TERMINAL PROGRESS REPORT

ON

NATIONAL INSTITUTE FOR OCCUPATIONAL SAFETY AND HEALTH

Grant No. 5 R01 OH 00896-08

PHYSIOLOGICAL ADAPTATION OF WOMEN TO HEAT STRESS

by

Barbara L. Drinkwater

Principal Investigator

Steven M. Horvath

Co-Principal Investigator

Work performed May 1, 1979 through October 30, 1982*

*Six month no-cost extension approved.

A. Background

The thermoregulatory response of older adults to exercise in hot environments has generally been shown to be inadequate to meet the demands of both metabolic heat production and the thermal load imposed by the ambient conditions (10, 11, 20, 27, 35). As morbidity and mortality rates during periodic heat waves can attest, older individuals are more at risk in the heat even without the additional stress of physical activity (32). Two factors have been suggested to explain the apparent effect of aging on heat tolerance. Some investigators (17, 18, 35) suggest that a decrease in the sensitivity and/or capacity of the sweating mechanism is responsible. Others (5, 7) link the problem to a decrease in aerobic power with age, implying that an inadequate cardiovascular response, not inadequate sweating, is the causative factor.

Recent studies (10, 11) from our laboratory have shown that age alone is not a valid predictor of tolerance to heat stress. Women of any age can, and do, react to acute exposure to high ambient temperatures with signs of physiological strain; a high heart rate, a substantial decrease in stroke volume, and a rising core temperature. Regardless of age, women with high levels of cardiovascular fitness ($\dot{V}_{O_2\ max}$) are better able to cope with acute exposure to heat stress (8, 10). It appeared that the fit woman was better prepared to tolerate the stress because her cardiovascular system could meet the competing demands for muscular and peripheral blood flow while maintaining an adequate venous return to the heart (8, 10). Since cardiovascular fitness has been

shown to decrease with age (19, 23), aerobic power must be included as an independent factor in any study designed to examine the effect of age on thermoregulatory response.

The precise mechanism whereby a high aerobic power enhances an individual's tolerance to heat stress is not known, but highly trained endurance athletes do appear to be partially acclimatized to heat (1, 9, 19, 22, 29). Wyndham et al. (36) and Senay et al. (26) have suggested that expansion of plasma volume early in heat acclimatization stabilizes the central circulation. Later in the acclimatization process, when blood volume has returned to initial levels, the acclimatized individual is able to expand blood volume rapidly when re-exposed to heat stress by shifting protein into the vascular space (25). The responses of highly trained women fit this hypothesis in some respects (9). Unlike fully heat-acclimatized individuals, they had the higher-than-average plasma volumes usually found in endurance athletes (4), but they were also able to shift twice the amount of protein into the vascular space than were a control group while performing light work (30% $\dot{V}_{O_2\ max}$) in a hot, dry environment. Both factors could have accounted for their greater cardiovascular stability. However, there is also the possibility that they required less blood flow to the working muscles, a recognized effect of physical training (3, 16, 33, 34), and thus did not have to deplete the central blood volume to the same extent as the non-trained females.

The response of the sweating mechanism may also be a factor. An earlier onset of sweating in the trained individual would keep the

skin temperature lower, thus delaying the increase in cutaneous venous capacitance and diverting less blood from the central to the peripheral circulation. Nadel et al. (21) have reported that fitness programs increase sweat rate by training the sweat glands, while standard acclimation procedures reduce the zero central sweating drive and shift the sweating threshold to a lower internal temperature. However, most studies of the cross adaptation of acclimation to heat from physical training report the opposite, a lowering of the threshold for the onset of sweating but no increase in sweat rate (1, 15, 28, 30, 31).

The purpose of the studies completed under this grant was to examine the factors hypothesized to explain the age-related changes in thermoregulation observed in previous studies (10, 11).

To minimize the effect of aerobic power, only healthy, active postmenopausal women were used as older subjects. Even so, it was impossible to match younger and older women on $\dot{V}_{O_2\ max}$. We resolved this problem by selecting subjects with similar activity patterns and with similar fitness levels relative to the average for their age groups. Another problem in designing thermoregulatory studies is that indices of physiological strain such as core temperature (T_c) and heart rate (HR) are a function of relative workload, while the sweating response is related to absolute workload. For this reason a resting protocol was selected for Studies #1 and #3, whose primary purpose was to examine various aspects of the sweating response. In Study #2, where exercise was added to the ambient thermal stress, all subjects worked at the same workload. Again this enabled us to

make direct comparisons of the sweating response but built into the design higher levels of T_{re} and HR for less fit subjects.

The basic protocol, common to all three studies, will be described first followed by the results of the studies and a discussion of implications of those results.

METHODS

Each subject completed a medical history form and was given a 12-lead electrocardiogram, a series of pulmonary function tests, and a modified Balke treadmill test for maximal aerobic power (12) prior to exposure to heat stress. Body density was determined hydrostatically (14) and converted to percent body fat using the revised formula of Brožek et al. (2).

The women reported to the laboratory at 1330 hours following a light lunch. No attempt was made to control the state of hydration; a normal variability was expected and desired. A nude weight was obtained, and then the subject inserted a rectal thermocouple to a depth of 12 cm and donned a bikini swim suit. ECG leads were attached in a CM5 position. Five areas of the body (anterior aspect of the forearm, the anterior thigh, the right pectoralis major, the supra-umbilical area of the abdomen, and the lower right portion of the back) were washed thoroughly with distilled water and allowed to dry. A 14.18 cm^2 sweat capsule, left open to the air, and skin thermocouple were attached in close proximity within each of the five areas. After the subject had sat in semi-reclining position for 20 min, a 3-ml sample of blood was drawn from the antecubital vein for analysis of

hemoglobin (IL282 CO-oximeter) and hematocrit (microhematocrit method). The subject was then weighed on an electronic scale (Scale-Tronix 2001) with an accuracy of ±10.0 g. A filter paper, dried overnight at 110°C and weighed dry (Mettler PC 440 balance) to within ±0.001 g, was then inserted under each capsule. These preliminaries were conducted in 23°C, 45% rh.

The subject entered the environmental chamber, maintained at 40.0°C, 22.2 Torr vp (40% rh) with air movement less than 0.5 $m \cdot min^{-1}$ [CET (corrected effective temperature) = 30.8°C], and sat in a semi-reclining position on a mesh cot while two hygrometry sweat capsules were attached to the left forearm and left abdominal area. Each capsule, covering 11.3 cm^2 of skin surface, was connected to a resistance hygrometer (Hygrodynamics). A pump drew room air through a chamber filled with Drierite into a tygon tube, through the capsule, and into the sensing element. The tube length was adjusted so that the incoming air (22-24°C) rose to chamber temperature (40°C) before reaching the capsule. This change was monitored by a thermocouple inserted in-line close to the capsule. Initial air flow was set at 2.5 ℓ/min until the hygrometers indicated 0% humidity, usually within 30 s. Flow was then decreased to 1.25 ℓ/min to monitor the onset of sweating at each site. Output from the hygrometers was directed to a chart recorder (Soltec-Rikandenki, Mark II).

A Whitney mercury-in-silastic strain gauge was attached over the belly of the right brachioradialis with pressure cuffs at the wrist and over the bicep for measurement of forearm blood flow.

An automated device inflated the arterial cuff to 220 Torr; the venous cuff, to 80 Torr at programmed intervals of 6 s on and 15 s off. Based on pre-test calibrations, an on line computer (PDP 11/60) calculated blood flow as $ml \cdot 100\ ml^{-1} \cdot min^{-1}$ and displayed the changes in limb volume as a graph on a CRT.

The thermocouples were connected to a data logger (Monitor Labs 9300), which printed temperatures every 1.5 min. Mean skin temperature was calculated as: $\bar{T}_{sk} = 0.30\ T_{arm} + 0.35\ T_{thigh} + 0.35\ [(T_{chest} + T_{abdomen} + T_{back})/3]$. Output from the ECG leads was displayed on an oscilloscope and sampled by the computer, which printed heart rate each min. Inspired ventilatory volumes were measured by a pneumotachograph (Fleisch No. 2), which was calibrated before each session by drawing a known quantity of air through the system. Mixed expired air was sampled continuously from a 2.5-liter plexiglass mixing chamber and analyzed for oxygen (Servomex O.A. 137) and carbon dioxide (Beckman LB-2). These analyzers were calibrated before and after each test using three known gas mixtures verified by Haldane analysis. The analyzers and pneumotachograph were on-line to the computer, which sampled their output at 50 Hz and calculated oxygen uptake ($\dot{V}_{O_2}$).

The cot was on a Potter platform scale which was calibrated prior to each experiment. The continuous output of weight change was recorded on the chart recorder and later calculated in $g \cdot m^{-2} \cdot min^{-1}$ for each 15 min of the experiment.

Respiratory water loss and metabolic weight loss from the exchange of oxygen and carbon dioxide molecules were calculated and used to correct this total weight loss to evaporative weight loss.

The experimental period lasted 120 min with time starting as the subject entered the chamber. Measurements began at min 3 after all instrumentation was in place and connected, and were continuous for temperatures, heart rate, and for the balance and the hygrometer. Five samples of forearm blood flow were obtained during the first and last 5 min of each 15-min period. During the final 2 min of each quarter hour, the filter papers were removed from the capsule and dry ones inserted. The used filters were placed in their original capsules and weighed. The difference in dry and wet weight was converted to a regional sweat rate ($g \cdot m^{-2} \cdot h^{-1}$) for each site. The sweat collected by these filters was pooled for each hour and later analyzed for potassium and sodium (flame photometry). Metabolic measurements were made between 53 and 58 min.

At the end of the period, a post-test sample (3 ml) of blood was drawn while the subject was still reclining on the cot. She then exited the chamber and was weighed immediately in the clothed state with instrumentation still attached. A final nude weight was obtained after the subject had disrobed and dried herself thoroughly.

Data Analysis

The data were analyzed by a two-factor factorial analysis of variance with repeated measures across time. When the overall F statistic

was significant, a test of simple main effects was done, followed by the Tukey test for differences between means if the levels of the factors exceeded two. Relationships between variables were quantified by correlation techniques. References to differences in the Results section imply significance at $\underline{P} \leq 0.05$.

Study #1. Sweating threshold and capacity of women related to age.

Ten postmenopausal and ten younger women volunteered as subjects. None of the women were on hormone replacement therapy or using oral contraceptives.

The physical characteristics of the subjects are described in Table 1. There were no differences between the age groups in the time required for the onset of sweating at either site; for both groups abdominal sweating preceded that of the forearm (Table 2). The initial core temperature (T_{re}), taken within 3 min of entering the chamber, and the threshold T_{re} at which sweating began were also the same for the younger and older women (Table 2). For all women, sweating was initiated while T_{re} was at or below its initial value.

Capsule sweat rates were the same for both groups for each 15-min period (Fig. 1). With the exception of the arm area, sweat rates had increased significantly over the initial rate by the end of 45 min. Arm sweat rate rose more slowly, and no significant increase was seen until the end of the first hour. Regional sweat rates reached a steady state during the second hour in all areas and were significantly higher than those recorded during the first 45 min of exposure. During the first 30 min there was no difference in sweat rate among the five regions.

Table 1. Physical characteristics of the subjects in Study #1 (mean ± SE)

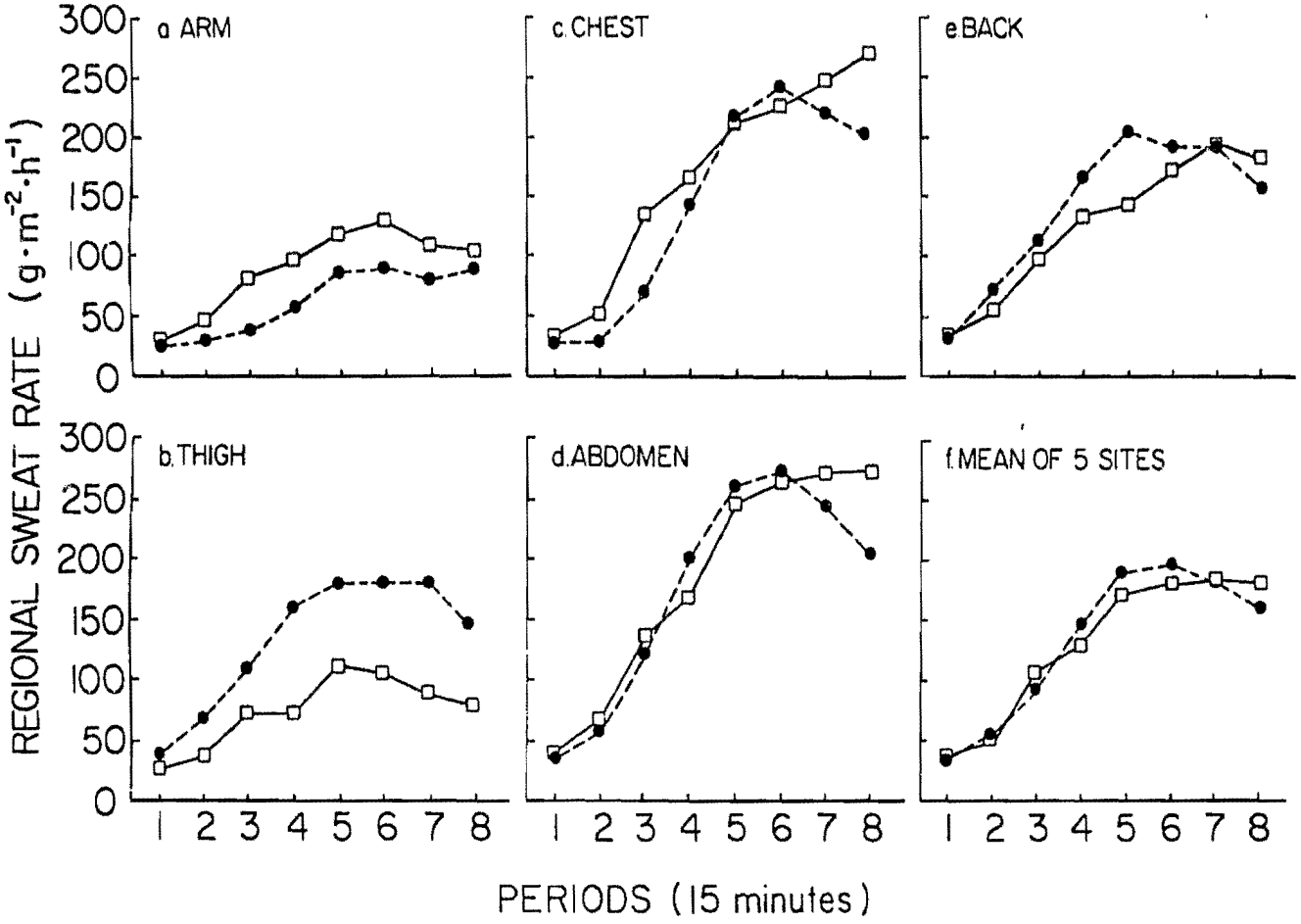
Group	Age (years)	Ht (cm)	Wt (kg)	BSA (m^2)	%BF	$\dot{V}O_{2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
Older Women ($\underline{n}$ = 10)	57.7±1.9*	164.7±2.6	63.7±3.4	1.70±0.05	34.1±3.3*	31.5±3.0*
Younger Women ($\underline{n}$ = 10)	38.4±2.1	168.8±1.7	60.0±3.2	1.69±0.05	20.1±1.7	46.8±2.1

