20 min during rest and 30 min during recovery, then they pedaled it with an intensity of 40% $\dot{V}O_2$ max for 60 min. T_{re} , $\bar{T}_{sk}$, and HR were recorded every minute. Total sweat loss and dripping were measured by independent bed balances which was connected to a computer processing with an accuracy of 1 g throughout the experiment. Sweat sodium concentration at forearm and back sites were collected by sweat capsule technique. These results showed that ΔT_{re} , $\bar{T}_{sk}$, evaporated sweat, dripping sweat, body heat storage of both sexes in HD were significantly higher than these in HW during exercise. HR of men in HD at the end of recovery was slightly higher than that of women. Whereas the sweat sodium concentration at forearm and back sites in both sexes remained unchanged either in HD or HW environment, it was found that HD was more stressful than HW environment under equivalent WBGT.

(*Appl Human Sci*, 15(6): 249-258, 1996).

Keywords: WBGT index, hot dry and hot wet, sweating, sex difference, temperature regulation

Introduction

In the past few years, there has been much controversy in research concerning the difference in physiological response of women and men when both sexes are exposed to an identical heat stress. Women have usually been deemed as less able to cope with an acute heat exposure, since their sweat rates are substantially lower than those of men (Fox et al., 1969; Hertig and Sargent, 1963; Wyndham et al., 1965). When both sexes were exposed to the same heat stress, several

authors reported that men sustained higher sweat rates with lower core temperatures and heart rates (HR) than women did (Bittel and Henane, 1975; Cunningham et al., 1978; Fox et al., 1969). Whereas others reported that women maintained similar (Brougha et al., 1960; Morimoto et al., 1967) or even lower (Weinman et al., 1967) core temperatures and HR. However, when the cardiorespiratory fitness of men and women was considered, both sexes maintained similar core temperatures and HR (Drinkwater et al., 1976; Kamon et al., 1978). Although their acclimatization served to eliminate many of the differences in sex-related physiological response, sweat rates still remained lower for women (Weinman et al., 1967; Wyndham et al., 1965). However, Shapiro et al. (1980) found that after acclimatization to heat for 6 days, the women can tolerate the heat better than men in humid heat conditions due to lower deep body and skin temperatures and lower sweat rate and subsequently less dehydration than men. We have reported that during exercise in humid environment (ambient temperature; $T_a=34.5^\circ\text{C}$, relative humidity; rh=65%), HR, rectal temperature (T_{re}) and sweat rate for men were significantly higher than those for women (Tochihara, 1984). On the contrary, Frye and Kamon (1983) found that there was no difference between sexes or environments on T_{re} or HR after acclimatization to heat. Most of the researchers compared the physiological responses of men and women after acclimatization, whereas the effect of dry and humid heats in short exposure is relatively less. A few research has been conducted to compare the responses of a group of men and women to both dry and humid climates, and the controversies of the physiological responses between sexes and thermoregulation in dry and humid heat still exist.

An ideal heat stress index which combines all of the climatic, physical, and individual factors into a single number and correlates them to one or more physiological responses, has not yet been found. In this study, we use WBGT index which is world widely used for industrial and military training but less in use to test during exercise in

the laboratory. The first purpose of this study was to investigate the physiological response of human being to hot-dry and hot-wet conditions under equivalent WBGT. The second one was to clarify further the sexual dependencies depend upon environmental conditions under equivalent WBGT.

Materials and Methods

Subjects

Eight young Japanese women and men volunteered to participate in this study. All subjects were totally informed with regard to experimental risk and gave their written informed consent. They are allowed to do their daily activities freely. The physical characteristics of women and men were shown in Table 1.

