Physiological Responses of Women during Exercise under Dry-Heat Condition in Winter and Summer

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Abstract. Fourteen young Japanese women were exposed to a dry-heat condition (Ta = 40 °C, rh = 30%) both in winter and summer. During an exposure for 110 min, they were rested on a bicycle ergometer for 20 min, exercised with an intensity of 40% \( \dot{V}O_2 \) max for 60 min and recovery for 30 min. Their rectal and skin temperatures, and heart rate were determined every minute. Total sweat loss and dripping sweat were recorded throughout the experiment by independent bed balances which connected to a computer processor with an accuracy of 1 g. Sweat capsule with filter paper was used to measure sodium concentration on the forearm and back sites. Rectal temperature was not significantly different between winter and summer. Mean skin temperature was significantly higher in summer than in winter during exercise while heart rate was significantly lower in summer than in winter. Sweat evaporation and dripping in summer showed a tendency to increase much more than those in winter, but there were not significantly different. Sweat sodium concentration were significantly lower in summer than that in winter. It was found that sweating responses were not influenced by seasonal variation during exercise in dry-heat except the sweat sodium concentration.


Keywords: seasonal variation, sweat rate, submaximal exercise, temperature regulation, females

Introduction

It was widely known that physiological responses of humans to heat stress are influenced by prevailing climatic conditions of their environment. Sweat rate, rectal temperature (\( T_r \)), skin temperature (\( T_s \)), and heart rate (HR) are generally used as measuring parameters of the physiological responses. In the past three decades, much of the research in physiological response of male subjects has been reported. Torii et al. (1985) reported that the mean sweat rate of male subjects during exercise (40% \( \dot{V}O_2 \) max) for 20 min in a hot environment (ambient temperature; Ta = 30 °C, relative humidity; rh = 45%) was significantly higher in summer than that in winter. Rectal temperature showed slight elevation during exercise in winter as compared with that in summer, whereas \( T_s \) during exercise in summer was decreased much more than that in winter under the same conditions. Yasuda and Miyamura (1983) also reported that after male subjects exposed to a hot-humid environment (Ta = 30 °C, rh = 70%) and exercise with intensity of 30-35% \( \dot{V}O_2 \) max for 30 min, the evaporative and total water loss in summer were significantly greater than those in winter whereas HR and \( T_r \) were not affected by season. On contrary, Williams et al. (1967) found that HR and \( T_r \) of male subjects decreased in summer as compared with those in winter under the same heat stress.

When first exposed to an acute heat stress, unacclimated and relatively unfit women have demonstrated higher HR and \( T_r \) and lower sweat rate than men (Bittel, 1975; Brougha et al., 1960; Fox et al., 1969). Paolone et al. (1978) found that the male subjects had higher HR and greater evaporative weight losses during exercise (50% \( \dot{V}O_2 \) max, 40 min) in the hot environment (Ta = 40 °C, rh = 50-55%) than those in female subjects. Tochihara (1984) also found that HR, \( T_r \) and sweat rate of the male subjects during the end of exercise (40% \( \dot{V}O_2 \) max, for 100 min) in hot environment (Ta = 34.5 °C, rh = 55-65%) were significantly higher than those of female subjects. In the studies on female physiological responses, the lower sweat rate and higher \( T_r \), \( T_s \) of women are thought to be responsible for their poorer performances during heat exposure. The studies of female physiological responses to combined heat and physical work stress during seasonal variation are found to be less than male (Araki et al., 1981). Therefore, whether the female physiological response differs from male remains to be investigated.

By taking these controversies into account, the purpose of this study was to investigate the physiological responses of women to dry-heat stress during exercise in winter and summer.
Materials and Methods

Subjects

Fourteen young Japanese women, age 20-23 years are served voluntarily as subjects in this experiment. All subjects were totally informed with regard to experimental risk and gave their written informed consent. Their physical characteristics are shown in Table 1.

Procedures

The experiment carried out in Tokyo was divided into two seasons, winter (W) and summer (S). The winter acclimation was conducted in March where the outdoor temperature varied from 4.2 °C to 13 °C, while the summer acclimation was in August and September with the temperature of 23.2 °C to 30.8 °C. All subjects participated in both seasons. To minimize effects of diurnal variations, the subject was always exposed at the same time of day in the two seasons. Prior to joining in the experiment, the subjects came to our laboratory and entered the neutral climatic environment (Ta = 25 °C, rh = 50%), then the anthropometric parameters (axillary temperature, blood pressure, body weight) were determined. The skinfold thickness was measured using a Caliper (Eiyoken 376843, Japan) at the sites of triceps and subscapula. Body density was calculated from the skinfold thickness based on Nagamine and Suzuki (1964), and the Brozek’s method (1963) was used for calculating the percentage of body fat. Maximal oxygen consumption (V\(_{\text{O}_2}\) max) was determined by bicycle ergometer (Siemens 930, Japan) testing and modified from the method of Åstrand and Rodahl (1986).