* $\underline{P} < 0.01$

Table 2. Variables associated with onset of sweating (mean ± SE)

	Older Women	Younger Women	P
Onset Sweating (min)			
Arm	29.5±6.7	33.6±4.1	NS
Abdomen	21.6±6.1	20.2±6.0	NS
Threshold T_{re} (°C)			
Arm	36.9±0.1	36.9±0.1	NS
Abdomen	37.0±0.1	36.9±0.2	NS
Initial T_{re} (°C)	37.1±0.2	37.0±0.2	NS

Fig. 1. Regional sweat rate for younger (•) and older (□) women during 2 h resting in the environmental chamber (40°C, 22.2 Torr vp).


a ARM
c.CHEST
e.BACK
b.THIGH
d.ABDOMEN
f.MEAN OF 5 SITES
REGIONAL SWEAT RATE (g·m⁻²·h⁻¹)
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8
PERIODS (15 minutes)

After 45 min in the chamber, all trunk areas had a higher sweat rate than the arm. Sweat rate on the chest and abdomen during the second hour was also greater than that observed on the thigh. The single site which most closely approximated the overall mean was the back. When the area sweat rates were averaged for the entire 2-hour exposure period, there were no significant differences between age groups at any site (Table 3). With one exception, sweat electrolytes were also similar for the younger and older women (Table 4). The postmenopausal women did have higher concentrations of sodium in sweat collected from the forearm during both hours in the chamber.

Evaporative heat loss ($\dot{E}_{sw}$), measured independently from capsule sweat rate by the Potter scale, showed a similar pattern (Fig. 2). There were no differences in $\dot{E}_{sw}$ between age groups at any time. During the second hour, $\dot{E}_{sw}$ remained constant, averaging 60.4 $W \cdot m^{-2}$ for the combined groups.

The mean skin temperature of the older women was less than that of the younger group throughout the first hour (Fig. 3). At 45 min, $\bar{T}_{sk}$ of the younger women decreased slightly, narrowing the gap between the two groups so the difference was no longer significant. Both groups reached a plateau in $\bar{T}_{sk}$ following 45 min in the chamber.

Two indices of heat strain, heart rate (HR), and T_{re}, were also similar for each age group (Figs. 4 and 5). The postmenopausal women had slightly higher heart rates throughout the exposure, but the difference was not significant. Both groups reached a steady state in HR following 45 min in the chamber. Core temperature

Table 3. Sweat rate ($g \cdot m^{-2} \cdot h^{-1}$) at five regional sites averaged for two-hour exposure period

	Older Women ($\underline{n}$ = 10)	Younger Women ($\underline{n}$ = 10)	$\underline{P}$
Arm	89.8 ± 20.5	62.1 ± 11.4	NS
Thigh	74.8 ± 15.1	132.8 ± 34.1	NS
Chest	168.8 ± 43.8	145.0 ± 36.1	NS
Abdomen	184.6 ± 41.1	176.7 ± 36.2	NS
Back	126.8 ± 34.2	141.4 ± 39.8	NS
Mean (5)	129.3 ± 25.8	131.5 ± 27.3	NS

Table 4. Sweat electrolytes at five regional sites during the first and second hours of exposure (mean ± SE) (n = 9)

	Older Women		Younger Women		P
	Hour 1	Hour 2	Hour 1	Hour 2	
Arm					
Na ($meq \cdot \ell^{-1}$)	24.0±4.4	33.4±6.1	16.6±3.0	18.0±3.1	<0.05
K ($meq \cdot \ell^{-1}$)	7.8±2.5	9.2±0.8	5.5±1.3	8.2±0.8	NS
Thigh					
Na ($meq \cdot \ell^{-1}$)	19.4±2.2	25.4±3.4	16.4±1.6	21.1±3.3	NS
K ($meq \cdot \ell^{-1}$)	6.9±1.5	7.1±0.7	7.1±0.9	6.6±0.6	NS
Chest					
Na ($meq \cdot \ell^{-1}$)	29.1±6.5	45.9±7.1	19.9±2.8	35.5±7.0	NS
K ($meq \cdot \ell^{-1}$)	6.7±1.7	8.2±0.7	5.4±0.8	8.5±1.4	NS
Abdomen					
Na ($meq \cdot \ell^{-1}$)	24.6±3.3	31.6±4.5	26.1±5.0	25.4±3.6	NS
K ($meq \cdot \ell^{-1}$)	7.3±1.4	6.1±0.3	10.3±1.9	6.6±0.6	NS
Back					
Na ($meq \cdot \ell^{-1}$)	25.9±4.1	33.0±5.4	18.6±2.2	22.9±3.0	NS
K ($meq \cdot \ell^{-1}$)	9.8±3.2	8.3±0.5	7.7±1.0	7.5±0.5	NS

Fig. 2. Evaporative heat loss ($W \cdot m^{-2}$) of younger (●) and older (□) women at 15-min intervals while resting in the heat for 2 h.

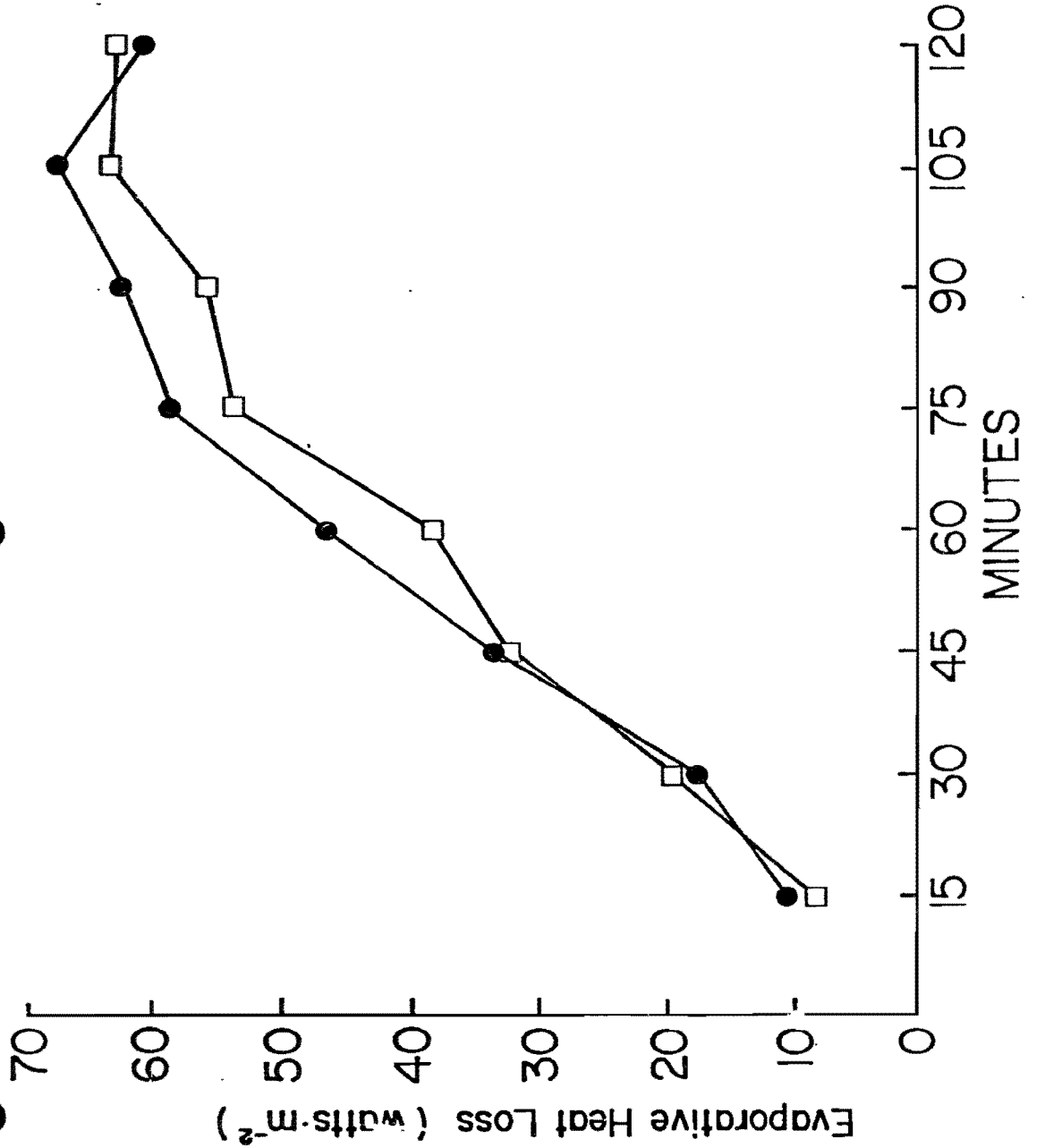

Evaporative Heat Loss (watts·m⁻²)
70
60
50
40
30
20
10
0
15
30
45
60
75
90
105
120
MINUTES

Fig. 3. Mean skin temperature (°C) of younger (•) and older (□) women during 2 h of rest in the environmental chamber (40°C, 22.2 Torr vp).

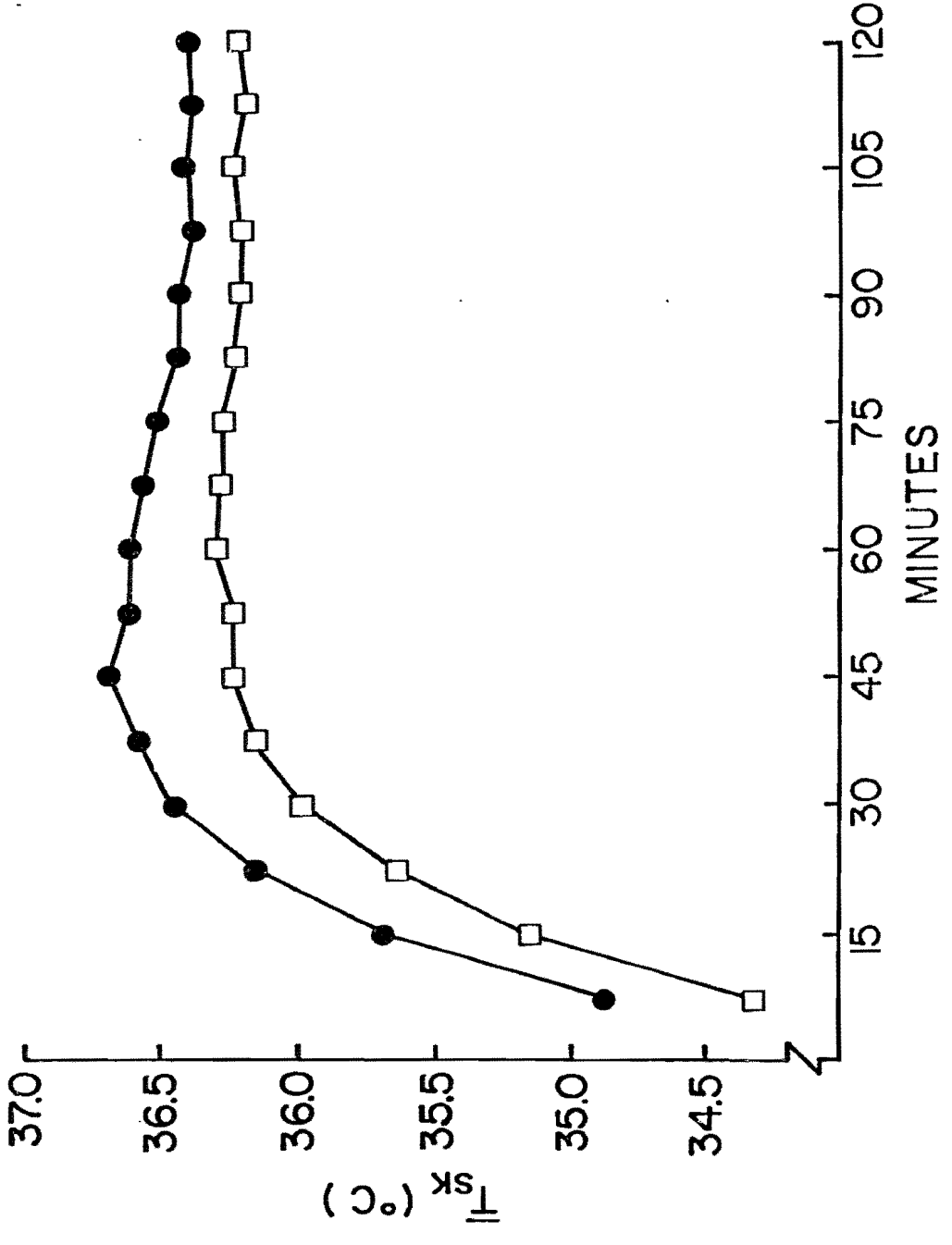

37.0
36.5
36.0
35.5
35.0
34.5
$\bar{T}_{sk}$ (°C)
15
30
45
60
75
90
105
120
MINUTES

Fig. 4. Heart rates (bpm) of younger (●) and older (□) women during 2 h of rest in the environmental chamber.