Procedures

Prior to joining the experiment, anthropometric parameters (axillary temperature, blood pressure, and body weight) of the subjects were measured in the neutral climatic chamber where an ambient temperature (T_a) and relative humidity were 25°C and 50%, respectively. Their skinfold thicknesses were measured using Caliper (Eiyoken type pat 376843, meikosha, Japan) at two sites: Triceps and subscapular. The skinfolds were determined from the right side of the body and were done in duplicate, then their mean values were recorded. A body density was calculated from the skinfold thickness based on Nagamine and Suzuki (1964), while the Brozek's method (1963) was used for calculating the percentage of body fat. $\dot{V}O_2$ max was determined by a bicycle ergometer (model 930, Siemens, Fukuda-denshi, Japan) testing and modified from Åstrand et al.'s method (1986). During this test, the gas volume was collected by the gas mask based on the closed-circuit method, which was connected directly to the oxygen (O_2), and carbon dioxide (CO_2) analyzer (MIJNHARDT model, Fukuda-denshi, Japan) for determining simultaneously oxygen consumption ($\dot{V}O_2$), and

pulmonary ventilation (V_E) in every minute. The telemeter of ECG monitor (Dynascope model, mode DS-502, Fukuda-denshi, Japan) was used to record ECG pulse and heart rate every minute during testing $\dot{V}O_2$ max.

Prior to testing, the women wore a bikini, while men wore short pants. After resting for 30 min in the thermoneutral climatic chamber where T_a and rh were 25°C and 50%, respectively, they were randomly exposed for 110 min to two climatic environments: hot-dry condition (HD); $T_a=40^\circ\text{C}$, rh=30%, wet bulb globe temperature (WBGT)=32°C, and hot-wet condition (HW); $T_a=31^\circ\text{C}$, rh=80%, WBGT=32°C, respectively. The two experiments were performed at the same time but on different days. The sequence of climate conditions was varied randomly. The exposed interval between the two conditions was within one week. During the first 20 min and the last 30 min, the subjects rested on an electrically braked bicycle ergometer (Cardio testing cycle, model 5 RH, Combi Company, Japan). Between these periods, the subjects constantly pedaled the bicycle ergometer at 50 rpm for 60 min with an intensity of 40% $\dot{V}O_2$ max. Air velocity was controlled to be equal to 20 cm/sec throughout this experiment. The telemeter of ECG monitor (Dynascope model, mode DS-502, Fukuda-denshi, Japan) was used for recording the heart rate. A skin temperature was measured with thermistors attached at seven sites (forehead, forearm, hand, trunk, thigh, leg, and foot) with surgical tape throughout the experiment. Mean skin temperature ($\bar{T}_{sk}$) was calculated by using Hardy and DuBois's equation (1938). Rectal temperature (T_{re}) was monitored continuously by the thermistor probe, which was inserted 12 cm above the anal sphincter. The expired gas volume was collected by Douglas bag during the first rest (between 10th-15th min) and exercise period (between 65th-68th min). Then the gas volume was measured by using the dry gas test meter (Shinagawa, model DC-5, Vice-Medical Company, Japan). After that the O_2 and CO_2 concentration were directly measured by O_2 and CO_2 analyzer (Mets-900, model 900, metabolic exercise testing system, Vise-Medical

Table 1 Physical characteristics of the subjects

Parameters	Female (n=8)	Male (n=8)
Age (yr)	21.13 ± 0.83	20.75 ± 2.60
Height (cm)	158.13 ± 4.12	169.38 ± 5.85***
Weight (kg)	53.61 ± 3.70	56.97 ± 6.39
BSA (m ²)	1.53 ± 0.04	1.64 ± 0.11*
BSA/Weight (cm ² /kg)	285.88 ± 12.79	288.29 ± 14.27
% Body fat (%)	19.23 ± 2.45	13.80 ± 3.08**
$\dot{V}O_2$ max (l/min)	2.52 ± 0.32	2.89 ± 0.43
$\dot{V}O_2$ max (ml/kg/min)	46.29 ± 7.72	50.90 ± 6.45
Work load (watts)	64.88 ± 9.34	75.38 ± 13.39

The data are means ± SD. *p<0.05, **p<0.01, ***p<0.001; Significant difference between sexes.