On the experimental day, the subjects in bikini dressed, rested for 20 min in the thermonutral climatic chamber where Ta and rh were 25 °C and 50%, respectively. Then she was exposed to another climatic chamber with Ta = 40 °C, rh = 30%, wet bulb globe temperature (WBGT) = 32.3 °C for 110 min. During the first 20 min and the last 30 min, the subject rested on an electrically braked bicycle ergometer (Combi 5 RH, Japan). Between these periods, the subject constantly pedaled the bicycle ergometer at 50 rpm for 60 min with intensity of 40% \(V_{\text{O}_2}\) max. Air velocity was less than 20 cm/sec.

Measurements

The telometer of EKG monitor (DS-502, Fukudenshi) was used for recording the heart rate. In order to measure the skin temperature for seven sites of forehead, forearm, hand, trunk, thigh, leg, and foot were recorded continuously using thermistor probes throughout the experiment. Mean skin temperature (TsK) was calculated by using Hardy and DuBois’s equation (1938). Rectal temperature (Tre) was monitored continuously by the thermistor probe, which was inserted 12 cm above the anal sphincter. In order to determine the total sweat loss and dripping, the two independent bed balances (ID1 and ID1s, Mettler) which connected to the computer processing with an accuracy of 1 g were used throughout the experiment. Hence, evaporated sweat was calculated from the total sweat loss minus dripping. Respiratory water loss was not considered. The amount of sweats 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 located under the bicycle ergometer) for protecting the evaporating dripped sweat. 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 cm² 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 modified from Ohara’s method (1966). Blood pressure (BP) was recorded using a sphygmomanometer during rest, exercise, and recovery. According to Gagge’s method (1967), 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.

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Physical characteristics of subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter</td>
<td>Summer</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>21.3 ± 0.7</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>157.8 ± 4.1</td>
</tr>
<tr>
<td>BW (Kg)</td>
<td>53.55 ± 4.80</td>
</tr>
<tr>
<td>BSA (m²)</td>
<td>1.52 ± 0.07</td>
</tr>
<tr>
<td>BF(%)</td>
<td>22.2 ± 3.5</td>
</tr>
<tr>
<td>(V_{\text{O}_2}) max (l/min)</td>
<td>2.30 ± 0.39</td>
</tr>
<tr>
<td>Work load (Watts)</td>
<td>58.64 ± 11.05</td>
</tr>
</tbody>
</table>

BW = body weight, BSA = body surface area, BF=percentage of body fat, \(V_{\text{O}_2}\) max = maximal oxygen consumption. The data are mean ± SD. *p<0.05, **p<0.001; Significant difference between winter and summer.

Statistics method

The differences in physiological parameters between winter and summer were tested by paired-t-test. The differences were considered statistically significant when p<0.05.

Results

The same subjects were exposed to the hot-dry environment for 110 min in winter and summer. Table 1 showed that the body weights before the subjects were exposed to the hot-dry environment in winter and sum-
mer, respectively. Their body weights were significantly higher (p<0.05) in winter (53.55 ± 4.8 kg) than that in summer (52.33 ± 4.19 kg). Moreover, the percentage of body fat which was calculated from skinfold thicknesses was also significantly (p<0.001) higher in winter (22.0 ± 3.5%) than that in summer (19.8 ± 2.5%). Because of the changes in the body weight between seasons, body surface area (which calculated from DuBois and DuBois’s method) in winter (1.52 ± 0.07 m²) was also significantly (p<0.05) higher than that in summer (1.51 ± 0.06 m²). Moreover, the maximal oxygen uptake (V̇O₂ max) in winter (2.30 ± 0.39 l/min) was significantly lower than that in summer (2.44 ± 0.35 l/min). These may due to the reduction of body weight in summer. However, we used the same work load during exercise both in winter and summer.

Figure 1 showed the time course of changes in rectal temperature during rest, exercise, and recovery. At rest, Tre in winter and summer were 37.51 ± 0.23 °C and 37.46 ± 0.19 °C, respectively. During exercise, Tre in winter increased higher than that in summer, but their differences were not significant. Furthermore, after the exercise, Tre did not return to the resting level within 30 min, but still maintains in steady state until the end of the experiment. This results showed that the Tre was not influenced by seasonal factors.

