Seasonal Variation of Trace Element Loss to Sweat during Exercise in Males

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Abstract

Objective: To clarify the seasonal differences of the trace element excretion in sweat, the trace element concentrations in sweat and their loss during exercise were compared between summer and winter.

Methods: Sweat samples were collected from ten healthy adult males. Bicycle ergometer exercise was conducted by each subject at a heart rate of 140 beats/min for 1 hour, in summer and in winter. Sweat was collected by the arm bag method.

Results: Concentrations of major (Na, K, Ca, and Mg) and trace elements (Zn, Cu, Fe, Ni, Mn, and Cr) in sweat tended to be lower in summer than in winter, and significantly lower concentrations of Mg ($p<0.01$), Na, Cu, and Mn ($p<0.05$) were found in summer. The sweat volume in summer (0.90 L) was 1.7-fold larger than that in winter (0.52 L) ($p<0.01$). The amount of loss of each element to sweat calculated from the concentrations in sweat and sweat volume showed no significant difference between summer and winter.

Conclusions: It is suggested that there was no significant difference in the amount of loss of trace elements in sweat due to exercise between summer and winter.

Key words: trace element, major element, sweat, exercise, seasonal variation

Introduction

Some trace elements such as iron (Fe), zinc (Zn), and copper (Cu) are essential minerals, performing important roles in regulating the whole body metabolism including energy utilization and work performance (1). Their excessive intake causes toxic symptoms, and insufficient intake induces deficiency symptoms (2). Recent studies have shown Fe, Zn, and Cu concentrations in blood flow and blood cells at lower levels (3–9) in athletes. A possible cause of these deficiencies is excessive loss of such trace elements that are indispensable to the body. We previously reported the amount of trace element loss during heat exposure, suggesting that the disappearance of trace elements associated with sweating induces trace elements deficiencies (10). However, the amount of trace element loss to sweat during exercise has not been adequately studied.

Sweat concentrations of major elements such as sodium (Na) and chlorine (Cl) were reported to differ among seasons. Their concentrations are lower in summer when acclimation to heat

occurs (11). Therefore, there is a possibility that the concentrations of trace elements in sweat and their loss differ among the seasons. As for the behavior causing sweating, physical exercise is common in daily life. Exercise in the summer may cause a larger loss of trace elements than that in winter.

In this study, we examined the concentrations and loss of trace elements in sweat due to exercise in summer and in winter in order to evaluate their seasonal difference.

Materials and Methods

Subjects and experimental design

The subjects were 10 healthy male graduate students belonging to the Nippon Sport Science University, Graduate School [age: 23.3 ± 1.3 yrs, (mean $\pm$ SD), height: 173.2 ± 3.3 cm]. They had not trained physically for at least 2 years. Body weight was not significantly different between summer (70.49 ± 6.05 kg) and winter (69.91 ± 6.69 kg). Table 1 shows the physiological characteristics of the subjects.

They were given a detailed explanation of this study, and informed consent was obtained from all of the subjects. The exercise protocols, performed in the morning after an overnight fast, consisted of 60-min work periods on a bicycle ergometer (Combi, Tokyo) at a heart rate of less than 140 beats/min, in summer between early August and early September (ambient temperature: $28.3\pm0.9^\circ\text{C}$, relative humidity: $70.3\pm5.5\%$) and in winter between

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Table 1 Physical characteristics and whole sweat volumes

	Mean±SD	Range
Age (yr)	23.3±1.3	22–26
Height (cm)	173.2±3.3	166–179
Maximal oxygen uptake (ml · min ⁻¹ · kg ⁻¹)	45.3±5.6	42.5–52.0
Summer		
Before exercise weight (kg)	70.49±6.05	58.70–80.83
After exercise weight (kg)	69.60±6.12 ^a	57.35–80.04
Sweat volume (L)	0.90±0.22	0.62–1.35
Winter		
Before exercise weight (kg)	69.91±6.69	59.01–82.72
After exercise weight (kg)	69.39±6.70 ^a	58.37–82.18
Sweat volume (L)	0.52±0.09 ^b	0.40–0.64