Company, Japan), respectively. In order to determine the total sweat loss and dripping, the two independent bed balances (Mettler ID1 multirange, type ID1s, Mettler-Toledo (Albstadt) GmbH, Germany) which were connected to the computer processing with an accuracy of 1 g were used throughout the experiment. The amount of sweat from the clothes (bikini, towel, and pocket) were determined and added, evenly distributed over the experimental period, to the amount of dripping. Paraffin was put to the pan (which was located under the bicycle ergometer) for protecting the evaporating sweat. Sweat rate was corrected for respiratory water loss (Fanger, 1970) and metabolic weight loss (Kerslake, 1972). Cutaneous sweat evaporation, skin wettedness (w), and efficiency of sweat evaporation (η) were calculated by Alber-Wallerstrom and Holmer's method (1985). Maximal evaporative capacity (E_{max}) was calculated by $E_{max} (W/m^2) = 2.2 \text{ he} \cdot F_{pcl} (P_{sk} - P_a)$; where evaporative heat transfer coefficient; $he = 6.05 \text{ W/m}^2 \cdot ^\circ\text{C}$, evaporative efficiency of clothing; $F_{pcl} = 1$, P_{sk} is the saturated water vapor pressure at skin temperature and P_a is the ambient water vapor pressure, both in mmHg. Body heat storage (ΔS) was calculated by Stolwijk and Hardy's method (1966). The sodium concentration in sweat was determined by attaching the sweat capsule, and sweat sodium was collected from the piece of filter paper with 12.4 cm^2 in area, on the middle of left forearm and back over the latissimus dorsi during rest, exercise, and recovery, respectively. Its sodium concentration was analyzed quantitatively by a flame photometer which was modified from Ohara's method (1966). Blood pressure (BP) was recorded using sphingomanometer during rest, exercise, and recovery. According to Gagge's method

(1967) the psychological responses to dry heat condition, thermal sensation and thermal comfort were measured. In order to indicate physical strain during physical work, the rating perceived exertion (RPE) was determined by Borg's scale (1982). Water losses were not replaced until all procedures were completed.

The effects of menstrual cycle on thermoregulation during thermal stress have been found to be negligible (Cunningham et al., 1978; Frye and Kamon, 1981, 1982; Shapiro et al., 1980; Pivarnik et al., 1992). Therefore, this present study did not take menstrual cycle into account. In addition, no subjects were in menstruation condition during the time of these experiments.

Statistics method

Each variables (ΔT_{re} , HR, sweat evaporated, etc) was compared by two way analysis of variance with sex and environment as factors. Significant F ratios were followed by Tukey's test for wholly significant difference to determine which means differed significantly.

Results

The time course of changes of the rectal temperature (ΔT_{re}) during rest, exercise, and recovery was shown in Fig.1. When the environmental conditions were compared to equivalent WBGT and the same relatively work load, ΔT_{re} in the men (1.1°C , 0.91°C) was significantly higher than that in the women (0.94°C , 0.64°C) at the end of exercise and recovery ($p < 0.05$, $p < 0.05$), respectively. Whereas at the end of rest, there was no significant difference in ΔT_{re} of both sexes. The ΔT_{re} of men and women in hot-dry environment (HD)

Fig. 1 Changes in rectal temperature under hot-dry (HD) and hot-wet (HW) in male (M) and female (F) groups. The data are means $\pm$ SD. * $p < 0.05$; Significant difference between HD and HW. + $p < 0.05$; Significant difference between M and F.

were significantly higher than these in hot-wet environment (HW). However, from the two-way analysis, there was no significant difference between sexes and environments according to equal WBGT and at the same work load.