During rest, Tsk in winter and summer are found to be 34.29 ± 0.99 °C and 34.82 ± 0.45 °C, respectively. There was not significant differences which was shown in Fig. 2. During exercise at 40th until 80th min, Tsk in winter was significantly lower (p<0.05) than that in summer, whereas Tsk during recovery did not differ in both seasons.

Figure 3 showed the changes in HR during rest, exercise, and recovery. The HR in winter (80.0 ± 8.8 beats/min) was significantly higher (p<0.05) than that in summer (71.2 ± 11.0 beats/min) at rest during exercise at 60th min. No significant differences were found in both seasons during the recovery.

At the end of experiment, the evaporated sweat in winter was 400.5 ± 42.2 g/m² while it was 410.7 ± 42.0 g/m² in summer. Even the evaporated sweat in summer was much more than that in winter, the significant seasonal difference was not found when the subjects were exposed to dry-heat for 110 min and performed exercise at the same relatively work load (Fig. 4). Moreover, the dripping sweat in winter and summer were 4.38 ± 3.52 g/m² and 6.69 ± 9.58 g/m² at the end of experiment, respectively. Although the dripping sweat in summer was higher than in winter, there was no significant differences in both seasons (Fig. 5). The ratio of the changes in total sweat loss to the changes in rectal temperature (sweat rate/ΔTrec) at the end of exercise in winter and summer were 330.2 ± 127.4 g/m² . °C⁻¹ and 330.8 ± 78.0 g/m² . °C⁻¹. The ratio of sweat rate/ΔTrec remained unchanged when compared between winter and summer.

Sodium concentration at the forearm and back sites were shown in Table 2. Sodium concentration at the forearm site was 103.12 ± 31.14 mEq/l and 158.35 ± 56.95 mEq/l during exercise (at 50th and 80th min), and 234.16 ± 115.36 mEq/l during recovery (at 110th min) in winter, while that was 68.51 ± 50.63 mEq/l and 79.74 ± 60.2 mEq/l during exercise (at 50th and 80th min) and 105.09 ± 83.61 mEq/l during recovery (at 110th min) in summer, respectively. There were significant differences in sodium concentration at forearm site at 80th and 110th min.

![Fig. 1](image.png)

**Fig. 1** Changes in rectal temperature during rest, exercise, and recovery in winter and summer. Values are means ± SD.
of experiments in both seasons (p<0.05). At the back site, sodium concentrations were 94.78 ± 25.49 mEq/l and 102.98 ± 34.61 mEq/l during exercise (at 50th and 80th min), and 106.83 ± 62.77 mEq/l during recovery (at 110th min) in winter, respectively. On the other hand those in summer were 50.65 ± 28.17 mEq/l and 55.95 ± 26.33 mEq/l during exercise (at 50th and 80th min), and 61.12 ± 42.44 mEq/l during recovery (at 110th min), respectively. There were significantly decreased (p<0.05) in sodium concentration in summer than that in winter throughout the experiment. Whereas, the local sweat volumes at forearm and back sites were not significant differences between the winter and summer seasons (Table 2). No correlation were observed between the local sweat rate and sodium concentration at forearm and back sites.

**Discussion**

There were numerous publications on seasonal variation of physiological responses of male during exercise in the environments, but remarkably few on female (Table 3). The result of different investigations may be due to
Fig. 4 Changes in evaporated sweat during rest, exercise, and recovery in winter and summer. Values are means ± SD.

Fig. 5 Changes in dripping sweat during rest, exercise, and recovery in winter and summer. Values are means ± SD.

Table 2 Sodium concentration and local sweat volume at forearm and back sites during exercise and recovery at 50th min, 80th min, and 110th min, respectively in winter and summer. The data are mean ± SD

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Summer</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Forearm</td>
<td>Back</td>
</tr>
<tr>
<td></td>
<td>50th min</td>
<td>80th min</td>
</tr>
<tr>
<td>Sodium conc.</td>
<td>103.1 ± 31.1</td>
<td>158.3 ± 57.0</td>
</tr>
<tr>
<td>(mEq/l)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local sweat vol.</td>
<td>8.6 ± 2.3</td>
<td>8.8 ± 4.2</td>
</tr>
<tr>
<td>(mg/12.4 cm²)</td>
<td></td>
<td></td>
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</tbody>
</table>

*p<0.05; Significant difference between winter and summer.
### Table 3. Seasonal variations of physiological responses during exercise in the hot environments

