

EFFECTS OF EXTENDED-TERM EXERCISE ON
THERMOREGULATION IN FEMALES

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ABSTRACT

Thermoregulatory responses to heat have been evaluated at rest in 27 university students: 11 female competitive athletes, 8 male non-athletes, and 8 female non-athletes. They rested for 2 hrs at ambient temperature of 32°C, 40 rh with legs immersed up to knees in a stirred water bath of 42°C. Total sweat volume of the female athletes was higher than the female non-athletes, but lower than the male non-athletes. Core temperature threshold for sweating was significantly lower in the female athletes than in the male and female non-athletes. The slope in sweat rate/core temperature relationship of the female athletes was not distinctly steeper than that of the female non-athletes. The thermoregulatory responses observed in the female athletes are thought to be comparable to those produced by heat adaptation. Comparing the heat responses in male and female non-athletes, no distinct sexual differences were observed in the rise in core temperature, mean skin temperature and the core temperature threshold for sweating. On the other hand, the slope in sweat rate/core temperature relationship was steeper in males than in females. The beneficial modifications of heat responses demonstrated in the present study in female athletes are similar to those observed in male athletes.

In many of the studies made upon thermoregulatory responses in women at rest (2,8,14) or during work (4,11,22), it has been reported that women have lower sweat rates, higher core temperature threshold for sweating and a greater rise of core temperature during heat exposure than men. Accordingly, these results have led to the prevalent opinion that women are less able to cope with

heat stress than men. However, some recent studies (3,18) have reported that physically fit women apparently can accomplish a work task as well as men in hot environments with lower body temperatures. This may suggest that apparent sex differences are, to some extent, related to some variables other than sex per se, and may be at least in part due to differences in physical fitness. Comparison of male and female thermoregulation during exercise is complicated by sexual differences in some factors such as maximal aerobic ability, muscular power, body fat, etc. Although most of the recent studies of sex differences have involved exercise in heat, studies at resting conditions may have benefit in avoiding the problems in equating work as $\dot{V}_{O_2 \text{ max}}$.

Only a few studies have been made in man employing resting conditions to evaluate the adaptive changes of thermoregulatory responses due to relatively strenuous exercise trainings (1,10). The purpose of the present study was to compare the thermal and cardiovascular responses of physically trained females with those of non-athlete male and females during rest in a hot environment.

MATERIAL AND METHODS

Eleven female athletes (FA), 8 male non-athletes (MNA), and 8 female non-athletes (FNA) from an university volunteered for this study, whose characteristics appear in Table 1. In this study, athletes had participated in endurance type sports (distance running and basketball) for many years usually 2 hrs daily, and non-athletes were those who had not regularly participated in any vigorous physical activity. Rectal temperatures of some subjects were measured with clinical thermometers after their work bouts in June and they ranged between 38.1 and 38.8°C. Prior to the experiments $\dot{V}_{O_2 \text{ max}}$ was determined by increasing the break load 150 kpm/min every 2 min baseline of 300 kpm/min until the subject was unable to maintain the pedalling rhythm of 50 rpm. ECG was monitored continuously throughout the test.

All experimental sessions were conducted between 0800-1100. Upon arrival at the laboratory at 0730 in a post absorptive state, each subject was weighed nude, a rectal thermocouples and ECG electrodes were then attached. In addition, two sweat capsules were attached which covered 12.6 cm² skin area as previously reported (17), one on the chest (above nipple) and one on the back (above the scapula), to collect sweat samples at intervals of 20 min. Thereafter, the subjects entered the climatic chamber which had been set a 28°C; and 40% rh. All base-line data were taken at the end of one hour in the sitting position. The temperature of the chamber was then rapidly raised to 32°C (the target Ta reached within a few minutes), while subject's legs were immersed to the knee in a stirred water bath at 42 + .5°C.