Figure 2 illustrated the changes in the mean skin temperature ($\bar{T}_{sk}$) during rest, exercise, and recovery. $\bar{T}_{sk}$ of both sexes were not different in either in HD or HW environments under the equivalent WBGT condition. However, $\bar{T}_{sk}$ of women and men in HD were significantly higher ($p < 0.001$) than these in HW at the end of rest,

exercise, and recovery. The differences of $\bar{T}_{sk}$ in both sexes between HD and HW environments were about 0.8–1.0°C at the end of rest, exercise, and recovery. No interaction between sexes and environments under the same equivalent WBGT and the same work load were found from these results.

The changes in HR during rest, exercise, and recovery was shown in Fig. 3. The HR of women at rest in HD environment was 79 beats/min and in HW environment 76 beats/min, while those of men were 81 and 76 beats/min, respectively. At the end of exercise,

Fig. 2 Changes in mean skin temperature under hot-dry (HD) and hot-wet (HW) in male (M) and female (F) groups. The data are means $\pm$ SD. *** $p < 0.001$; Significant difference between HD and HW.

Fig. 3 Changes in heart rate under hot-dry (HD) and hot-wet (HW) in male (M) and female (F) groups. The data are means $\pm$ SD. ** $p < 0.01$; Significant difference between HD and HW. + $p < 0.05$; Significant difference between M and F.

the men's HR was higher than women by about 10 beats/min in HD environments. However, there was no significant difference in HR of women and men at the end of rest and exercise in both environments. On the contrary, the women's HR decreased faster than men. At the end of recovery, it was significantly lower than that of men ($p<0.05$). There was no interaction between sexes and environments.

Figure 4 showed the evaporated sweat during rest, exercise, and recovery. The evaporated sweat of men at the end of experiment for 110 min in HD was 499 g/m²

and in HW was 273 g/m², while women were 423 and 224 g/m², respectively. The men's evaporated sweat in both environments were significantly higher than that of women at the end of exercise, and recovery ($p<0.01$ and $p<0.05$). Furthermore, the evaporated sweat of both sexes in HD were significantly higher ($p<0.001$). It was approximately twice as these in HW at the end of rest, exercise and recovery, respectively. There was no relation between sexes and environments.

Dripping sweat during rest, exercise, and recovery was illustrated in Fig. 5. At the end of the experiment,

Fig. 4 Changes in evaporated sweat under hot-dry (HD) and hot-wet (HW) in male (M) and female (F) groups. The data are means $\pm$ SD. *** $p<0.001$; Significant difference between HD and HW. + $p<0.05$, ++ $p<0.01$; Significant difference between M and F.

Fig. 5 Changes in dripping sweat under hot-dry (HD) and hot-wet (HW) in male (M) and female (F) groups. The data are means $\pm$ SD. + $p<0.05$; Significant difference between M and F.

the dripping of men in HD and HW were 94 and 90 g/m², respectively. Women's dripping were 9 and 18 g/m², respectively. The men's dripping showed a significant increase ($p < 0.05$) than women's dripping throughout the experiment in both environments. However, the dripping sweat in both sexes were less and widely varied between individuals. In the present study, only two subjects from the men and women groups secreted a lot of dripping sweat, while the others did less. There was no significant difference in dripping sweat between HD and HW environments neither for men nor women throughout the experiment.

The rate of body heat storage (ΔS), metabolic energy production (M), maximal evaporative capacity (E_{max}), skin wettedness (w) and efficiency of sweat evaporation (η) at the end of exercise were shown in Table 2. ΔS and E_{max} of women and men in HD at the end of exercise were significantly higher ($p < 0.05$) than these in HW. On the other hand, no difference in ΔS and E_{max} were shown by both sexes throughout the experiment. M , w ,

and η of men were significantly higher than these of women, while these parameters of both sexes were not influenced by the environments.

Table 3 illustrated the oxygen consumption ($\dot{V}_{O_2}$) during rest and exercise. $\dot{V}_{O_2}$ of men were significantly higher than these in women during rest and exercise ($p < 0.001$ and $p < 0.001$) both in HD and HW. However, there was no significant difference in $\dot{V}_{O_2}$ of both sexes between HD and HW.

