

Thermoregulatory responses of middle-aged and young men during dry-heat acclimation



KENT B. PANDOLF, BRUCE S. CADARETTE, MICHAEL N. SAWKA,
ANDREW J. YOUNG, RALPH P. FRANCESCONI, AND RICHARD R. GONZALEZ
United States Army Research Institute of Environmental Medicine, Natick, Massachusetts 01760-5007

PANDOLF, KENT B., BRUCE S. CADARETTE, MICHAEL N. SAWKA, ANDREW J. YOUNG, RALPH P. FRANCESCONI, AND RICHARD R. GONZALEZ. *Thermoregulatory responses of middle-aged and young men during dry-heat acclimation*. *J. Appl. Physiol.* 65(1): 65-71, 1988.—Thermoregulatory responses during heat acclimation were compared between nine young (mean age 21.2 yr) and nine middle-aged men (mean age 46.4 yr) who were matched ($P > 0.05$) for body weight, surface area, surface area-to-weight ratio, percent body fat, and maximal aerobic power. After evaluation in a comfortable environment (22°C, 50% relative humidity), the men were heat acclimated by treadmill walking (1.56 m/s, 5% grade) for two 50-min exercise bouts separated by 10 min of rest for 10 consecutive days in a hot dry (49°C ambient temperature, 20% relative humidity) environment. During the first day of heat exposure performance time was 27 min longer ($P < 0.05$) for the middle-aged men, whereas final rectal and skin temperatures and heart rate were lower, and final total body sweat loss was higher ($P < 0.05$) compared with the young men. These thermoregulatory advantages for the middle-aged men persisted for the first few days of exercise-heat acclimation ($P < 0.05$). After acclimation no thermoregulatory or performance time differences were observed between groups ($P > 0.05$). Sweating sensitivity, esophageal temperature at sweating onset, and the sweating onset time did not differ ($P > 0.05$) between groups either pre- or postacclimation. Plasma osmolality and sodium concentration were slightly lower for the young men both pre- and postacclimation; however, both groups had a similar percent change in plasma volume from rest to exercise during these tests. Final rated perceived exertion was generally higher ($P < 0.05$) for the young men throughout the acclimation period, whereas final thermal sensation was higher ($P < 0.05$) only on the first acclimation day. Greater regular weekly aerobic activity for the middle-aged men was associated with their better initial performance during exercise in the heat; however, heat acclimation negated this advantage. Evidence from the present study indicated little impairment of the thermoregulatory system at least through the fifth decade of life for physically trained middle-aged men.

aging; blood responses; exercise-heat tolerance; heat acclimatization; perceptual responses; physiological responses; sweating responses; temperature regulation.

IN GENERAL, exercise-heat tolerance has been reported to be reduced in middle-aged¹ men and women (5, 30). Middle-aged men have been shown to have higher heart rates, mean skin and core temperatures, and lower sweat

¹ The medical subject heading of the National Library of Medicine for 1987 defines "middle aged" as between 45 and 64 yr.

rates than young men during exercise in the heat both pre- and postacclimation (13, 30). It has also been reported that middle-aged men start to sweat later and/or sweat less during exercise in the heat than young men (12, 16). However, a group of presumably active middle-aged women had the same sweating capacity and core temperature at sweat onset as younger women during both rest and exercise in the heat (4, 6).

Some authors (25) have implied that physically fit middle-aged men had fewer decrements in performance of exercise in the heat than less fit individuals of the same age. In fact, Robinson et al. (25) compared the acclimation responses to exercise in the heat for fit men during 1942 with the responses of these same individuals some 21 yr later. These middle-aged men were acclimated to exercise in the heat at the same rate and to the same degree as when they were younger (25). However, none of the above-mentioned studies (4-6, 12, 13, 16, 25, 30) attempted to match middle-aged and younger individuals for any pertinent physiological and/or morphological variables. Many authors (1, 2, 7, 9, 10, 15, 18, 20, 22, 24) have suggested that body weight, surface area, body fat, and/or maximal aerobic power were closely related with an individual's ability to thermoregulate in the heat. Furthermore, these studies on aging did not answer whether the exercise-heat intolerance observed with aging was due to age per se or was more related to other factors such as decreased physical activity and lowered maximal aerobic power (15).

Two recent studies (1, 7) have demonstrated that when men and women were similar with regard to maximal aerobic power, surface area, and/or surface area-to-mass ratio, the previously reported (32) sex-related differences in thermoregulatory responses to heat were diminished or eliminated both pre- and postacclimation. Therefore it seemed likely that age-related differences in thermoregulatory responses would be reduced if two groups differing in age were similar to each other in terms of maximal aerobic power and selected morphological factors.

The purpose of this investigation was to examine thermoregulatory responses during heat acclimation in a young and middle-aged group of men. We hypothesized that if young and middle-aged men were matched for maximal aerobic power and selected morphological factors, many of the reported differences in thermoregula-

tory responses during exercise-heat acclimation associated with aging would disappear.