Table. 1 Physical characteristics and work capacity of subjects

Group	Age, yr	Ht, cm	Wt, kg	BSA, m ²	$\dot{V}_{O_2 \text{ max}}$ ml/kg min ⁻¹
FA (N=11)	20.8(1.5)	158.8(3.9)	55.0(3.6)	1.56(0.06)	48.2(3.6)
FNA (N=8)	20.5(1.8)	158.9(6.9)	52.6(10.8)	1.53(0.17)	38.4(3.0)
MNA (N=8)	19.8(1.0)	168.1(5.0)	59.8(11.5)	2.03(0.16)	44.1(2.4)
Significance of Differences					
FA vs FNA	NS	NS	NS	NS	<0.001
FA vs MNA	NS	<0.05	NS	<0.01	<0.001
FNA vs MNA	NS	<0.05	NS	<0.01	<0.001

Values are means ± (1 SD)

Oral temperature (T_{or}) was measured by a copper-constantan thermocouple located under the tongue. The skin temperatures were measured at 3 sites (chest, upper arm, and thigh) and mean skin temperature (\bar{T}_{sk}) was calculated by standard procedures (20). Sweat rate (SR) was monitored by weighing the filter paper discs (17) in the capsules, and an average of the chest and back samples was computed. The total sweat loss was calculated by weighing nude on a platform balance (accuracy + 5g). No correction was made for respiratory weight loss. Oral and skin temperatures were continuously monitored by multichannel recorder (Okura Type) during pre-exposure and during the 2 hr heat-exposure period. Sweat onset was determined on the forearm using a starch-iodine method (21).

The analysis of variance was used to test for statistical differences among the means. Furthermore, the Scheffe test was applied for determination of the significance of the mean difference between any two variables. A $P < 0.05$ was accepted to imply significance in this study.

RESULTS

Fig. 1 shows the mean T_{or} , \bar{T}_{sk} and SR of the three groups during the 2 hr exposure. Group differences for all pre-exposure parameters were in significant. At the 30 min of the exposure, T_{or} of FA was significantly lower ($P < 0.05$) than those of MNA and FNA, and continued lower throughout the exposure. However, no significant differences were seen between MNA and FNA throughout the 2 hr heat exposure. No differences in \bar{T}_{sk} were observed between sexes as well as fitness levels.

Total sweat loss for FA, MNA, and FNA is presented in Table 2. The rate of FA and FNA compared to MNA was 90 and 71%, respectively. The difference was significant between the two non-athlete groups ($P < 0.01$). In addition, the sweat loss of FNA was 79% of the rate of FA, and this difference was significant as well ($P < 0.05$).

The mean of the threshold T_{or} for sweating measured by the starch-iodine method was presented in Table 3. The threshold temperature for sweating in FA was significantly lower ($P < 0.01$) than the values for FNA and MNA. On the other hand, sweat rate measured by the sweat capsules at a given T_{or} for the three groups is presented in Fig. 2. In this figure individual values of sweat rate before sweat suppression had occurred, were plotted against given T_{or} . The SR/ T_{or} relationship line was then obtained in each group. As the result the slope of the relationship line for MNA was steeper than for either FA or FNA. In addition, the line for FA was placed as if it shifted toward the left (lower T_{or}) from the line for FNA.

Table. 2 Total sweat loss, $g/m^2 \cdot hr$

	F A	F N A	M N A
F A	200.5 (36.4)	$P < 0.05$	N S
F N A		157.8 (32.3)	$P < 0.01$
M N A			223.6 (51.7)

Values are mean \pm (1 S D)

Table. 3 Threshold T_{or} for sweat onset ($^{\circ}C$)

	F A	F N A	M N A
F A	36.92 (0.29)	$P < 0.01$	$P < 0.01$
F N A		37.33 (0.24)	N S
M N A			37.32 (0.26)

Values are mean \pm (1 S D)

The mean values of control HR's were 64+7, 73+11, and 74+9 bpm for FA, FNA, and MNA, respectively. However, none of the values in the three groups were significantly different from each other. The corresponding values at 120 min of the exposure were 85+9, 100+14, and 100+10 bpm, respectively. The differences between FA and other two groups were significant ($P < 0.01$). The time-course changes in HR of the three groups are illustrated in Fig. 3.

DISCUSSION

The results show differences in thermoregulation between athletic and sedentary females. The core temperature threshold for sweating was lowered by 0.4°C in FA compared to FNA as well as MNA. The results also show that the sweat rate corresponding to an identical core temperature (Fig. 2) is generally higher in FA than in FNA. The characteristics of the thermoregulatory responses observed in the athletes could be ascribed to the effects of daily heavy exercise, inducing metabolic hyperthermia. The observations described above are in agreement with the reports of the previous studies (1,10) in which male distance runners, cross country skiers, and competitive swimmers have been tested. In recent studies (10,12,16) threshold core temperatures for sweating were decreased as untrained male subjects became adapted to exercise, and the investigators attributed the reduction to the repeated rise of body temperature due to exercise which might act as an effective internal stimulus for development of central adaptation to heat stress. The difference of the threshold temperature for sweating (0.4°C) between FA and FNA obtained in the present study is in the same order of that (0.3°C) observed by Nadel *et al.* (16) in acclimation by exercise in heat. Baum *et al.* (1) have also reported a difference of 0.3°C of threshold core temperature for sweating between male distance runners and male non-athletes. Thus it appears that in females, too, daily heavy prolonged exercise produced modifications in sweating mechanisms which resemble those produced by heat acclimation.