The sweat sodium concentration during exercise, and recovery at the forearm and back sites were shown in Table 4. There was no significant difference in the sweat sodium concentration between men and women throughout the experiment. Moreover, the sweat sodium concentration of both sexes were not significantly different either in HD or HW.

Discussion

The body weight, body surface area, body fat, and

Table 2 Body heat storage (ΔS), metabolic energy production (M), maximum evaporative capacity (E_{max}), skin wettedness (w), and efficiency of sweat evaporation (η) at the end of exercise

	Female		Male	
	Hot-dry	Hot-wet	Hot-dry	Hot-wet
ΔS (W/m ²)	28.22 $\pm$ 9.81	22.78 $\pm$ 8.48*	32.17 $\pm$ 2.99	25.53 $\pm$ 3.80*
M (W/m ²)	212.42 $\pm$ 29.11*	212.00 $\pm$ 28.47*	251.22 $\pm$ 31.80*	236.05 $\pm$ 28.19*
E_{max} (W/m ²)	405.24 $\pm$ 22.01	234.74 $\pm$ 17.58***	408.99 $\pm$ 10.20	235.17 $\pm$ 6.28***
w (N.D)	0.45 $\pm$ 0.08**	0.43 $\pm$ 0.08**	0.50 $\pm$ 0.09**	0.55 $\pm$ 0.13**
η (%)	98.69 $\pm$ 2.24*	94.02 $\pm$ 9.15*	88.45 $\pm$ 16.28*	84.37 $\pm$ 18.18*

Data are means $\pm$ SD. * $p < 0.05$, *** $p < 0.001$; Significant difference between hot-dry and hot-wet. * $p < 0.05$, ** $p < 0.01$; Significant difference between male and female groups.

Table 3 Oxygen consumption ($\dot{V}_{O_2}$) during rest and exercise

$\dot{V}_{O_2}$ (ml/kg/min)	Female		Male	
	Hot-dry	Hot-wet	Hot-dry	Hot-wet
Rest	0.23 $\pm$ 0.03	0.23 $\pm$ 0.03	0.32 $\pm$ 0.04	0.30 $\pm$ 0.03
Exercise	0.98 $\pm$ 0.12	0.97 $\pm$ 0.12	1.23 $\pm$ 0.17	1.15 $\pm$ 0.16

The data are means $\pm$ SD. *** $p < 0.001$; Significant difference between male and female.

Table 4 Sodium concentration at forearm and back sites during exercise at 30 and 60 min and recovery at 110 min

Sodium concentration (mEq/l)	Forearm				Back			
	Female		Male		Female		Male	
	Hot-dry	Hot-wet	Hot-dry	Hot-wet	Hot-dry	Hot-wet	Hot-dry	Hot-wet
Ex-30 min	42.2 $\pm$ 22.6	47.1 $\pm$ 20.0	51.3 $\pm$ 36.4	58.6 $\pm$ 53.4	42.1 $\pm$ 24.8	33.5 $\pm$ 13.2	63.6 $\pm$ 36.0	48.9 $\pm$ 34.9
Ex-60 min	54.0 $\pm$ 40.5	45.6 $\pm$ 20.9	54.6 $\pm$ 35.0	51.5 $\pm$ 53.8	49.8 $\pm$ 28.3	38.7 $\pm$ 14.3	71.8 $\pm$ 33.7	56.2 $\pm$ 38.4
Recovery	81.2 $\pm$ 81.2	42.8 $\pm$ 32.1	55.2 $\pm$ 42.3	55.7 $\pm$ 61.6	55.8 $\pm$ 54.3	38.8 $\pm$ 15.2	58.9 $\pm$ 36.2	39.5 $\pm$ 16.7

The data are means $\pm$ SD.