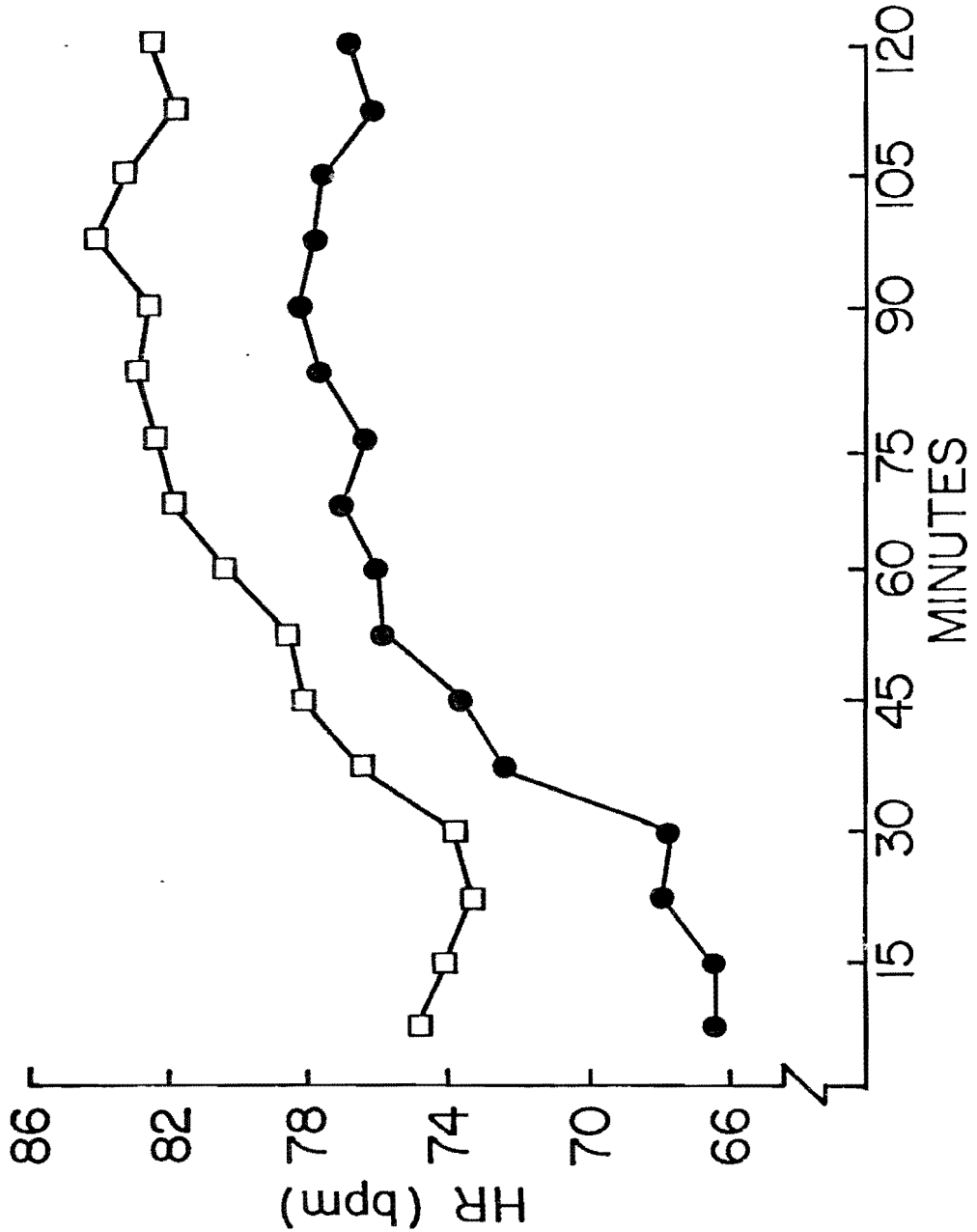
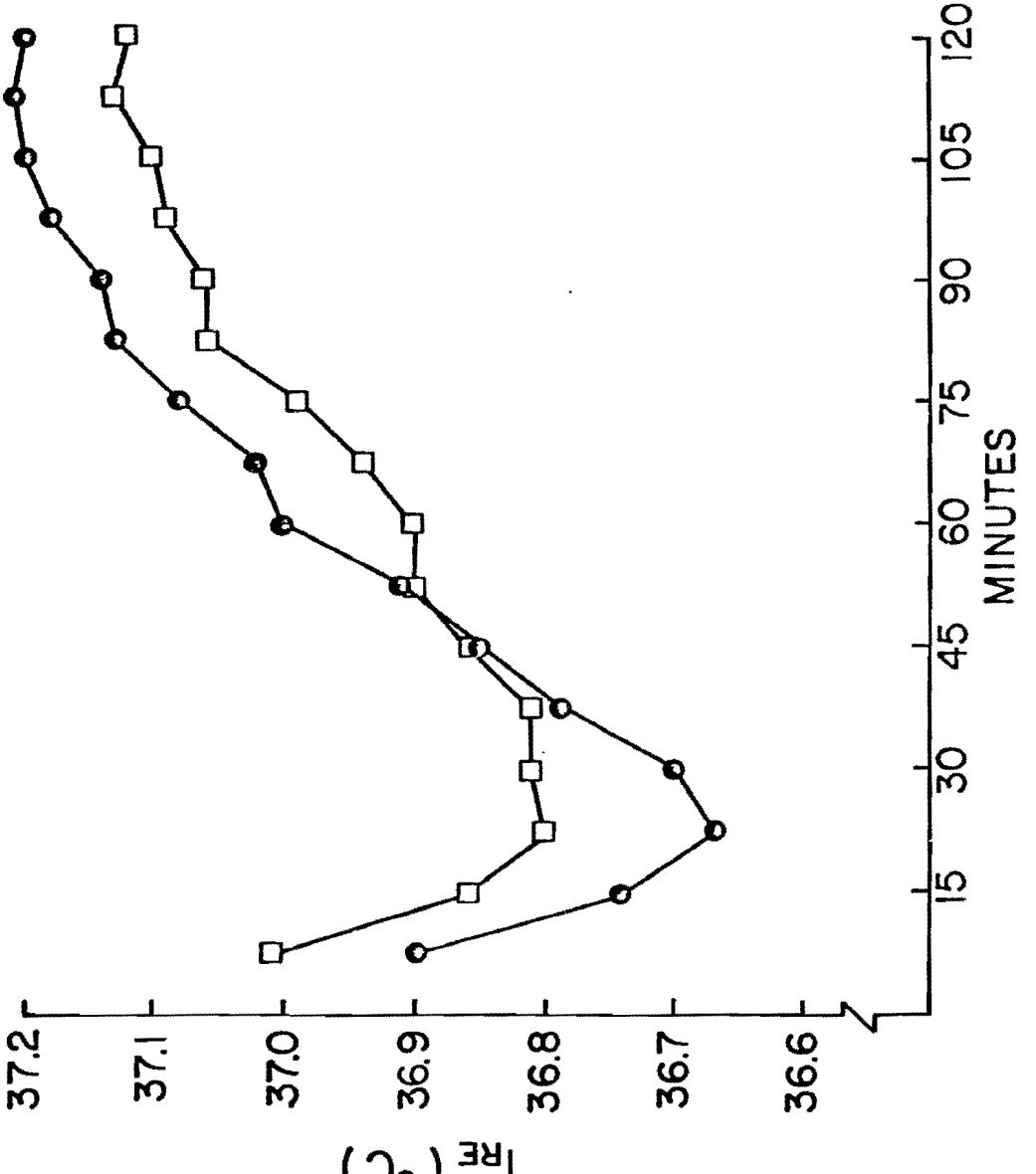

HR (bpm)
86
82
78
74
70
66
15
30
45
60
75
90
105
120
MINUTES

Fig. 5. Rectal temperature of younger (●) and older (□) women during 2 h resting in the environmental chamber.


37.2
37.1
37.0
36.9
36.8
36.7
36.6
T_{RE} (°C)
15
30
45
60
75
90
105
120
MINUTES

decreased during the first 22 min of exposure for young and old alike (Fig. 5) and then increased until it reached a plateau at 37.2°C for the young women and 37.1°C for the postmenopausal women during the final 30 min in the chamber. Throughout the entire period, T_{re} was higher than $\bar{T}_{sk}$ (Figs. 3 and 5).

The increase in forearm blood flow was the same for the younger and older subjects, 80% and 82% respectively, and occurred primarily in the first 60 min (Fig. 6). There was no significant change in flow during the second hour of exposure. The observed differences in flow between groups were not significant because of the marked variability among subjects in this measurement.

Plasma volume shifts were independent of age, decreasing 0.2% and 0.15% for the older and younger women respectively (6).

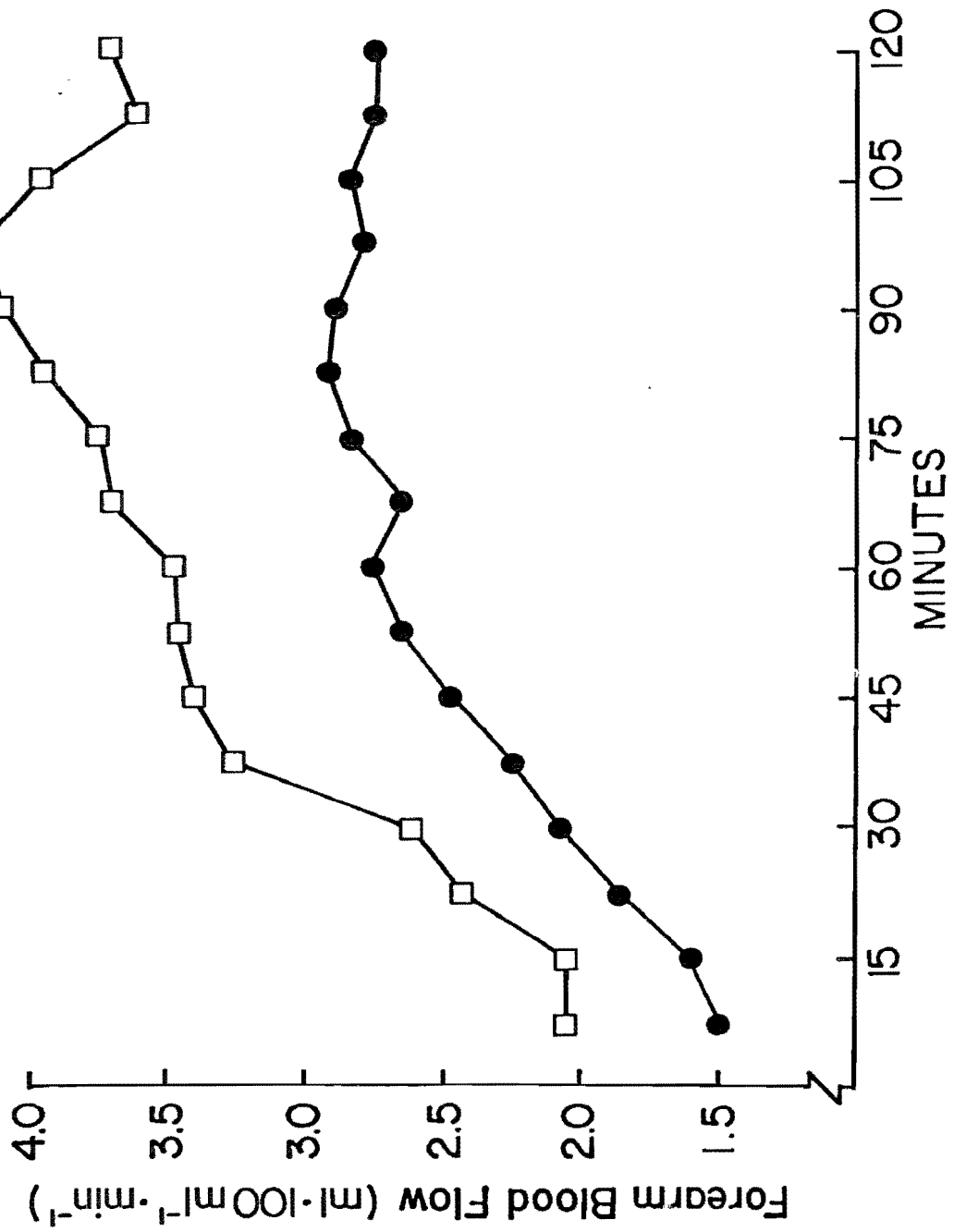
Since the responses to the heat stress were similar for both age groups, the data from all 20 subjects were combined to examine relationships between these responses and the age and fitness ($\dot{V}_{O_2\ max}$) of the subjects. Only $\dot{V}_{O_2\ max}$ ($\underline{r}$ = -0.76) and percent body fat ($\underline{r}$ = 0.61) were significantly related to age. However, sweat rate ($g \cdot m^{-2} \cdot min^{-1}$) ($\underline{r}$ = 0.48) and peak skin temperature ($\underline{r}$ = -0.43) were both significantly related to fitness level.

Study #2. Aging effect of women's response to exercise under thermal stress.

Modifications to Standard Protocol

For this study, a light (60 W) workload on a cycle ergometer (Monark) was added to the thermal stress of the environment. The women sat in a plastic seat behind the cycle with their legs in a horizontal position.

Fig. 6. Forearm blood flow of younger (•) and older (□) women during 2 h resting in the environmental chamber.


Forearm Blood Flow (ml·100ml⁻¹·min⁻¹)
4.0
3.5
3.0
2.5
2.0
1.5
15
30
45
60
75
90
105
120
MINUTES

The seat, with multiple openings cut in the plastic, was firmly attached to the frame supporting the cycle ergometer and could be adjusted for the leg length of the subject. Both cycle and seat were on the Potter scale.

The experimental period began with a 5-min rest period while instrumentation was attached to the subject seated in pedalling position. Four periods alternating 10-min work and 5-min rest followed. Total time in the environmental chamber was 65 min.

For this study, one hygrometer capsule for detection of the onset of sweating was placed on the anterior thigh overlying the active muscles; the other, on the forearm as in Study #1. Regional sweat sites were reduced to three, the forearm, the thigh, and the back. Since determination of regional sweat electrolytes did not show any significant age-related differences in Study #1, this measurement was eliminated from this study for financial reasons.

Seven postmenopausal women and nine younger women volunteered as subjects. None of the women were on hormonal replacement therapy or using oral contraceptives. Five of the older women and three of the younger women had participated in the previous experiment.

Results

As in the previous study, the two groups of women differed not only in age but also in percent body fat (%BF) and aerobic power ($\dot{V}_{O_2\ max}$) (Table 5).