<table>
<thead>
<tr>
<th>Studies</th>
<th>age</th>
<th>sex</th>
<th>exercise &amp; intensity</th>
<th>duration &amp; acclimatized</th>
<th>temperature conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shapiro et al., 1981</td>
<td>22</td>
<td>male</td>
<td>treadmill, walk 1.34 m/sec</td>
<td>120 min &amp; A = 10 days</td>
<td>Ta=40 °C, rh=30% wind 1 m/sec</td>
</tr>
<tr>
<td>Araki et al., 1981</td>
<td>20</td>
<td>female</td>
<td>bicycle 483,981* kgn/min</td>
<td>120 min</td>
<td>Ta=30 °C, rh=60% wind 0.3 m/sec</td>
</tr>
<tr>
<td>Yasuda et al., 1983</td>
<td>-</td>
<td>male</td>
<td>bicycle 60 watts</td>
<td>60 min</td>
<td>Ta=30 °C, rh=70% wind 0.5-0.7 m/sec</td>
</tr>
<tr>
<td>Torii et al., 1985, 1991</td>
<td>30</td>
<td>male</td>
<td>bicycle 40% V₀₂ max</td>
<td>35 min</td>
<td>Ta=30 °C, rh=45% fan 1.5 m behind subject</td>
</tr>
<tr>
<td>Waree et al., 1994</td>
<td>20</td>
<td>female</td>
<td>bicycle 40% V₀₂ max</td>
<td>110 min</td>
<td>Ta=40 °C, rh=30% wind &lt; 0.2 m/sec</td>
</tr>
</tbody>
</table>

### Table 4. Thermoregulatory responses during exercise in the hot environments

<table>
<thead>
<tr>
<th>Studies</th>
<th>Tre</th>
<th>Tsk</th>
<th>HR</th>
<th>sweat rate</th>
<th>dripping sweat</th>
<th>sodium concentration</th>
<th>local sweat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shapiro et al., 1981</td>
<td>w&gt;s</td>
<td>w&gt;s</td>
<td>w&gt;s</td>
<td>s&gt;w</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Araki et al., 1981</td>
<td>w=s</td>
<td>w&lt;s</td>
<td>w=s</td>
<td>s&gt;w</td>
<td>-</td>
<td>s=w</td>
<td>-</td>
</tr>
<tr>
<td>Yasuda et al., 1983</td>
<td>w=s</td>
<td>-</td>
<td>w=s</td>
<td>s&gt;w</td>
<td>w=s</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Torii et al., 1985, 1991</td>
<td>w=s</td>
<td>w&gt;s</td>
<td>-</td>
<td>s&gt;w</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Waree et al., 1994</td>
<td>w=s</td>
<td>w&lt;s</td>
<td>w&gt;s</td>
<td>w=s</td>
<td>forearm scw</td>
<td>forearm w=s</td>
<td>back s&lt;w back w=s</td>
</tr>
</tbody>
</table>

A=acclimatized, w=winter, s=summer.

* Work rate is adjusted by their own ergometer and it is not comparable to the other bicycle ergometer.

The intensity and duration of exercise, and environmental conditions. It is indeed that the evaporative heat loss plays a major role in the cooling of the skin and blood during exposure to heat. In the present study, the evaporative sweat loss of female subjects during exposure in a hot environment and exercise with the intensity of 40% V₀₂ max did not differ in both seasons. Moreover, there were no significant differences in the dripping sweat in both winter and summers, and the evaporative cooling capacity per °C change in Tre were unchanged in both seasons. The reason of discrepancy from the other investigators may be due to followings. Firstly, the wide variations in individual sweat volume in the present study. Secondly, the lower of sweat rate in women may be related to a more efficient suppression of non evaporative sweat output (Weinman et al., 1967; Wyndham, 1965). Avellini et al. (1980) reported that the physically fit men and women who exposed in a chamber maintained at 36 °C dry bulb temperature and 30 °C wet bulb temperature, for 3 h (before and after acclimation to humid heat for 10 days) have the same rate of decline in sweat rate both before and after acclimation. However, the women began to demonstrate sweat depression at a significantly lower sweat rate than did the men. He suggested that this may be the women have a more sensitive feed back from the wetted skin surface to prevent excessive dripping of non evaporative sweat. Thirdly, most of the subjects have individual physical activities such as play badminton, aerobic dance, swimming, etc. in the present study. Saltin and Hermansen (1966) went on to suggest that in addition to exercise intensity, training status may also influence the degree of sweat loss during exercise. Fourthly, air movement is one of the important factors in enhancing heat dissipation during exercise and heat exposure (Candas et al., 1979; Torii et al., 1986). Nadel and Stolwijk (1973) reported that sweating rate was increased significantly in any given environment with a wind velocity of 2.2 m/sec compared to 0.1 m/sec. Many investigators (from Table 3) also used the air velocity much more than 0.2 m/sec which is in contrast with the present study. For this reason skin evaporation being in part due to air velocity should be taken into account. Fifthly; acclimatization, after a few day's exposure to a hot environment, the individual is able to tolerate the heat much better than when first exposed. This improvement in heat tolerance is associated with increased sweat production, a lower skin and body temperature, and a reduced heart rate (Wyndham, 1967). The increased sweat rate provides the possibility for a more effective cooling of the skin through the evaporative heat loss, and the re-
sultant lowered the skin temperature provides for a better cooling of the blood flowing through the skin. Sixthly; environmental conditions, Shapiro et al. (1980) reported that the men can tolerate in hot-dry condition better than hot-wet, in adversely with women can tolerate in hot-wet condition better than hot-dry. However, the sweat rate of male in dry heat is same as female (Frye and Kamon, 1983). However, the female still have less sweat rate than men. Araki et al. (1981) found that there was no significant differences of the total body sweat rate between trained and untrained women who worked with the intensity 483 and 981 kgm/min for 2 h in hot-wet condition (Ta = 30 °C, rh = 60%, air velocity 0.3 m/sec) in either summer or winter. However, the total sweat rate of both groups in summer were much more than that in winter. In contrast with his study, the total sweat rate of untrained female was unchanged by the seasonal variation in hot-dry condition. Therefore, the effect of hot-dry and hot-wet conditions influenced by seasonal variation will be investigated for the further study.