cardiorespiratory fitness which differ between men and women are intricately related to the ability to thermoregulate effectively. In the present study, an attempt was made to minimize the differences in the above variables as much as possible. It is the fact that the rate of heat loss is a function of surface area, subjects with a larger surface area would be able to lose heat at faster rate than subjects with a smaller surface area, provided the metabolically active tissue mass is the same. However, men usually have a greater mass than women and hence have a smaller surface area to mass ratio (BSA/wt). This smaller BSA/wt would prove advantageous in environments in which ambient temperature exceeds skin temperature, since less heat will be gained from the environment via radiation and convection. On the other hand, when skin temperature is above ambient temperature, the larger BSA/wt in women would be more of an advantage because of their larger area available for heat loss in relation to the smaller mass for heat production. (Shapiro et al., 1980). However, in the present study, even the body fat content (% fat) and BSA of female subjects showed significantly higher than those of male subjects, but the BSA/wt of both sexes were not different.

Ljungberg et al. (1979) reported that unacclimatized men and women were exposed to HW ($T_a=32^{\circ}\text{C}$, $rh=80\%$) and HD ($T_a=40^{\circ}\text{C}$, $rh=40\%$) conditions during sedentary work, for 90 min under equivalent Swedish wet-bulb globe temperature (SWBGT= 32°C). HR, $\bar{T}_{sk}$, and sweat rate were higher under HD than under HW conditions in both sexes. While, Morimoto et al. (1967) reported that each subjects was exposed to a heat and work stress in dry-heat and in high humidity subsequently. The subjects sat on a chair for 30 min, then exercise by walking on the treadmill at 5.6 km/h for 30 min, and finally sat on a chair for 30 min, and was conducted 2 times. The sweating of men and women were higher in HD than in HW. These are in agreement with the present study in that under equivalent WBGT and similar relative work load, the evaporated sweat of both sexes in HD was significantly higher than those in HW. Moreover, $\bar{T}_{sk}$ of both sexes in HD condition showed significantly higher than these in HW condition. It seems that under equivalent WBGT their sweating were different according to whether the atmosphere was wet or dry. Furthermore, when the effects of dry and wet heats are compared, it appears that regardless of sex there is a significantly lower sweat rate in wet-heat than in dry-heat.

On the contrary, Frye and Kamon (1983) reported that there were no differences between sexes or environments in Tre or HR after acclimatized subjects exposed to hot-dry ($T_{db}=48^{\circ}\text{C}$, $T_{wb}=25^{\circ}\text{C}$) and hot-wet conditions ($T_{db}/T_{wb}=37/30^{\circ}\text{C}$) with exercise 25-30% $\dot{V}_{O_2}$ max for 3 h and water replacement was used during heat

exposure under equivalent corrected effective temperature (CET). However, both sexes had significantly lower total sweat rate and local sweat rate on the chest in the humid heat compared with the dry-heat. The women maintained significantly lower sweat rate than the men in humid heat. Our results agreed with those of the above reports concerning sweat rate, but not with Tre, HR, and $\bar{T}_{sk}$. The reason for this discrepancy of these parameters may be (a): in this present study, there was no water replacement during exposure to the hot environments throughout the experiment; (b): the heat acclimation may affect the cardiorespiratory and thermoregulation function.

The advantage of the WBGT is that the elements are easy to measure and that practical tool for industrial purpose (Minard, 1973). However, there are also some disadvantages such as that the WBGT estimate gets progressively poorer under low humidity condition (Ramsey, 1976); the same WBGT value does not have consistent physiological meaning independent of the climatic factors and higher air temperatures, and work rates would exaggerate these inconsistencies (Ramanathan and Belding, 1973). Pulket et al. (1980) reported that for light work in hot-humid environment, the WBGT correlated well with skin temperature but poorly with rectal temperature, heart rate and sweat loss. The fundamental claim of the index is that no matter what the combination of ambient factors is, if the index is the same, the physiological responses, whether measured as pulse rate, Tre, or sweat rate should be equal. Therefore, these controversies may assume that physiological equivalence of conditions of many kinds of heat indices require further study.