^a p<0.01, significant difference vs. before exercise weight^b p<0.01, significant difference vs. sweat volume in summer

late January and early February (18.6±0.7°C, 61.3±5.7%), respectively. Subjects were weighed immediately before and after exercise (HW-100; A&M, Tokyo). Whole body sweat volume during exercise was estimated as the loss of body weight due to exercise. Sweat was collected in a polyethylene arm bag (circumference, 50 cm; length, 80 cm) from the non-dominant arm of each subject (12). The arm was scrubbed with surfactant (Sunny safe; Daiichi Kogyo Yakuhin, Kyoto), rinsed copiously with distilled water, and dried by evaporation before exercise. Heart rates were continuously recorded by a heart rate monitor (Canon, Tokyo).

Determination of major and trace elements

Sweat samples were centrifuged (1,000×g, 10 min). The supernatants were filtered through a 0.45 µm Millipore micro-filter. Samples were frozen and stored at -20°C for later analyses. Sweat samples were diluted with 0.5% nitric acid solution. Fe, Cu, Zn, nickel (Ni), manganese (Mn), chromium (Cr), Na, potassium (K), calcium (Ca) and magnesium (Mg) were determined by microwave induced plasma-mass spectrometry (P-7000; Hitachi, Tokyo) (13).

Statistical analyses

Statistical analyses were performed using the Halbau statistical package (Gendaiigakushoin, Kyoto). Values are expressed as mean and standard deviations. The paired Wilcoxon test was used to compare the values between summer and winter in the major and trace elements, and the paired t-test was used for body weight and work load. The level of significance was defined as p<0.05.

Results

Sweat volume and heart rates

The body weight decreased significantly after exercise in both seasons, but the loss of weight, which we used as whole body sweat volume, in summer was 1.7-fold larger than that in winter (p<0.01) (Table 1).

Fig. 1 shows the changes in heart rates and work load during exercise. During exercise, heart rates increased with time and were 137.8±7.0 beats/min in summer and 134.7±8.0 beats/min in winter immediately before the end of exercise; no significant difference was observed in the heart rates during exercise between summer and winter.

The work load at the last stage of exercise in summer was

Fig. 1 Changes in heart rates and work loads during exercise in summer and winter.

** p<0.01, significant difference vs. summer.

significantly lower (p<0.01) than that in winter. In addition, the work load from 20 minutes of exercise to the end of exercise was significantly lower (p<0.01) in summer than that in winter (Fig. 1).

Major and trace element concentrations in sweat

Fig. 2 shows the concentrations of major elements in sweat. These values tended to be higher in winter than in summer, and significantly higher Na (p<0.05) and Mg (p<0.01) concentrations were found.

Fig. 3 shows the trace element concentrations in sweat. Both major and trace element concentrations tended to be higher in winter than in summer, and significantly higher concentrations were observed in Cu (p<0.05) and Mn (p<0.01).

Amounts of trace element loss in sweat

Fig. 4 shows the amounts of trace element loss in sweat. The amount of loss of each element was calculated from the concentration in sweat and the whole sweat volume. None of these values showed any significant difference between summer and winter.

Fig. 2 Major elements concentrations in sweat during exercise in summer and winter.

* p<0.05, ** p<0.01, significant difference vs. summer.

Fig. 3 Trace elements concentrations in sweat during exercise in summer and winter.

* $p < 0.05$, ** $p < 0.01$, significant difference vs. summer.

Fig. 4 Amounts of trace elements loss in sweat during exercise in summer and winter.

Discussion

No difference was observed in the heart rate during exercise between summer and winter. Therefore, the degree of the body burden during exercise may be similar in both seasons. In summer, a decrease in physical performance due to heat has been reported (14). The exercise intensity from 20 minutes of exercise to the end of exercise in summer was significantly lower ($p < 0.01$) than that in winter, showing a decrease in performance in summer compared with winter.