Table 5. Physical characteristics of subjects in Study #2 (mean ± SE)

Group	Age (years)	Wt (kg)	Ht (cm)	BSA (m^2)	%BF	$\dot{V}O_{2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
Older Women ($\underline{n}$ = 7)	60.0±2.6[a]	60.6±5.7	165.9±3.8	1.66±0.09	29.5±3.3[b]	32.5±3.2[a]
Younger Women ($\underline{n}$ = 9)	30.4±2.4	59.6±2.1	170.2±1.5	1.69±0.03	20.7±1.5	44.6±2.8

[a] $P < 0.01$

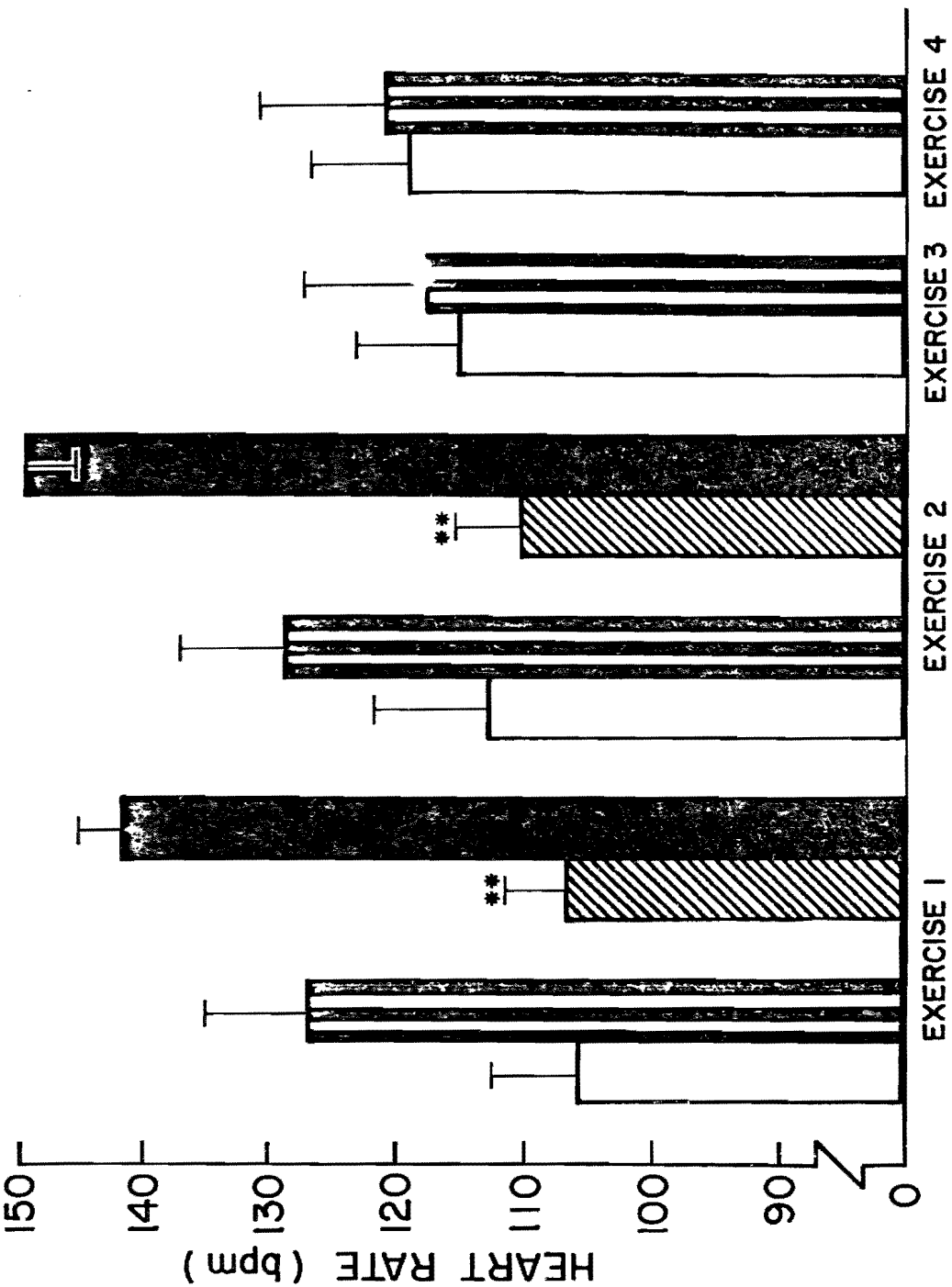
[b] $P < 0.05$

All women completed at least two work-rest cycles. Two of the older women were removed from the chamber following two cycles and one older and one younger subject were removed after three completed cycles. Each of these women had exercise HR's in excess of 90% HR_{max} prior to terminating the experiment; core temperature was not a factor in the decision to remove them. Because of the differences in tolerance time the data were analyzed in three sections: (1) All subjects during work-rest cycles 1 and 2, (2) Older (n = 4) and younger (n = 8) women who completed cycles 3 and 4, and (3) subjects divided into those who completed the experiment (n = 12) and those who did not (n = 4), regardless of age, for cycles 1 and 2. Final values for the NC group include those at the end of cycle 3 for two women.

For the younger women a 60 W workload was equivalent to 34% $\dot{V}O_{2\ max}$; for older women, 46% $\dot{V}O_{2\ max}$. Those women who failed to complete the session (Group NC) were working at 64% $\dot{V}O_{2\ max}$, while those who finished all cycles (Group C) averaged 34% $\dot{V}O_{2\ max}$.

The differences in relative workload between the two age groups did not result in significant differences in heart rate between the groups during cycles 1 and 2 (Fig. 7). In fact, HR for those women completing cycles 3 and 4 were almost identical for younger and older subjects. The marked effect of relative workload, which was directly related to fitness levels, was apparent between the NC and C groups during both cycle 1 and 2. Those women able to complete four cycles averaged 110 bpm (61% HR_{max}) during cycle 2, while those unable to complete the session averaged 149 bpm (86% HR_{max}). Final exercise

Fig. 7. Mean heart rates (bpm) of younger (white bars) and older (vertical striped bars) women during the final 5 min of each exercise period. Also included are HR's for the same subjects divided into those completing the experiment (crosshatched bars) and those unable to finish the session (black bars). (** $\underline{P} < 0.01$.)


HEART RATE (bpm)
150
140
130
120
110
100
90
0
EXERCISE 1
EXERCISE 2
EXERCISE 3
EXERCISE 4
**
**

heart rates were significantly higher for the NC (158 bpm, 92% HR_{max}) than the C (123 bpm, 68% HR_{max}) group. While HR tended to drift upward slightly from one cycle to the next, the increases were not significant. HR's for those women who completed the entire session averaged 64% HR_{max} and 69% HR_{max} for younger and older women respectively.

Differences in rectal temperature (T_{re}) between age groups were not significant (Fig. 8). However, for both younger and older women, T_{re} rose significantly from one cycle period to the next throughout the experimental period. By the end of the second cycle period, those women unable to complete the session had a significantly higher T_{re} than those who finished the experiment. Final T_{re} for the NC group was 38.1 ± 0.1°C, well below the criteria for withdrawal, and not significantly higher than the 37.9 ± 0.1°C level of the C group at the end of four cycle periods.

There were no age group differences in mean skin temperature nor at any individual thermocouple sites. During the first two work-rest cycles, $\bar{T}_{sk}$ rose significantly from one period to the next for all subjects and then plateaued for those women who completed the experiment (Fig. 9). When the women were divided into the NC and C groups, this plateau was apparent for the C group from cycle 2 on. Throughout the first two cycles, $\bar{T}_{sk}$ rose 1.5°C and 0.9°C for the NC and C groups respectively, but the differences between groups was not significant.

Threshold T_{re} and time for onset of sweating were the same for both age groups (Table 6) and for those who did or did not complete the experimental period.

Fig. 8. Mean rectal temperature (°C) during final 5 min of each exercise period. See Fig. 7 for explanation of symbols. (* $\underline{P} < 0.05$.)

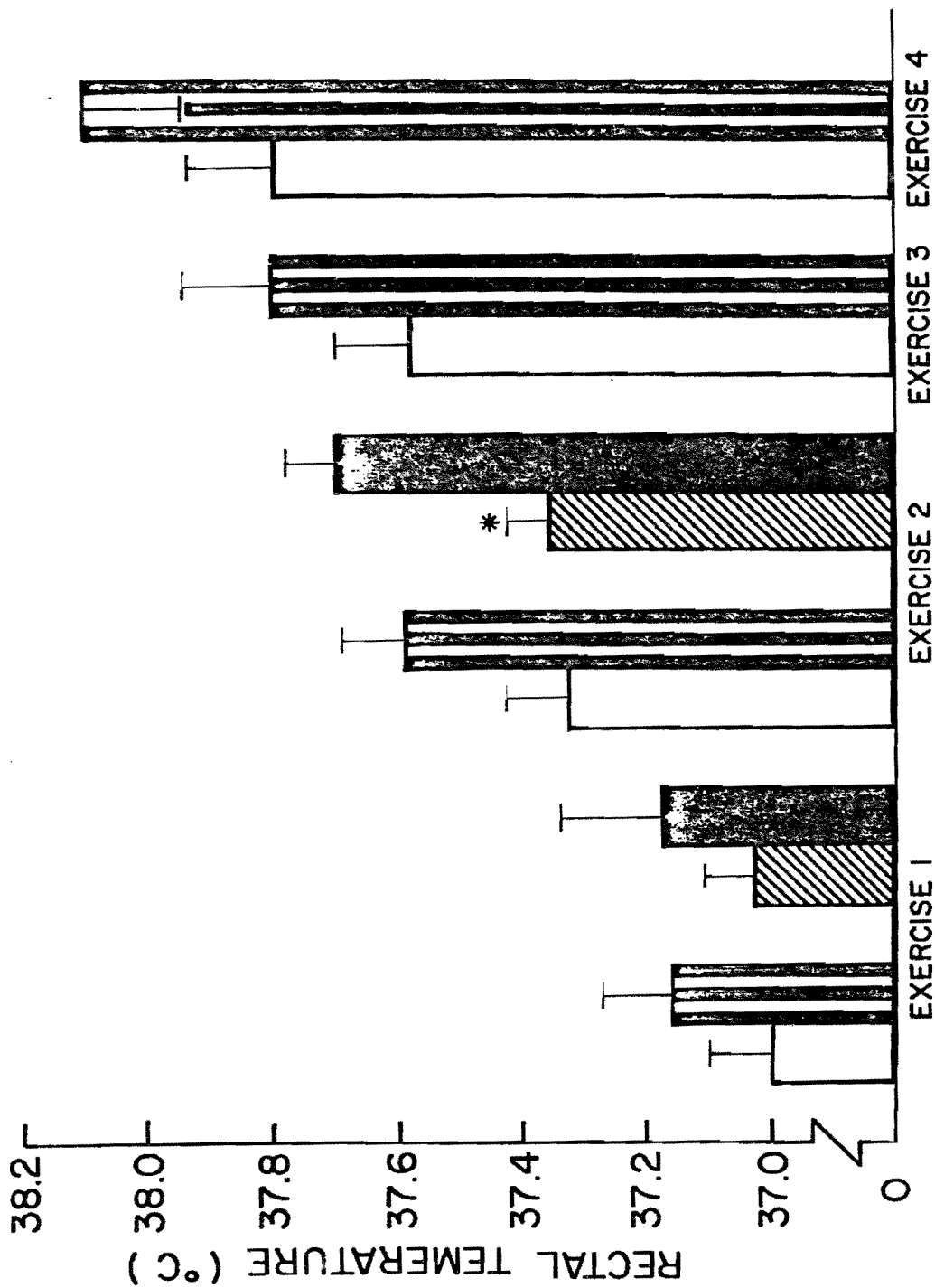

RECTAL TEMPERATURE (°C)
38.2
38.0
37.8
37.6
37.4
37.2
37.0
0
EXERCISE 1
EXERCISE 2
EXERCISE 3
EXERCISE 4
*

Fig. 9. Mean skin temperature (°C) during final 5 min of each exercise period. See Fig. 7 for explanation of symbols.

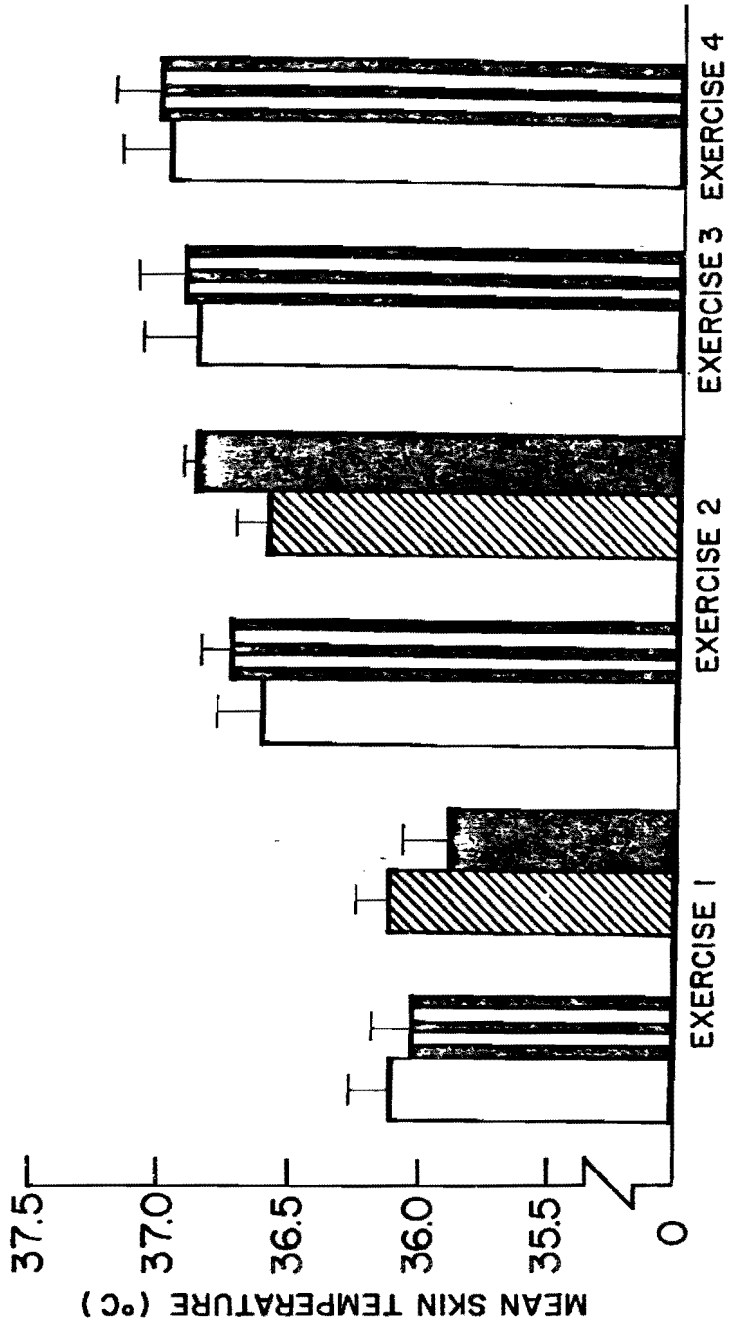

MEAN SKIN TEMPERATURE (°C)
37.5
37.0
36.5
36.0
35.5
0
EXERCISE 1
EXERCISE 2
EXERCISE 3
EXERCISE 4

Table 6. Variables associated with onset of sweating (mean ± SE)