In this study, the efficiency of sweat evaporation was determined by a continuous weighing technique which has been used by other investigators (Berglund and Gonzalez, 1977; Candas et al., 1979; Holmer and Elnas, 1981) and proved to be accurate and reliable and could be applied to resting or exercising states. The dripping sweat was also measured by an independent balance which is connected to the computer processing. For this quantitative technique, it was proved that the effective temperature and subject evaluation indicated that the HD environment was more stressful than the HW environment in both sexes. In HD environment, the increase of evaporated sweat observed in men and women suggested an increasing ability of the body to dissipate the excess heat.

Skin wettedness (w) is an important factor in setting the evaporate rate (Candas et al., 1979; Givoni, 1976; Kerslake, 1972; Libert et al., 1978). It is the fact that when the skin is fully wet, the efficiency of sweat evaporation is reduced. Furthermore, Kerslake (1972) concluded that when the skin is 100% wet, at least 40% of sweat drips off the subject. Givoni and co-workers

(1976) studied the cooling efficiency of sweat evaporation on semi nude and clothed subjects under various conditions, and they concluded that efficiency is reduced already when w was less than 0.2. Alber-Wallerstrom and Holmer (1985) found that when unacclimatized men were exposed to hot-humid 50% rh, with work load 50 W and 70% rh, work load 100 W, the w were 0.47 and 1.0 respectively and efficiency of sweat (η) were 87% and 51% respectively. These results are similar to our present study comparing the men who were exposed to 80% rh with work load 75 W, and the w and η were 0.55 and 84% respectively. However, in our study both sexes did not show the fully skin wettedness. Thus, a little dripping sweat was observed in this study. These may depend on the intensity of work load and wide individual variations. Furthermore, our results allow a quantification of the qualitative conclusion of Houdas et al. (1972) regarding the interactions between skin wettedness, sweat efficiency, and thermal equilibrium. This will depend on the magnitude of E_{req} (required evaporation for a thermal equilibrium) compared to E_{max} . In dry conditions, where E_{req} is very low in relation to E_{max} , all sweat secreted will be evaporated and homeostasis will be maintained: this phenomenon will be observed in unacclimated subject. In humid conditions, however, where 50% of the skin area must be wetted to maintain body heat balance, some sweat may drip off the body. The amount of drippage will increase from 0-10% when the skin wettedness increases to 80% depending on two factors. The first is air velocity: when air movement increases, dripping also tends to increase. The other factor which is more reliable, is related to the subject's ability to wet his own body by sweating, and this will depend on whether the subject is acclimated to heat or not.

Many investigators (Paolone et al., 1978; Avellini et al., 1980; Frye and Kamon, 1981) found that when physically fit men and women were exposed to dry heat or humid heat, there were no difference in physiological responses between sexes and environment. This finding agrees with our study, but discrepancy with Shapiro et al. (1980) found that the acclimatized men could tolerate the hot-dry condition ($T_a=49^\circ\text{C}$, $rh=20\%$, $WBGT=34.0^\circ\text{C}$, air velocity=1 m/sec) by showing lower deep body and skin temperatures, and lower HR than women. However, the acclimatized women could tolerate hot-humid ($T_a=37^\circ\text{C}$, $rh=80\%$, $WBGT=34.2^\circ\text{C}$, air velocity=1 m/sec) more than men. This discrepancy may be due to the air velocity which is one of the important factors in enhancing heat dissipation during exercise and heat exposure. Ljungberg et al. (1979) found that during the last half hour of exposure to humid heat ($T_a=32^\circ\text{C}$, $rh=80\%$), air velocity was increased with the aid of a fan, the subject increased the sweat rate and $\bar{T}_{sk}$ was decreased. On the other hand, the men and women in