Some investigators (Ohara, 1966; Hori et al., 1974), reported that sweat rate is higher and salt concentration in sweat was lower in summer than in winter. The seasonal variations in sodium concentration in local sweat observed in the present experiment were consistent with those reported by other workers.

The seasonal variations in sweat chloride content may be thought as due to seasonal changes in adrenocortical activity and sweat chloride is controlled by the salt reabsorption activity. The salt concentration in sweat is one of the most reliable index of heat tolerance (Kuno, 1956). He reported that thermal sweating is induced essentially by nervous action while during exercise sweat secretion is caused largely by a humoral process due to adrenalin discharge. It is a fact that the reduction in sweat chloride is a more reliable sign than the increase in the rate of sweating for indicating the tolerability of man to heat seems to be natural, since it may be presumed that the adrenocortical hormones act not only the sweat glands, but also on other organs important for tolerance of the body to heat. Furthermore, Nose et al. (1988) investigated the influence of [Na+] in sweat on the distribution of body water during dehydration in 10 volunteer subjects who exercised with intensity of 40% Vo2 max in the heat (Ta = 36 °C, rh < 30%) for 90-110 min. He found that the decrease in the intracellular fluid (ICF) space was correlated with the increase in plasma osmolality. The increase in plasma osmolality was a function of the loss of free water, which is analogous to "free water clearance" in renal function, showed a strongly inverse correlation with [Na+] in sweat. Fluid movement out of the ICF space attenuated the decrease in the extracellular fluid (ECF) space. Then he suggested that the maintenance of circulating blood volume during dehydration induced by exercise in the heat is a function of the body's ability to mobilize fluid from the ICF space, which itself is linked to the sodium concentration in sweat.

Less increase in rectal temperature in summer may be reflect such an increased evaporative heat loss caused by more profused sweating with a lower sodium concentration in the sweat and a prompt sweat reflex in summer. Indeed, it is well known that the shortening of the latent period for sweating reflex and a higher sweat rate accompanying a lower body temperature are observed when unacclimatized subjects repeatedly exposed to a hot environment (Dill et al., 1938). This finding agrees with our result, whether the rectal temperature were not difference in both seasons, but it showed the tendency to increased much more than that in summer during exercise at the same work load.

Heart rate and rectal temperature decreased and sweat rate increased in summer than in winter under the same heat stress (Williams, 1967). Araki et al. (1981) found that Tre in winter was lower than that in summer during exercise at 483 kgm/min while Tsk and HR in summer showed higher than these in winter. Whereas other researcher (Yasuda and Miyamura, 1983) did not find any changes in HR and Tre excepting sweat rate. In our study, HR also showed the significantly decreased in summer than in winter whereas Tre showed slightly decreased but were not differences between the seasons. This may be concerned with the intensity and duration of exercise (Araki et al. (1981), 483 kgm/min, for 2 h; Yasuda and Miyamura (1983), 60 watts, for 1 h) on the environmental condition.

In conclusion, the sweating responses of female did not affect by seasonal variations excepting sweat chloride contents under a dry heat condition.

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