Nadel *et al.* (16) suggested different mechanisms underlying the sweating responses between exercise and heat acclimation. According to them physical training resulted in an increase in the slope of the sweat rate/ T_{CORE} relationship as well as in a reduction of the core temperature threshold for sweating. However, heat acclimation when given after physical training produced a further decrease in T_{CORE} threshold for sweating due to the parallel shift to the left of the sweat rate/ T_{CORE} relationship line in men. However, in the present study, it was observed in FA, as compared to FAN, that the threshold temperature for sweating was lowered, but the slope of SR/ T_{OR} did not increase distinctly (Fig. 2). Henane *et al.* (10) also observed a parallel shift to the left of the relationship line representing of evaporative rate/ T_{RE} in three male subjects after physical training.

Compared with male subjects who are sedentary, FA are superior in temperature regulating responses to heat stress, showing the following characteristics; a reduction in sweating threshold (Table 2), a higher SR for a given core temperature up to about 38°C (Fig. 2), lower core temperatures during heat stress (Fig. 1), and an attenuated heart rate response (Fig. 3). These results are in agreement with those reported by Weinman *et al.* (22) and Paolone *et al.* (18), who observed lower HR and T_{RE} in physically fit females than in males performing a standard submaximal or the same relative submaximal exercise. In the present study although threshold temperature of

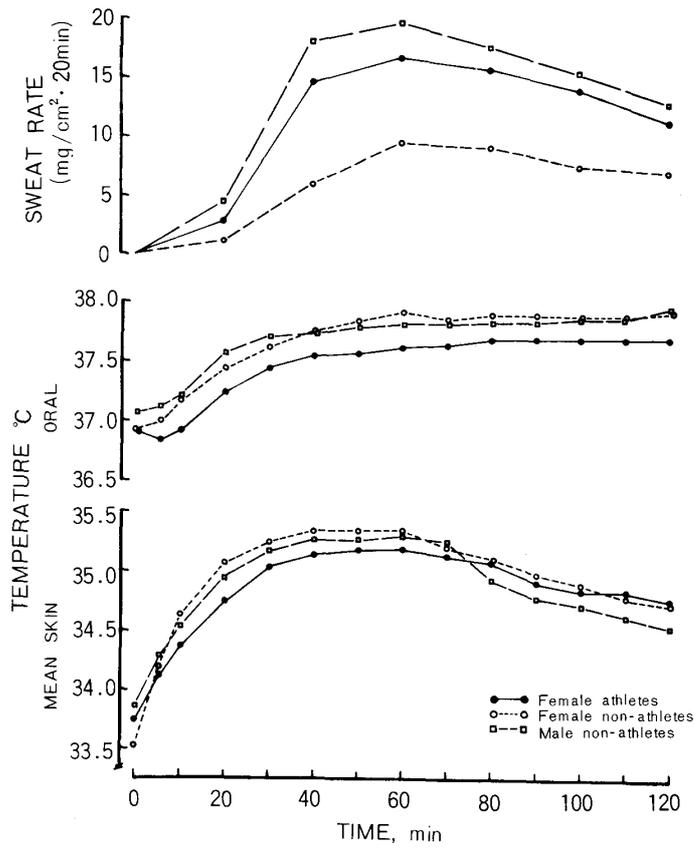


Figure 1. Means of sweat rates, oral temperatures, and skin temperatures of three during 2 hr of rest in heat.