During exercise, sweating increases (15), and major elements such as Na and Cl are lost (16, 17). In this study, the major element concentrations in sweat during exercise were similar to the previously reported values (16, 17). The concentrations of trace elements discharged from the body during exercise in this study were similar to those during heat exposure (11). In addition, Arouma et al. (18) reported concentrations of Fe, Cu, and Zn in sweat during exercise at 80% VO_2 max for 30 min and 40 min, with which the concentrations of Fe, Cu, and Zn in the sweat obtained in the present study agreed.

It was reported that the concentrations of major elements in sweat are lower in summer than in other seasons, due to adaptation to high temperatures and heat (10). In the present study, the major element concentrations in sweat were lower in summer than in winter, the difference being significant for Na ($p < 0.05$) and Mg ($p < 0.01$).

Tipton et al. (19) reported that there was no significant differences in the loss of Zn due to exercise between 25°C and at 35°C, because the concentration of Zn in the sweat at the exercise of 70–75% VO_2 max for one hour was lower at 35°C than at 25°C, but the amount of sweat was about two times larger at 35°C than at 25°C. Mary & Haymes (20) also reported no difference in the loss of Fe by sweating during exercise between 25°C at 35°C, because the concentration of Fe in the sweat while exercising at 50% VO_2 max for one hour was lower at 35°C than at 25°C but the quantity of sweat was larger at 35°C than at 25°C. These findings suggest that there were no differences in the loss of trace elements from the body due to exercise at different temperatures, because the concentrations of trace elements in the sweat were low under exposure to a hot environment. However, the amount of sweat in the hot environment was large. In the present study, the concentration of trace elements in the sweat tended to be lower in summer than in winter, and the concentrations of Cu and Mn were significantly lower ($p < 0.05$ and $p < 0.01$, respectively). In the present study, exercise was performed at a heart rate of less than 140 beats/min. It has been suggested that the amount of sweat generated is proportional to the work load (15). Since the work load was significantly lower in summer than in winter, the amount of sweat in summer was suggested to be smaller than that generated by exercise at the same load in winter. However, the amount of sweat in summer (0.9 L) was about 1.7-fold that in winter (0.52 L). Therefore, there were no significant differences in the loss of any of the examined trace elements between summer and winter. These results agreed with the results of Tipton et al. (19) and Mary & Haymes (20) in which there were no differences in the loss of Zn and Fe by sweating during exercise at the same load between neutral (25°C) and hot environments (35°C).

There are two types of sweat glands; the eccrine and apocrine sweat glands. The eccrine sweat glands perform the physiological role of sweating. They consist of secretory ducts and excretory ducts. In the secretory cells of the secretory ducts, precursor sweat is produced, reabsorbs many elements during its passage through the excretory ducts, and is secreted onto the skin surface as sweat (21). In summer when acclimation to heat occurs, reabsorption of major elements in the excretory ducts increases, and therefore the major element concentrations in sweat are low in summer (10). It is suggested that the reabsorption of trace elements in the excretory duct is also enhanced, resulting in the concentrations of trace elements in the sweat being lower in summer than in winter.

Mary & Haymes (20) also reported that the lower concentration of iron in the sweat under hot conditions compared with under neutral conditions may be caused by dilution with sweat, whose amount was greater than twice as large under the former condition than under the latter condition. In the present study, since the amount of sweat was about 1.7-fold greater in summer than in winter, the low concentration of trace elements in summer would be diluted by the large quantity of sweat. The sweat samples examined in the present study were collected using arm bags. It was reported that since vapor derived from sweat is saturated in the arm bag worn for a long time, possibly preventing the evaporation of sweat, hydromeiosis is likely to occur (21). Hydromeiosis, which is more likely to occur in summer than in winter due to a larger amount of sweat, would affect the concentration of trace elements in the sweat.

Conclusions

Major elements, Na, K, Ca, and Mg, and trace elements, Fe, Zn, Cu, Mn, Cr, and Ni, were discharged from the body with sweat during exercise. The values in the sweat were lower in summer than in winter. The loss of elements is determined by their concentration in sweat and the amount of sweat. Since the amount of sweat was about 1.7-fold larger in summer than in winter, it is

suggested that there were no significant differences in the loss of trace elements due to sweating between summer and winter.

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