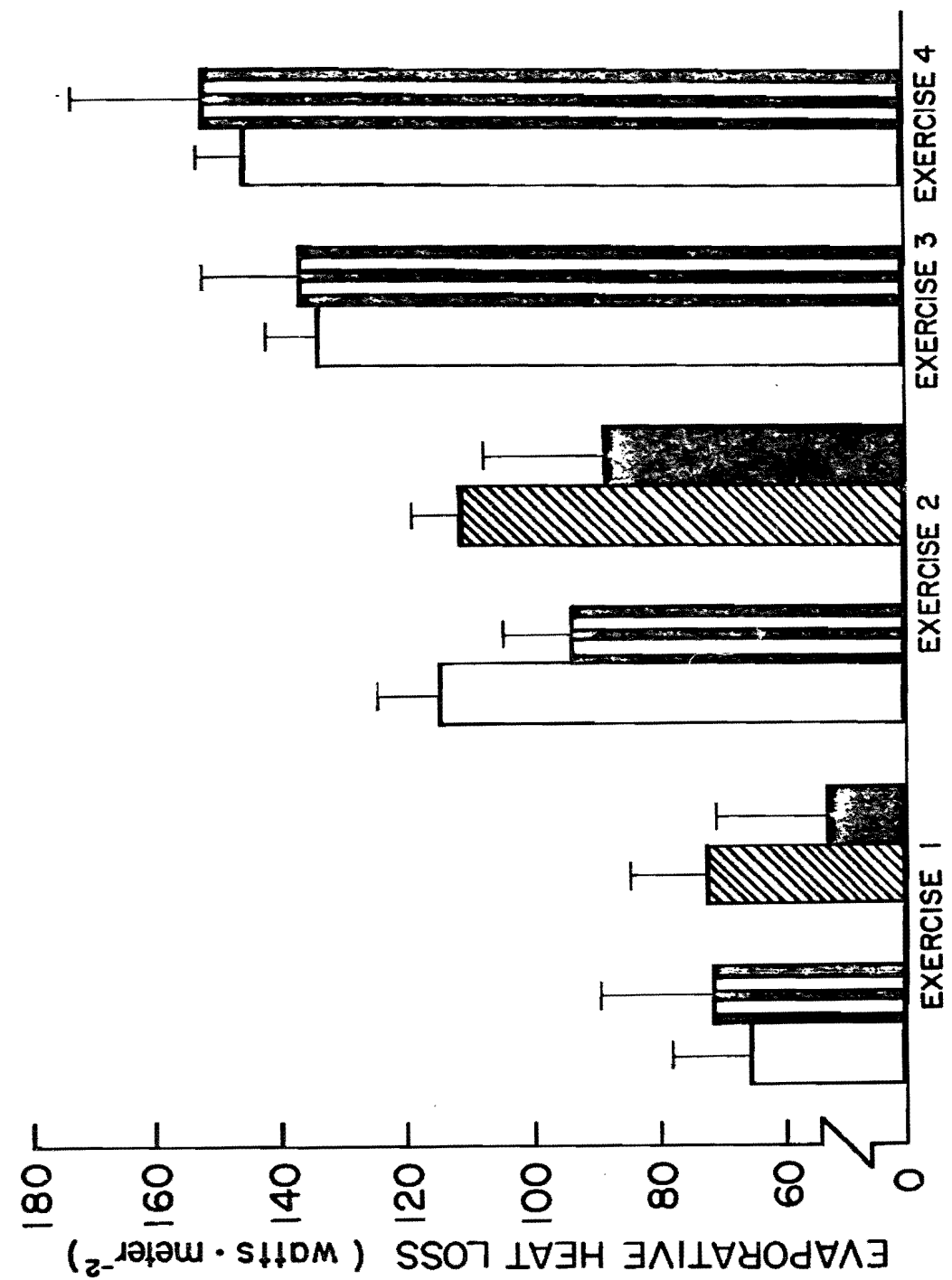
	Older Women	Younger Women	P
Onset sweating (min)			
Arm	4.0 ± 1.6	9.4 ± 2.6	NS
Thigh	4.2 ± 1.5	7.9 ± 2.6	NS
Threshold T_{re} (°C)			
Arm	37.1 ± 0.1	37.1 ± 0.1	NS
Thigh	37.1 ± 0.1	37.1 ± 0.1	NS
Initial T_{re} (°C)	37.0 ± 0.1	36.9 ± 0.1	NS

Evaporative heat loss ($\dot{E}_{sw}$), calculated from the corrected weight losses recorded from the Potter scale, did not differ between age groups (Fig. 10). For all women there was a significant increase in $\dot{E}_{sw}$ between the first and second exercise periods. Those women who completed the sessions did not have any further significant increase in $\dot{E}_{sw}$ following the second cycle. Although the difference between NC and C groups was larger than between age groups, it was not significant in itself. However, when $\dot{E}_{sw}/E_{req}$ was calculated the ratio was significantly lower for NC (0.26) than for C (0.39) during the first hour. A nonsignificant difference between older (0.32) and younger (0.38) women disappeared during the second hour for those older (0.63) and younger (0.62) women completing the experiment.

Although group differences in energy expenditure ($\dot{M}$) and $\dot{E}_{sw}$ were not significantly different, the slightly higher $\dot{M}$ and lower $\dot{E}_{sw}$ for the NC group resulted in their lower $\dot{E}_{sw}/E_{req}$. Since the workload was the same for all subjects, the higher $\dot{M}$ for the older subjects represents a difference in efficiency between groups, 17% and 20% for NC and C respectively.

Although final mean body temperature ($\bar{T}_b$), body heat content (BHC), and storage (S) did not differ between age groups or NC and C, when storage per minute of heat exposure was calculated the ratio for NC (1.06 ± 0.05 watts$\cdot$m$^{-2}\cdot$min^{-1}) was significantly higher than for the C group (0.26 ± 0.03 watts$\cdot$m$^{-2}\cdot$min^{-1}). The difference between older (0.31 ± 0.09 watts$\cdot$m$^{-2}\cdot$min^{-1}) and younger (0.23 ± 0.11 watts$\cdot$m$^{-2}\cdot$min^{-1}) women completing the sessions was not significant.

Fig. 10. Evaporative heat loss (watts·m^{-2}) during each 10 min exercise period. See Fig. 7 for explanation of symbols.


EVAPORATIVE HEAT LOSS (watts · meter^{-2})
180
160
140
120
100
80
60
0
EXERCISE 1
EXERCISE 2
EXERCISE 3
EXERCISE 4

During the first exercise period older women had higher regional sweat rates on the forearm and back and therefore a higher average rate (Fig. 11, a-d). By the second period, differences in arm and mean sweat rate were no longer apparent. During the final two exercise periods there was no difference in sweat rate between age groups. At all sites, sweat rate increased significantly from exercise period 1 to 2 and then plateaued during the final two exercise periods. There was no difference in regional sweat rates between those women who completed the experimental period and those who did not.

Pre-exercise forearm blood flows (FBF) were 2.07 ± 0.32 and 3.19 ± 1.06 $ml \cdot 100\ ml^{-1} \cdot min^{-1}$ for older and younger women respectively. Neither this resting value nor any exercise blood flows were significantly different between age groups (Fig. 12). The apparent difference in FBF between NC and C groups during cycle period 2 was not significant because of the large inter-individual variability. For both groups FBF was higher during exercise period 2 than during period 1 but showed no further increase in periods 3 and 4 for those women completing the full hour of work-rest cycles.

All subjects had a decrease in plasma volume (PV), but values did not differ significantly between older (-8.36 ± 1.61%) and younger (-6.28 ± 1.48%) or between NC (-10.33 ± 1.5%) and C (-6.14 ± 1.21%) groups.

Correlations among selected variables are shown in Table 7. While age was significantly related to final T_{re}, it was not related to tolerance time. The quantity of heat stored per minute of exposure (S/min) was most closely related to tolerance time, and was also

Fig. 11. Regional sweat rates ($g \cdot m^{-2} \cdot h^{-1}$) of younger (●) and older (□) women during each 10 min exercise period for the a. forearm, b. thigh, and c. back. The mean of all three sites is shown in d.

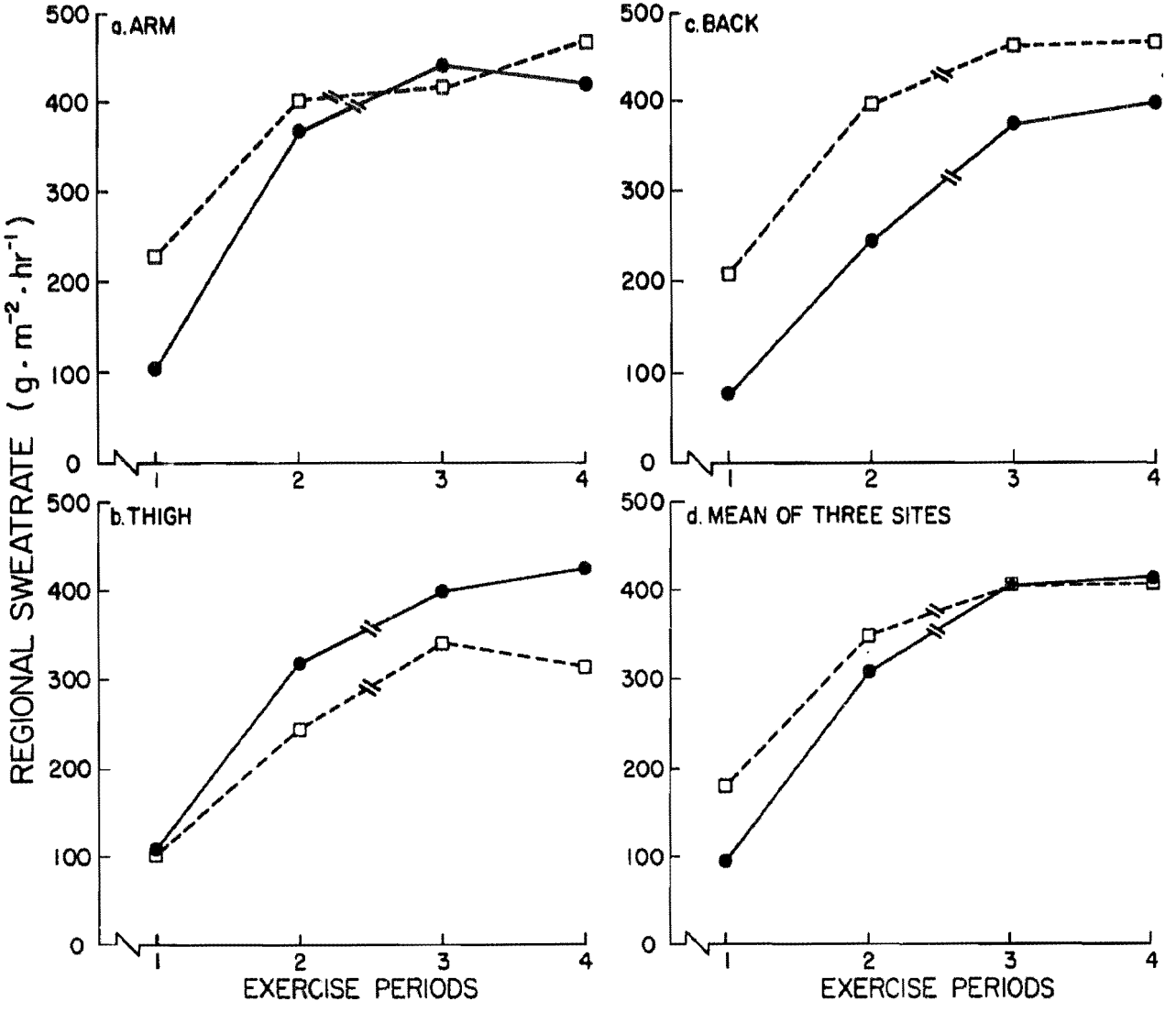

a. ARM
b. THIGH
c. BACK
d. MEAN OF THREE SITES
REGIONAL SWEATRATE (g · m⁻² · hr⁻¹)
EXERCISE PERIODS
EXERCISE PERIODS
0
100
200
300
400
500
1
2
3
4

Fig. 12. Forearm blood flow ($ml \cdot 100\ ml^{-1} \cdot min^{-1}$) during final 3 min of each exercise period. See Fig. 7 for explanation of symbols.

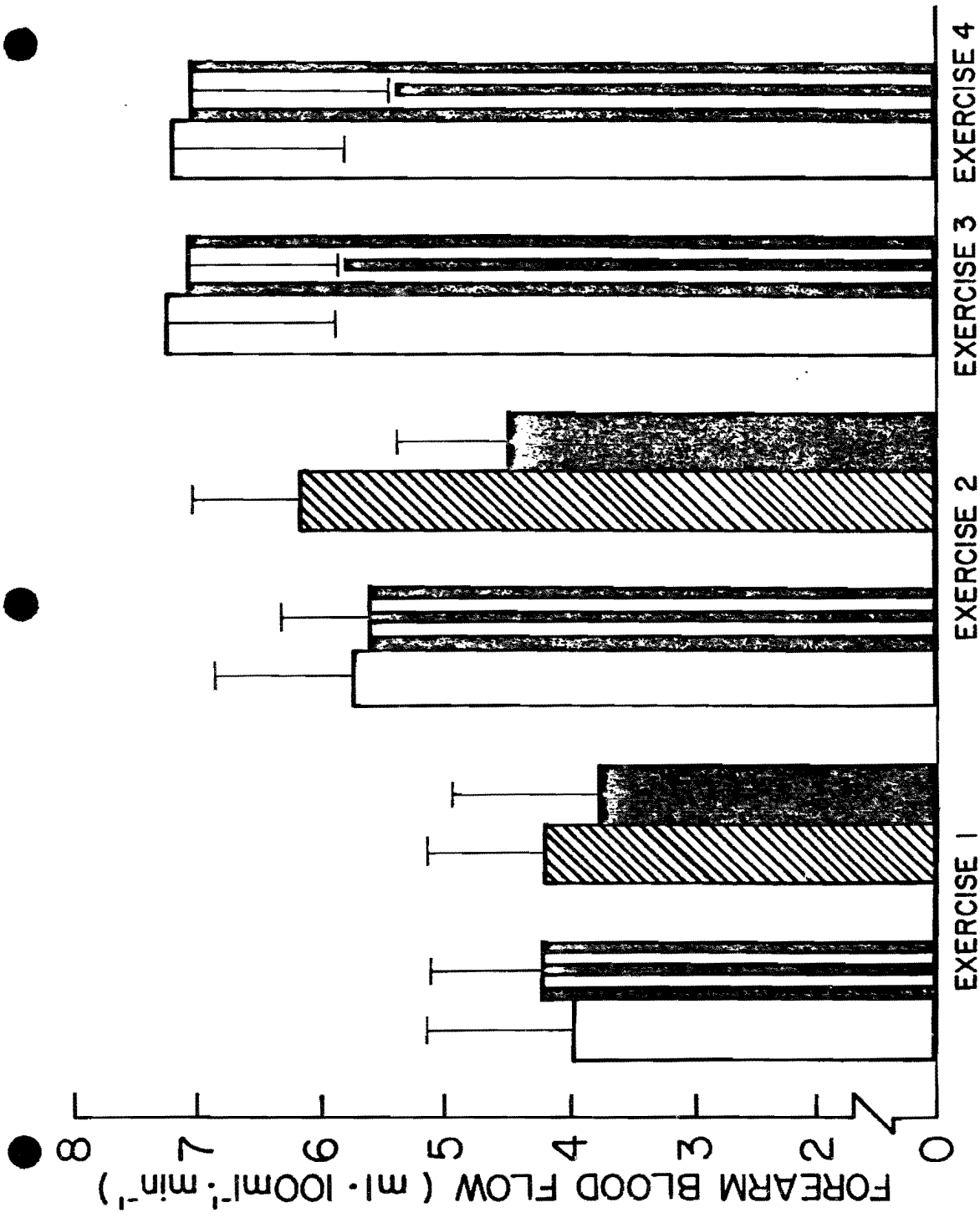

FOREARM BLOOD FLOW (ml · 100ml⁻¹ · min⁻¹)
0
2
3
4
5
6
7
8
EXERCISE 1
EXERCISE 2
EXERCISE 3
EXERCISE 4

Table 7. Significant relationships among physical characteristics and selected physiological responses to exercise in the heat