our study showed higher sweat rate and ΔT_{re} during exercise in HD than HW. However, women still showed a lower sweat rate than men. Furthermore, men and women showed a lower sweat rate in HW than HD. Since in high humidity, the rate of evaporation could not be increased due to the high ambient vapor pressure, any increase in sweat rate beyond the maximum evaporative of the environment would result in increased dripping of unevaporated sweat. The men were found to have greater increase in the rate of unevaporated sweat production than women. The reason for the often documented lower sweat rate of women in humid heat is unclear. In this study, the BSA/wt and the $\bar{T}_{sk}$ were similar in men and women, hence differences in rate of heat loss via radiation and convection could not account for the differences in sweat rate. The lower sweat rate in women may be related to a more efficient suppression of nonevaporative sweat output (Weinman et al., 1967; Wyndham et al., 1965). The men showed significantly higher dripping than women. This may imply that women have a more sensitive feedback from the wetted skin surface to prevent excessive dripping of the nonevaporative sweat (Avellini et al., 1980). Frye and Kamon (1983) suggested that the lower sweat rate of men and women in wet-heat compared with the dry-heat may be due to conserving body water without a loss of sweat efficiency. The women reduced sweat loss to a rate approximating the E_{req} (required evaporation for a thermal equilibrium) through a reduction in the number of actively secreting sweat glands, significantly improving sweat efficiency in humid heat as compared with the dry-heat. The men reduced sweat loss through a reduction in sweat gland flow, but gained no improvement in sweat efficiency by that reduction. Thus, the women demonstrated a more effective response to a high degree of skin wettedness, and we must concur with the previous reports (Morimoto et al., 1967; Shapiro et al., 1980) that the conservation of body water through the reduction of nonevaporative sweat provides an advantage to women during exercise in humid heat.

In the present study, the rate of temperature and comfort disclosed clear differences in the perception of the two types of climate. At 40°C the climate was always regarded as being hotter and more uncomfortable than at 31°C , as also reflected by the physiological measurements. The present study disclosed that the sexes tended to differ with respect to thermal sensation. A number of studies have found a clear correlation between heat discomfort, sweating intensity, and especially skin wettedness (Gagge et al., 1969). On the other hand, the thermal sensation appeared to be better correlated to skin and ambient temperature. In the present study, the men felt to be uncomfortable during exposure to HD and HW, while the women felt comfortable in HW much more than HD. Thus greater sweating

intensity of the men in this study may have contributed to the greater discomfort felt by them.

In conclusion, men and women showed significantly higher stress due to high sweat rate, HR, ΔT_{re} and $\bar{T}_{sk}$ in HD than HW. However, women showed lower heat stress than the men. Accordingly, the sex differences in sweat rate become more obvious under higher heat stress. This increments of sweating on environmental heat differ according to whether the stress is hot-wet or hot-dry under equivalent WBGT. For both sexes there is a lower sweat rate in wet than in dry heat. These general findings are intriguing from the viewpoint of thermoregulation. We can only conclude, therefore, that the mechanisms of thermoregulation differ quantitatively in the two sexes and that even in wet-heat sufficient sweat is evaporated to permit regulation to be achieved. The details of this striking sex difference remain to be elucidated and a suitable heat stress index during exercise would be further investigated.

Acknowledgments. One of the authors, Waree Keatisuwan, wishes to thank Prof. Dr. T. Koyama of the Research Institute for Electronic Science, Hokkaido University, for his continuous guidance. The authors are grateful to Prof. Dr. C. Ohkubo for his encouragement throughout this work. The authors also wish to thank S. Yamagishi, M. Hosaka, N. Tamura, M. Nagao, and Y. Sumomozawa for their technical assistance. Last, but not least, the authors wish to thank all the subjects for their participation in this study. This study was supported by a grant from the Science and Technology Agency 1994.

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Received: May 13, 1996

Accepted: August 6, 1996

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