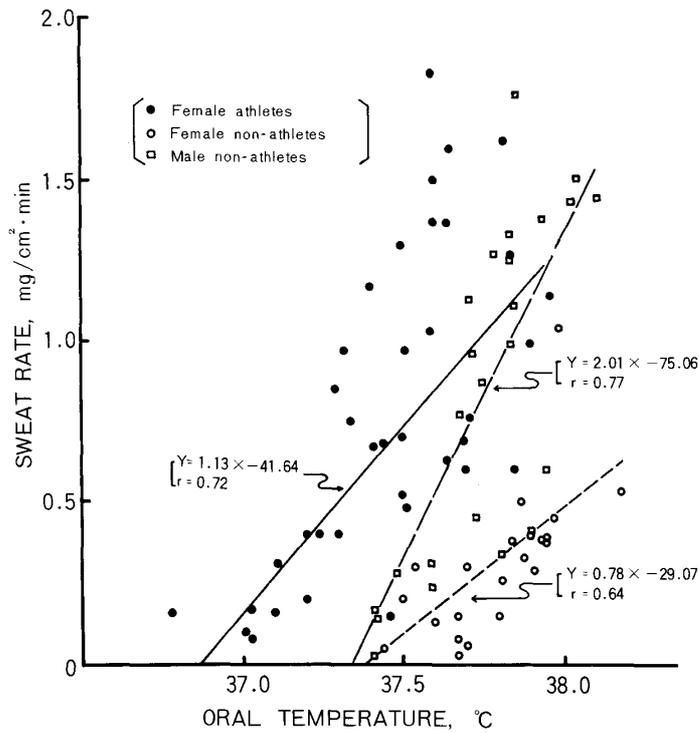


Figure 2. Sweat rate as a function of oral temperature in three groups.

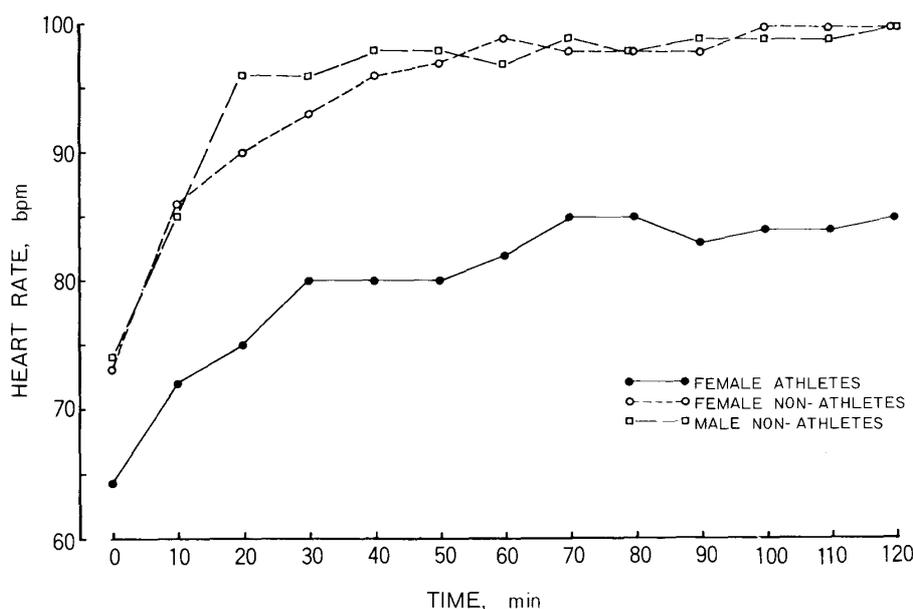


Figure 3. Means of heart rates of three groups during 2 hr of rest in heat.

sweating was lower in FA than in MNA, the slope of the SR/T_{OR} regression line was greater ($P < 0.01$) in MNA than in FA. Such a steeper slope or a relatively higher sweat rate at any given core temperature of males as compared to females has been frequently observed in previous studies (2,7,14,20). An increase in this slope has previously been reported in physically trained males compared to untrained ones (10,16,19). Such steeper slope of the SR/T_{CORE} relationship line in males than in females may be due to sexual differences. In addition, total sweat output of FA increased by 27% from FNA, but was still lower by 10% than that of MNA. A probable explanation of the aforementioned point could be related to sex differences in the distribution (density) of sweat glands in the skin as well as in the secretory capacity of the individual sweat glands relating to the glands size, though available data on this point is lacking. In this regard, Morimoto et al. (15) have speculated that sweat glands of men can maintain higher sweat flow than can do those of women when they are exposed to dry heat.