	Age	Tolerance Time		Final T_{re}		Final HR		Storage/minute	
%BF	0.55	Total S,	0.57	Total S,	0.72	$\dot{V}_{O_2\ max}$,	-0.52	Tolerance time,	-0.96
$\dot{V}_{O_2\ max}$	-0.66	$\dot{V}_{O_2\ max}$,	0.76	$\dot{E}_{sw}/T_{re}$,	-0.63	Final $\bar{T}_{sk}$,	0.62	Total S,	-0.55
Final T_{re}	0.55	S/mm,	-0.96	Final HR,	0.56	Final T_{re},	0.56	$\dot{E}_{sw}/\Delta T_{re}$,	-0.59
Final $\bar{T}_b$	0.51	Final HR,	-0.66	Final $\bar{T}_{sk}$,	0.88	Total S,	0.60	Final HR,	0.75
		%BF,	-0.51	Threshold T_{re}, thigh,	0.54	S/min,	0.75	$\dot{V}_{O_2\ max}$,	-0.76
				Final FBF,	0.54	Final $\bar{T}_b$,	0.59		
				Age,	0.55	Tolerance time,	-0.66		
						$\dot{E}_{sw}/\Delta T_{re}$,	-0.50		

$\underline{r} = 0.50$, $\underline{P} < 0.05$

$\underline{r} = 0.62$, $\underline{P} < 0.01$

significantly related to total sweat production, $\dot{E}_{sw}/\Delta T_{re}$, final HR, and $\dot{V}_{O_2\ max}$. In a multiple regression analysis, S/min was selected as the first variable in predicting tolerance time; total storage was second. The two combined predict tolerance time with a high degree of accuracy ($\underline{r}$ = 0.996). When a discriminant function test was run for the NC and C groups, these same two variables were 100% accurate in discriminating between those who finished the session and those who did not. The most significant variable in predicting S/min was $\dot{V}_{O_2\ max}$ followed by the time for onset of sweating on the thigh. Together these two variables predicted 75% of the variability in rate of storage.

Study #3. Effect of endurance training on women's regional and whole-body sweating response.

The results of Studies #1 and #2 support the theory that a decrease in cardiovascular function, not an impaired sweating response, is the primary cause of the decrease in heat tolerance in older women. In the resting protocol there were no differences in sweating response nor indicators of heat strain between age groups. When the same absolute work (60 W) was performed by both younger and older women, the sweating response remained the same for both age groups. Tolerance time was a function of cardiovascular fitness, quantified by $\dot{V}_{O_2\ max}$, not age. Women with low levels of aerobic power and working at higher relative workloads ($\%\dot{V}_{O_2\ max}$) were removed from the chamber when their HR's reached 90% HR_{max}. At that time their core temperature was significantly higher than that of other women.

Although many studies (1, 9, 19, 22, 29) have shown that highly trained subjects tolerate exercise in the heat better than sedentary individuals, there is disagreement in the literature as to whether training lowers the threshold core temperature (T_c) for the onset of sweating or whether it increases sweat rate. Nadel et al. (21) report that training enhances the peripheral sweating response while heat acclimatization reduces the zero point of central sweating drive. Other investigators (1, 15, 28, 30, 31) report the opposite, a decrease in sweat threshold and no change in sweat rate following training. Study #3 was designed to determine how endurance training associated with high levels of cardiovascular fitness influences the sweating response of women.

Methods

Nine women who trained for distance races (>10 km) and nine active but non-running women, matched for age and body surface area (BSA) participated in the study (Table 8). To avoid confounding the effect of exercise with that of heat, the resting protocol described in Study #1 was used.

Results

As expected, the runners (R) had significantly higher levels of aerobic power ($\dot{V}O_{2\ max}$) than the non-runners (NR) (Table 8). The active life-style of both groups is reflected in a $\dot{V}O_{2\ max}$ above average for their age group and a percent body fat (%BF) well below average.

Table 8. Physical characteristics of the subjects in Study #3 (mean ± SE)

Group	Age (years)	Ht (cm)	Wt (kg)	BSA (m^2)	%BF	$\dot{V}_{O_2\ max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$)
Runners ($\underline{n}$ = 9)	35.6±2.6	164.7±2.4	56.7±2.7	1.61±0.05	16.9±2.0	54.4±2.6*
Non-Runners ($\underline{n}$ = 9)	34.7±3.9	167.5±1.3	57.9±2.7	1.65±0.03	22.2±3.8	42.2±2.2

* $\underline{P} < 0.01$

There was no difference between activity groups in the threshold core temperature (T_{re}) for the onset of sweating or in the time at which abdominal sweating began (Table 9). Runners did have an earlier onset of forearm sweating. For both groups sweating was initiated on the forearm and abdomen, while T_{re} was below initial levels (Fig. 13a).

Mean capsule sweat rates were significantly higher for R at four of the five sites monitored (Table 10). Only forearm sweat rate was comparable for the two groups. Differences between groups became apparent at 30 min (Period 2) for the thigh, abdomen, and back (Fig. 13b,d,e). Not until 90 min (Period 6) did chest sweat rate differentiate between groups (Fig. 13c). With the exception of the chest, regional sweat rates plateaued during the second hour of exposure for both groups. Chest sweat rate reached a steady state for NR during the final 60 min but continued to increase in R until the final 30 min in the chamber.

During the first hour there was no difference among the five regional sweat rates for NR. In contrast, R had higher rates on the thigh, abdomen, and back than on the chest and forearm by 30 min. At 75 min their chest sweat rate also exceeded that of the arm. Not until the second hour did NR demonstrate differences in sweat production among regions. During Periods 5 and 6, thigh, chest, and abdominal rates for NR were greater than that of the arm; only the chest SR remained significantly higher than forearm SR during the final 30 min.

Table 9. Variables associated with onset of sweating (mean ± SE)

	Runners	Non-Runners	P
Onset sweating (min)			
Arm	21.5 ± 4.9	35.9 ± 5.6	<0.10
Abdomen	15.7 ± 4.9	17.1 ± 6.3	NS
Threshold T_{re} (°C)			
Arm	36.7 ± 0.2	36.8 ± 0.1	NS
Abdomen	36.8 ± 0.2	36.9 ± 0.1	NS
Initial T_{re} (°C)	36.9 ± 0.2	37.0 ± 0.1	NS

Fig. 13. Regional sweat rates for runners (■) and non-runners (o) during 2 h resting in the environmental chamber (40°C, 22.2 Torr vp).

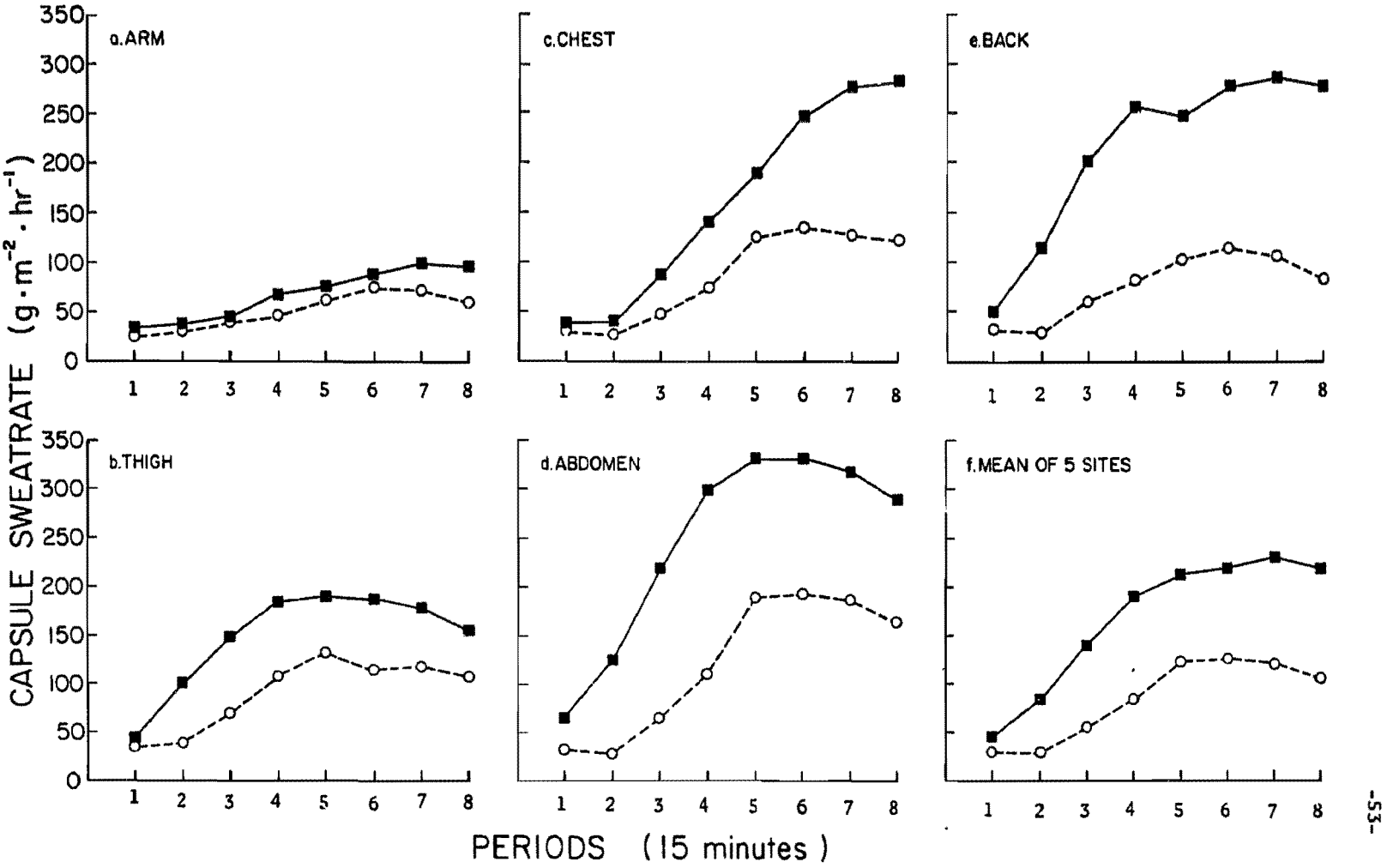

a.ARM
c.CHEST
e.BACK
b.THIGH
d.ABDOMEN
f.MEAN OF 5 SITES
CAPSULE SWEATRATE (g·m⁻²·hr⁻¹)
0
50
100
150
200
250
300
350
1 2 3 4 5 6 7 8
PERIODS (15 minutes)

Table 10. Sweat rate ($g \cdot m^{2} \cdot h^{-1}$) at five regional sites averaged for two-hour exposure period (mean ± SE*)

	Runners (n = 9)	Non-Runners (n = 9)	P
Arm	67.9 ± 10.0	50.7 ± 6.8	NS
Thigh	149.0 ± 19.5	90.6 ± 14.2	<0.05
Chest	163.4 ± 38.3	85.9 ± 17.5	<0.01
Abdomen	248.7 ± 28.7	122.2 ± 27.0	<0.01
Back	212.9 ± 32.7	75.8 ± 12.2	<0.01
Mean (5)	168.4 ± 26.6	84.9 ± 15.4	<0.01

*SE represents variability of group means across time.

Sodium (Na) levels were higher for NR than R in sweat collected from the abdomen and back during both the first and second hour of exposure (Table 11). Samples from the forearm differed only in Hour 2, while differences between groups in Na from the chest and thigh were not significant. With the exception of higher potassium levels (K) in R's forearm sweat, this electrolyte did not disciminate between groups.

Evaporative heat loss ($\dot{E}_{sw}$), calculated from weight loss recorded on the Potter scale, was significantly higher for R throughout the experiment (Fig. 14c). This difference was established by the end of 15 min in the chamber, and the rate of increase during Hour 1 was the same for R (0.67 watts$\cdot m^{-2} \cdot min^{-1}$) and NR (0.60 watts$\cdot m^{-2} \cdot min^{-1}$). Both groups reached a steady state during the second hour.

Neither T_{re} (Fig. 14a) nor $\bar{T}_{sk}$ (Fig. 14d) was significantly different between groups. Not until the final 15 min in the chamber did T_{re} rise significantly above initial levels for either group. $\bar{T}_{sk}$, however, rose significantly throughout the first 45 min of exposure and then remained constant throughout the remainder of the session. Temperature levels at individual thermocouple sites were also similar between groups.

After 45 min in the chamber, the HR of NR was significantly higher than that of R and remained so throughout the experiment. The difference appeared when the HR of NR increased significantly above initial levels while that of R remained constnat. In fact R did not increase their HR significantly until the final 15 min of the experiment.

Table 11. Sweat electrolytes at five regional sites during the first and second hours of exposure (mean ± SE)

	Runners		Non-Runners		P
	Hour 1	Hour 2	Hour 1	Hour 2	(<0.05)
Arm					
Na (meq·ℓ$^{-1}$)	15.1 ± 2.2	13.9 ± 1.7	15.6 ± 1.8	21.4 ± 3.1	b,d
K (meq·ℓ$^{-1}$)	10.4 ± 2.5	10.9 ± 1.8	4.2 ± 1.1	9.2 ± 1.0	a,d
Thigh					
Na (meq·ℓ$^{-1}$)	14.6 ± 2.0	16.2 ± 2.3	17.8 ± 2.0	23.5 ± 3.4	c,d
K (meq·ℓ$^{-1}$)	10.3 ± 2.2	9.3 ± 1.0	7.6 ± 1.0	7.6 ± 0.7	NS
Chest					
Na (meq·ℓ$^{-1}$)	21.1 ± 4.4	23.2 ± 4.0	23.9 ± 5.0	39.6 ± 8.7	d
K (meq·ℓ$^{-1}$)	10.1 ± 2.3	8.3 ± 0.7	5.0 ± 1.3	8.6 ± 1.3	NS
Abdomen					
Na (meq·ℓ$^{-1}$)	17.1 ± 2.9	16.9 ± 2.4	30.5 ± 5.5	29.4 ± 3.7	a,b
K (meq·ℓ$^{-1}$)	10.9 ± 2.3	7.1 ± 0.6	10.4 ± 2.1	8.4 ± 1.5	NS
Back					
Na (meq·ℓ$^{-1}$)	15.9 ± 2.0	15.4 ± 1.3	21.5 ± 2.2	28.0 ± 3.5	a,b
K (meq·ℓ$^{-1}$)	11.7 ± 3.1	8.2 ± 1.5	9.3 ± 2.5	9.1 ± 1.1	NS

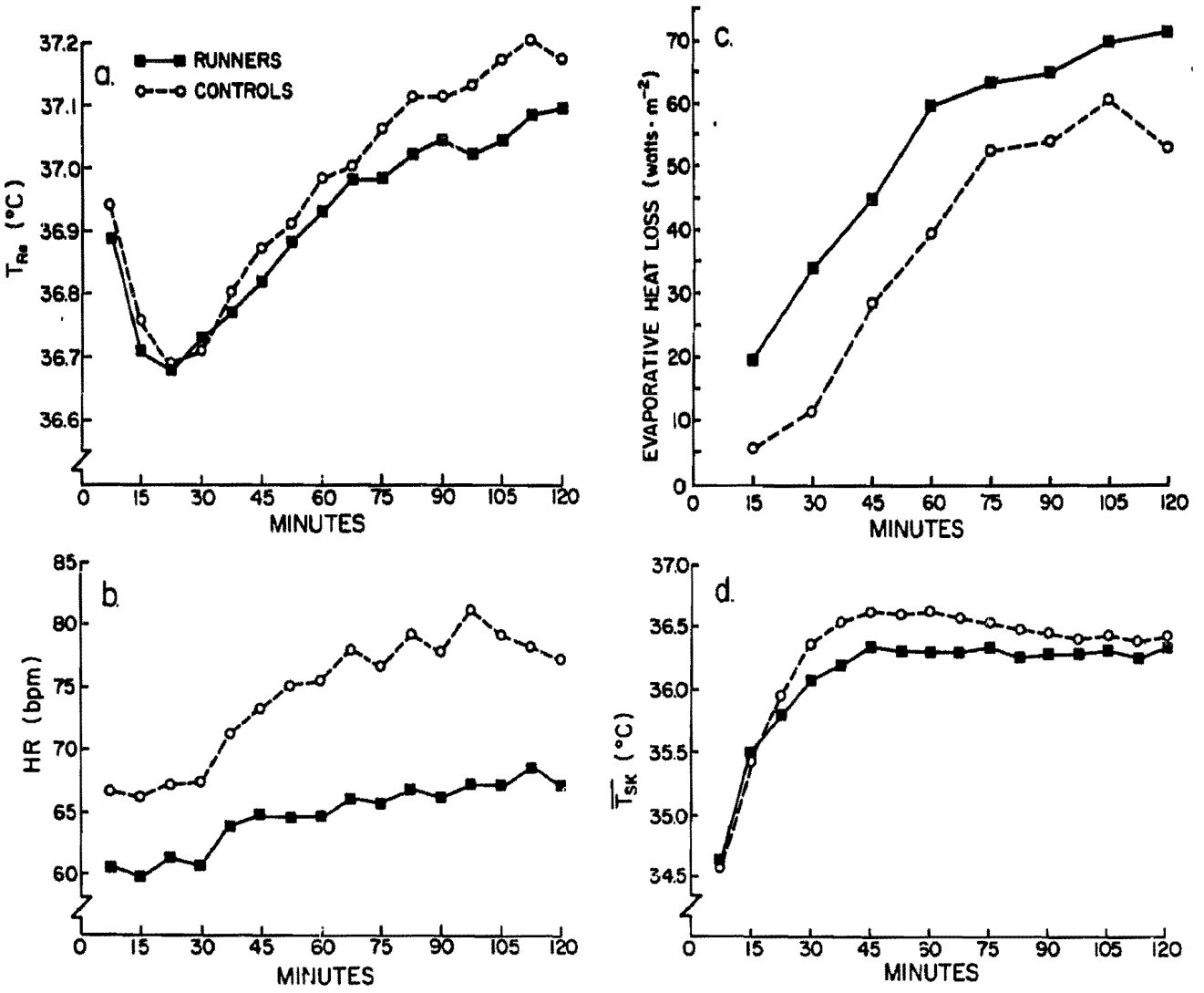
[a] Runners vs. Non-Runners: Hour 1

[b] Runners vs. Non-Runners: Hour 2

[c] Hour 2 vs. Hour 1: Runners

[d] Hour 2 vs. Hour 1: Non-Runners

Fig. 14. a: Rectal temperature (°C); b: heart rate (bpm); c: evaporative heat loss (watts·m^{-2}); and d: mean skin temperature (°C) of runners (■) and non-runners (o) during 2 h resting in the environmental chamber.


a.
RUNNERS
CONTROLS
T_{Re} (°C)
37.2
37.1
37.0
36.9
36.8
36.7
36.6
0 15 30 45 60 75 90 105 120
MINUTES
b.
HR (bpm)
85
80
75
70
65
60
0 15 30 45 60 75 90 105 120
MINUTES
c.
EVAPORATIVE HEAT LOSS (watts · m^{-2})
70
60
50
40
30
20
10
0
0 15 30 45 60 75 90 105 120
MINUTES
d.
$\overline{T}_{SK}$ (°C)
37.0
36.5
36.0
35.5
35.0
34.5
0 15 30 45 60 75 90 105 120
MINUTES

Forearm blood flow did not differ between groups (Fig. 15). There was a steady rise in flow for both groups during the first 45 min and a constant rate averaging 3.27 ml·100 ml^{-1}·min^{-1} and 2.75 ml·100 ml^{-1}·min^{-1} for R and NR respectively.

Plasma volume shifts were insignificant and did not differ between R (-0.19%) and NR (0.06%) for the two-hour exposure.

Study #4. Thermoregulation and the menstrual cycle.

A complete report of this study, which was started under NIH Grant NIH 1 R01 ES00849 and completed under the present grant, NIH 5 R01 OH00896, is found in the publication:

Horvath, S. M., and B. L. Drinkwater
Thermoregulation and the Menstrual Cycle
Aviat. Space Environ. Med. 53: 790-794, 1982

DISCUSSION

Study #1. Sweating threshold and capacity of women related to age.

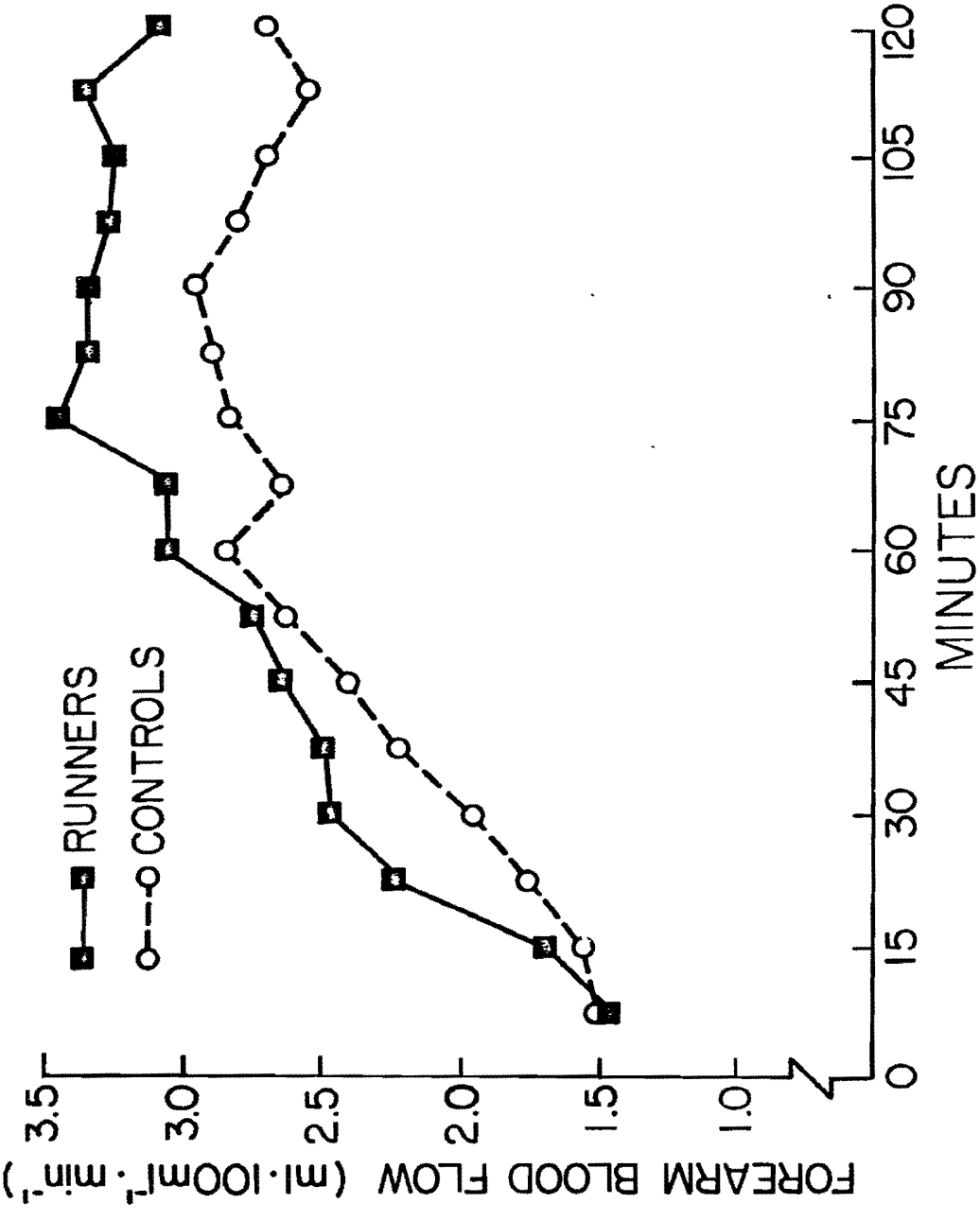
A complete discussion of the results of this study is found in the publication:

Drinkwater, B. L., J. F. Bedi, A. B. Loucks, S. Roche, and S. M. Horvath
Sweating Sensitivity and Capacity of Women in Relation to Age
J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 53: 671-676, 1982

Study #2. Aging effect of women's response to exercise under thermal stress.

In Study #1 the challenge to the thermoregulatory system was thermal stress from the environment. The results uniformly supported

Fig. 15. Forearm blood flow of runners (■) and non-runners (○) during 2 h resting in the environmental chamber.


FOREARM BLOOD FLOW (ml·100ml⁻¹·min⁻¹)
3.5
3.0
2.5
2.0
1.5
1.0
0
15
30
45
60
75
90
105
120
MINUTES
RUNNERS
CONTROLS

the concept that aging per se does not result in a diminished function of the sweating mechanism while women are resting in a hot environment. This study went further and addressed the question, "Does aging diminish the sweating response when exercise-induced metabolic heat production is added to environmental heat stress?" Again the answer is no. As in the previous study, the data do not show any aging effect on the sweating response. Both times for onset of sweating and whole-body evaporative heat loss were the same for both age groups. Differences in regional sweat rate favored the older women during the first exercise period, but after 30 min in the chamber regional sweat rate was the same for both groups. Temperature-related variables - T_{re}, $\bar{T}_b$, $\bar{T}_{sk}$, body heat content, and heat storage - were the same for older and younger women.

Since the sweating response was of primary concern, the same absolute workload was assigned each subject regardless of her $\dot{V}_{O_2\ max}$. It was anticipated that the older subjects would have a higher HR and T_{re} because they would be exercising at a higher relative intensity (% $\dot{V}_{O_2}$ max). While this difference did appear during Cycles 1 and 2, it was not significant because of the large variability within age groups. When the entire subject pool was divided into the C and NC groups, the effect of relative workload became apparent. Those women who failed to complete the entire 60 min of the experiment did so because their HR's reached 90% HR_{max}. Their low aerobic power resulted in a much higher relative workload (64%) than that of the other women (34%). In contrast, the heart rates for the older women

able to complete the session were no different than those of younger women (Fig. 7). A similar pattern was observed for core temperature (Fig. 8). In spite of their lower tolerance time, the NC women had the same whole-body sweat rate, threshold T_{re} for onset of sweating, mean regional sweat rate, and time for onset of sweating as those who completed the 60-min exposure. These data plus the results of the correlation analysis support the hypothesis that some factor(s) related to cardiovascular fitness ($\dot{V}O_{2\ max}$), not age-related changes in the sweating mechanism per se, are responsible for the decrease in heat tolerance noted in older individuals.

Study #3. Effect of endurance training on women's regional and whole-body sweating response.

Previous reports from this laboratory (8, 9) have shown quite clearly that differences in cardiovascular fitness, not gender, were primarily responsible for the belief that women could not withstand heat stress as well as men. The results of the present studies suggest that a decrease in cardiovascular fitness, or some factor(s) related to it, are also responsible for the decrease in heat tolerance noted among many older individuals.

The lower heart rate, core temperature, and heat storage observed for physically trained subjects during heat exposure are generally attributed to a more effective sweating response as well as improved cardiovascular function. The question which has not been resolved is whether the effect of physical conditioning on

the sweating response is identical to that of heat acclimatization, which is characterized by both an earlier onset of sweating and an increase in sweat rate (21, 36).