As mentioned previously, there are large discrepancies and uncertainties in results obtained about the sexual differences of temperature regulation. A prevalent conception is that females are inferior to males in terms of sweating efficiency, as indicated by a higher sweat threshold, greater rise of body temperatures, and a lower sweat output (2,3,5), although some investigators (4,6,12) concluded that proper corrections for body size and metabolic rate eliminate any meaningful differences. In the present study differences were observed in the thermoregulatory response between MNA and FNA; a greater sweat loss (weight loss) and a steeper slope of the SR/T_{OR} relationship in male subjects. Responses of body temperatures to heat stress were essentially similar. In addition, no difference was observed in sweat threshold between MNA and FNA. These results confirm the study made on resting subjects of both sexes (9). Since not only the response of \bar{T}_{sk} during heat exposure, but also internal temperature (T_{OR}) of FNA were similar to those of MNA in this study, as well as in a previous study (9), sweating in females with lower sweat rates may be considered as an increased efficiency of sweating in this sex dissipating heat by evaporation.

A more precisely regulated and economical sweat output in females than in males has been postulated by some investigators (14,15,22). However, FA in the present study showed greater sweat output with lower body temperature. Consequently, more studies are required to clarify these findings.

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長期間の運動鍛練が女子の 体温調節に及ぼす影響

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〈要 約〉

本研究は暑熱ストレスに対する体温調節応答についての男女差、および、長期間にわたって高度に鍛練された女子スポーツ選手の応答について検索した。

合計27名の大学生被検者〔運動鍛練女子(F A) 11名, 非鍛練女子(F N A) 8名, 非鍛練男子(M N A) 8名〕が本実験に参加した。ここでいう運動鍛練者とは、過去5ヶ年以上、持久的なスポーツ種目に参加しているスポーツ選手であり、非鍛練者とは、定期的に身体トレーニングの場に加わっていない者をいう。

暑熱ストレスの条件は、被検者が椅座安静位で、温度42℃の水槽中に両脚を浸し(水面が膝の高さまでくるように調節する)、室温32℃(湿度40%)に2時間暴露されるものであった。深部体温として舌下温(Tor)を用い、発汗開始の閾値体温を測定するために、前腕部にヨード澱粉を塗布してその反応を用いた。総発汗量は、暑熱暴露前後の体重(ヌード)減量から求め、発汗速度は大原カプセル法を用いて測定した(胸部と背部)。

Torは時間の経過とともに上昇するが、両非鍛練群間に差はなかった。しかしF AのTorは、暴露30分ですでに他の2群より有意に低くなった。発汗量の最っとも大きいのはM N Aで、つぎにF A、もっとも小さいのがF N Aであった。また暴露時の心拍数の変動では、両非鍛練群の

値がほぼ同じで、F Aの心拍数は有意に低くなった。F Aの発汗閾値体温はF N A, M N Aより0.4℃低かった($P < 0.01$)。つぎに発汗速度を縦軸に、Torを横軸にとって、単位Torあたりの発汗速度(SR)をプロットして得たSR/Tor関係直線では、M N AがF AおよびF N Aよりも有意に急峻となり、F AとF N A間には有意差が認められなかった。しかし、F Aの関係直線は、F N Aより左方向(低体温)にシフトされた格好を呈した。

鍛練者の発汗閾値体温が非鍛練者より低くなったのは、暑熱ストレスに対する中枢性の温度適応と考えられ、このことが、暴露中の体温上昇を他の2群よりも有意に低くおさえるのに働いたものと思われる。そして、このような温度適応は、四季を通じて、激しい身体運動による熱産生(冬季でも、体温が39℃に上昇することもある)からくる暑熱ストレスへの適応結果であろう。非鍛練の男女群の深部体温に有意差が見られないのに、男子群の発汗量が女子群より有意に多いのは、女子の方が効果的な発汗をしていると考えてもよい。ところが、女子鍛練群の発汗量は、非鍛練の女子群より多くなっているために、この問題はさらに検討されねばならない。SR/Torの関係直線の勾配を比較すると、F AとF N Aには差が現われないが、男子の直線は女性鍛練者よりも有意に急峻である。発汗開始温度が同一とすれば、SR/Tor関係直線の勾配の急峻の方が、単位深部体温あたりの発汗

量が大きいことを意味するものである。このことは、男子の汗腺の分布が女子よりも多く、また個々の汗腺の発汗能力が男子において大きい、という生得的な要因にもとづくものと思われる。

本研究の結果、長期間にわたって高度に鍛練された女子スポーツ選手は、暑熱ストレスに対

して、①低い深部体温、②低い発汗開始閾値温、③相対的に単位深部体温あたりの大きな発汗量、④循環系に対する小さな負担度、などの応答を示し、鍛練されない男子よりもすぐれた体温調節機構を備えているといえよう。

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