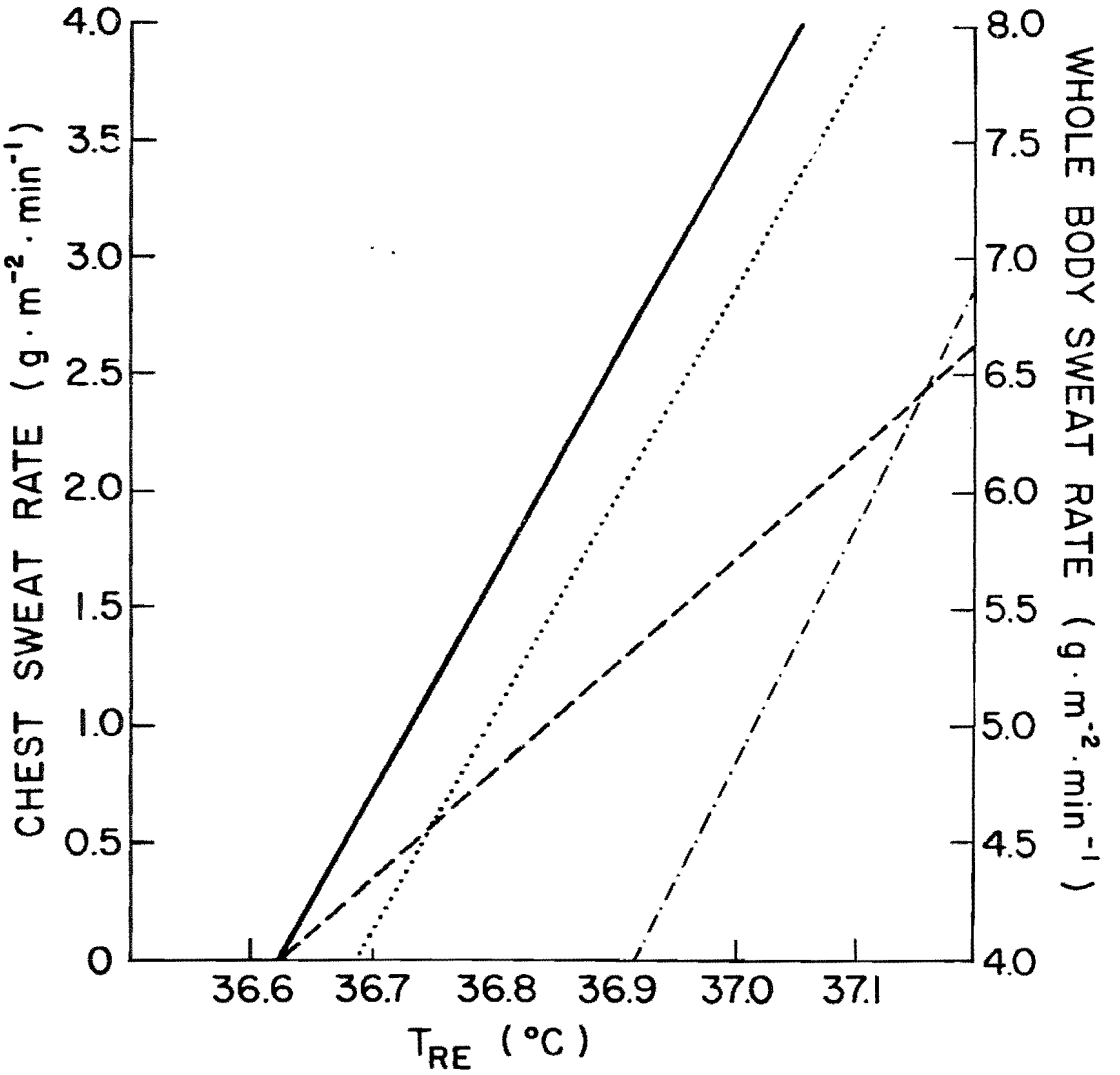
The group at the John B. Pierce Foundation has reported that exercise training increases the slope of the sweat rate to core temperature relationship ($\dot{m}_{sw}/T_{re}$) with a small decrease in sweating threshold and no change in the zero point central drive for sweating (21, 24). Heat acclimatization, according to these investigators, changes the zero point of the central drive for sweating without any increase in the gain constant for $\dot{m}_{sw}/T_{re}$. Their conclusion is that exercise training affects the sweating response at the periphery, while heat acclimatization has an effect on the central mechanisms.

Other investigators (13, 19) have attributed the change in sweating response following training to a central mechanism and the change due to heat acclimatization to a modification of the peripheral response. The lack of consensus may be due to differences in experimental protocol. If, for example, chest sweat rate is not representative of whole-body sweating, the choice of measurement site may explain the different conclusions reached by Henane et al. (19) and Nadel et al. (21). There may also be differences in sweating response between rest, when thermal stress is largely environmental, and exercise, when heat stress is both metabolic and environmental. These and other differences in experimental design such as humid vs. dry environments, level of conditioning, relative vs. absolute workloads, etc. make it difficult to resolve the issue.

The results of our study provide strong evidence that not all regional sites reflect the sweating response of the body as a whole and that the selection of site is an important variable in determining the effect of physical training and/or heat acclimatization on the sensitivity and capacity of the sweating mechanism. Data from the chest capsule are in agreement with those of Nadel et al. (21), who used chest sweat rate to illustrate an increase in the gain constant with a minimal decrease in T_{es} threshold following training. Our women runners had twice the sweat rate gain per degree rise in T_{re} than NR subjects (R: $\beta = 9.43$; NR: $\beta = 4.62$) but no difference in the T_{re} threshold for onset of sweating as derived by extrapolating the regression lines to SR = 0 (Fig. 16). Yet when whole-body sweat is used to illustrate the difference in sweating response of the R and NR groups, there is no difference in slope but a marked difference in T_{re} threshold (Fig. 16), as reported by Henane et al. (19), who also used whole-body sweat rate.

In this study we have determined the onset of sweating at two sites, the forearm and abdomen, and can compare the observed T_{re} at onset with that calculated by extrapolating the regression lines for capsule sweat rates at the same sites. For both arm and abdomen, the difference in observed T_{re} threshold between R and NR was 0.1°C; by extrapolation, ~ 0.03°C. Neither difference was significant. The regression lines for these sites converge at 36.6° ± 0.02°C at SR = 0, while the measured T_{re} thresholds ranged from 36.7-36.9°C.

Fig. 16. Regression lines derived from the relationship between chest sweat rate (R: ——— ; NR: — —) and whole-body sweat rate (R: ····· ; NR: — · —) and rectal temperature (T_{re}).


CHEST SWEAT RATE (g · m⁻² · min⁻¹)
WHOLE BODY SWEAT RATE (g · m⁻² · min⁻¹)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
36.6
36.7
36.8
36.9
37.0
37.1
T_RE (°C)

It appears that extrapolating from capsule sweat rates underestimates T_{re} thresholds, since 36.6°C was below the actual T_{re} of both groups at any point in the 2-h period. A cardinal rule of regression analysis is not to extrapolate a regression line beyond the data points. Violating that rule may introduce another source of error into the effort to delineate the specific effects of physical conditioning vs. heat acclimatization on sweating response.

The effect of endurance training on the sweating response of the women in this study was a significantly higher sweat rate for R subjects. This was true whether it was expressed as capsule sweat rate, total body evaporative heat loss ($W \cdot m^{-2} \cdot h$), or as $\dot{m}_{sw}/T_{re}$. Although there were no significant differences in either time or threshold T_{re} for the onset of sweating, the R group had a higher sweat rate at every level of T_{re} for both capsule and whole-body measurements (Fig. 15).

The significant difference in HR between groups probably reflects lower initial levels for the endurance trained group. Since differences in $\bar{T}_{sk}$ and FBF between R and NR were not significant, one would not expect marked differences in HR response to the heat stress between groups.

The results of all three studies suggest that healthy older individuals who remain physically active are less likely to have adverse reactions to heat stress than their sedentary counterparts. They will have an even greater advantage if the activity they select raises their core temperature to the point where they are actively sweating.

REFERENCES

1. Baum, E., K. Brück, and H. P. Schwennicke. Adaptive modifications of the thermoregulatory system of long-distance runners. J. Appl. Physiol. 40: 404-410, 1976.

2. Brožek, J., F. Grande, J. T. Anderson, and A. Keys. Densitometric analysis of body composition: Revision of some quantitative assumptions. Ann. N.Y. Acad. Sci. 110: 113-140, 1963.

3. Clausen, J. P., O. A. Larson, and J. Trap-Jensen. Physical training in the management of coronary artery disease. Circulation 40: 143-154, 1969.

4. Dill, D. B., K. Braithwaite, W. C. Adams, and E. M. Bernauer. Blood volume of middle-distance runners: Effect of 2,300-m altitude and comparison with non-athletes. Med. Sci. Sports 6: 1-7, 1974.

5. Dill, D. B., and C. F. Consolazio. Responses to exercise as related to age and environmental temperature. J. Appl. Physiol. 17: 646-648, 1962.

6. Dill, D. B., and D. L. Costill. Calculation of percentage changes in volumes of blood, plasma, and red cells in dehudration. J. Appl. Physiol. 37: 247-248, 1974.

7. Dill, D. B., F. W. Kasch, M. K. Yousef, L. F. Soholt, and D. L. Wolfenbarger. Cardiovascular responses and temperature regulation in relation to age. Aust. J. Sports Med. 7: 99-106, 1975.

8. Drinkwater, B. L., J. E. Denton, I. C. Kupprat, T. S. Talag, and S. M. Horvath. Aerobic power as a factor in women's response to work in hot environments. J. Appl. Physiol. 41: 815-821, 1976.

9. Drinkwater, B. L., I. C. Kupprat, J. E. Denton, and S. M. Horvath. Heat tolerance of female distance runners. Ann. N.Y. Acad. Sci. 301: 777-792, 1977.

10. Drinkwater, B. L., and S. M. Horvath. Heat tolerance and aging. Med. Sci Sports 11: 49-55, 1979.

11. Drinkwater, B. L., and S. M. Horvath. Thermoregulatory response of postmenopausal women to exercise in the heat. Proceedings, NIA Conference on Exercise in the Elderly, Washington, D.C., October 27-29, 1977.

12. Drinkwater, B. L., S. M. Horvath, and C. L. Wells. Aerobic power of females, ages 10 to 68. J. Gerontol. 30: 385-394, 1975.

13. Elizondo, R. S., and R. W. Bullard. Local determinants of sweating and the assessment of the "set point." Int. J. Biometeorol. 15: 273-280, 1971.

14. Flint, M. M., B. L. Drinkwater, C. L. Wells, and S. M. Horvath. Validity of estimating body fat of females: Effect of age and fitness. Hum. Biol. 49(4): 559-572, 1977.

15. Gisolfi, C. Work tolerance derived from interval training. J. Appl. Physiol. 35: 349-354, 1973.

16. Grimby, G., E. Häggendal, and B. Saltin. Local xenon 133 clearance from the quadriceps muscle during exercise in man. J. Appl. Physiol. 22: 305-310, 1967.

17. Hellon, R. F., and A. R. Lind. Observations of the activity of sweat glands with special reference to the influence of ageing. J. Physiol. 133: 132-144, 1956.

18. Hellon, R. F., A. R. Lind, and J. S. Weiner. The physiological reactions of men of two age groups to a hot environment. J. Physiol. 133: 118-131, 1956.

19. Henane, R., R. Flandrois, and J. P. Charisonnier. Increase in sweating sensitivity by endurance conditioning in man. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 43: 822-828, 1977.

20. Lofstedt, B. Human Heat Tolerance. Lund, Sweden: Department of Hygiene, University of Lund, 1966.

21. Nadel, E. R., K. B. Pandolf, M. F. Roberts, and J. A. J. Stolwijk. Mechanisms of thermal acclimation to exercise and heat. J. Appl. Physiol. 37: 515-520, 1974.

22. Piwonka, R. W., S. Robinson, V. L. Gay, and R. S. Manalis. Pre-acclimatization of men to heat by training. J. Appl. Physiol 20: 379-384, 1965.

23. Plowman, S. A., B. L. Drinkwater, and S. M. Horvath. Age and aerobic power: A longitudinal study. J. Gerontol. 34: 512-520, 1979.

24. Roberts, M. F., C. B. Wenger, J. J. Stolwijk, and E. R. Nadel. Skin blood flow and sweating changes following exercise training and heat acclimation. J. Appl. Physiol.: Respirat. Environ. exercise Physiol. 43: 133-137, 1977.

25. Senay, L. C., Jr. Plasma volumes and constituents of heat-exposed men before and after cllimatization. J. Appl. Physiol 38: 570-575, 1975.

26. Senay, L. C., D. Mitchell, and C. H. Wyndham. Acclimatization in a hot, humid environment: Body fluid adjustments. J. Appl. Physiol. 40: 786-796, 1976.

27. Shoenfeld, Y., R. Udassin, Y. Shapiro, A. Ohri, and E. Sohar. Age and sex differences in response to short exposure to extreme dry heat. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 44: 1-4, 1978.

28. Shvartz, E., L. Bhattacharya, S. J. Sperinde, P. J. Brock, D. Sciaraffa, and W. Van Beaumont. Sweating responses during heat acclimation and moderate conditioning. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 46: 675-680, 1979.

29. Shvartz, E., Z. Glick, and A. Magazanik. Responses to temperate, cold, and hot environments and the effect of physical training. Aviat. Space Environ. Med. 48: 254-260, 1977.

30. Shvartz, E., A. Magazanik, and Z. Glick. Thermal responses during training in a temperate climate. J. Appl. Physiol 36: 572-576, 1974.

31. Strydom, N. B., C. H. Wyndham, C. G. Williams, J. F. Morrison, G. A. G. Bredell, A. J. S. Benade, and M. Von Rahden. Acclimatization to humid heat and the role of physical conditioning. J. Appl. Physiol. 21: 636-642, 1966.

32. U.S. Department of Health and Human Services. Heatstroke. In: United States, 1980, Morbidity and Mortality Weekly Reports 30: 277-279, 1981.

33. Vanderhoof, E. R., C. J. Imig, and H. M. Hines. Effect of muscle strength and endurance development on blood flow. J. Appl. Physiol. 16: 873-877, 1961.

34. Varnauskakas, E., P. Bjorntorp, M. Fahlen, I. Prerovsky, and J. Stenberg. Effects of physical training on exercise blood flow and enzymatic activity in skeletal muscle. Cardiovasc. Res. 4(4): 418-422, 1970.

35. Wagner, J. A., S. Robinson, S. P. Tzankoff, and R. P. Marino. Heat tolerance and acclimatization to work in the heat in relation to age. J. Appl. Physiol. 33: 616-622, 1972.

36. Wyndham, C. H., A. J. A. Benade, C. G. Williams, N. B. Strydom, A. Goldin, and A. J. A. Heyns. Changes in central circulation and body fluid spaces during acclimatization to heat. J. Appl. Physiol. 25: 586-593, 1968.