METHODS

Subjects. Nine middle-aged men served as volunteer subjects after medical screening. To match these individuals with their younger counterparts for maximal aerobic power and selected morphological factors, we had to evaluate 22 young men. The physical characteristics of the nine young and nine middle-aged men are presented in Table 1. All subjects were informed of the potential risk and gave their written consent. All experiments were conducted between mid-March and mid-April when subjects were not naturally heat acclimated. All subjects had resided in the Northeast for the previous 6 mo.

Protocol. Before experimental testing in the heat, each subject's percent body fat was determined by hydrostatic weighing and maximal aerobic power ($\dot{V}O_{2\max}$) determined by a treadmill-running test. The maximal treadmill protocol was progressive in intensity and continuous in nature. The initial treadmill grade was zero and increased by 2.5% increments every 1.5 min while subjects ran at either 2.68 or 3.13 m/s. Each subject's running speed was determined from his heart rate response to a 10-min warm-up walk (1.56 m/s, 10% grade). If the heart rate response was ≥ 145 beats/min, the 2.68-m/s speed was selected for the maximal test. Documented criteria (17, 29) were employed for determination of $\dot{V}O_{2\max}$ for the 2.68 and 3.13-m/s tests.

Subjects were then concurrently heat acclimated by walking on a treadmill (1.56 m/s, 5% grade) for two 50-min exercise bouts separated by a 10-min rest period for 10 consecutive days in a hot dry [49°C ambient temperature (T_a), 20% relative humidity (rh)] environment. It was anticipated that this exercise intensity would require $\sim 45\%$ $\dot{V}O_{2\max}$ for both groups. During testing subjects wore gym shorts and tennis shoes; ad libitum water drinking was encouraged during most of the acclimation sessions. However, on the first and last acclimation days, some water drinking restrictions were enforced because of the need to measure esophageal temperature and to control for the effects of gastrointestinal absorption on collected blood samples. All acclimation sessions were individually terminated, if necessary, by predetermined end points of a rectal temperature $>39.5^\circ\text{C}$, physical exhaustion, dizziness, nausea, or dry skin. Heat acclimation was preceded by an identical protocol in a comfortable environment (22°C, 50% rh) to familiarize subjects with the testing procedures and collect base-line data. Each subject was tested at the same time of day in

a fairly consistent state of hydration.

Physiological and perceptual variables. Electrocardiograms were obtained with chest electrodes (CM5 placement) and radiotelemetered to an oscilloscope-cardiotachometer unit (Hewlett-Packard). Oxygen uptake ($\dot{V}O_2$, l/min STPD) was determined by open-circuit spirometry. Subjects breathed via a two-way breathing valve (Collins two-way J), and expired gases were collected in 150-liter Douglas bags. Expired gases were analyzed for O_2 concentration using an Applied Electrochemistry S-3A analyzer and for CO_2 with a Beckman LB-2 analyzer. Volume of expired air was measured by a Tissot gasometer. During $\dot{V}O_{2\max}$ tests an automated system (Sensormedics Horizon MMC) was used to measure $\dot{V}O_2$ employing a Hans Rudolph (no. 2700) breathing valve.

During these sessions core temperature was obtained from a thermistor inserted ~ 10 cm beyond the anal sphincter and in the esophagus at the level of the heart (31). Rectal temperature was measured during each of these sessions, but esophageal temperature was measured during the comfortable environment evaluation and the first and last heat acclimation days only. Skin temperatures were monitored with a three-point thermocouple skin harness (chest, calf, and forearm), and mean weighted skin temperature was calculated (2, 27). Both rectal temperature and mean skin temperature values were plotted for each subject at 2-min intervals using a HP 9825-B computer and HP 9872-C plotter. Local sweating rates (\dot{m}_s) from the upper arm were determined by ventilated dew-point sensors placed on the skin (11). Before each test, nude body weight was determined on a K-120 Sauter precision electronic balance (accuracy ± 10 g). Total body sweat loss (M_{sw}) was calculated from nude body weight changes adjusted for water intake and urine output. Rated perceived exertion using the Borg scale (19) and thermal sensation using a category rating scale (22) were evaluated every 25th min of each exercise bout. The rating scale for thermal sensation was recently illustrated by Young et al. (33). All subjects were interviewed to determine their regular weekly aerobic activity in terms of miles run per week over the past year and their general physical activity habits since entering high school.

Blood analysis. Venous blood samples were collected from a Teflon catheter placed in a superficial arm vein. Patency was maintained with heparinized saline; the catheter (2 ml) was flushed with 4 ml of blood before each 10-ml sample was obtained. During the first and last heat acclimation sessions, resting blood samples were obtained with the subjects in a standing position (for 30

TABLE 1. Physical characteristics of young and middle-aged subjects

	n	Age, yr	Ht, cm	Wt, kg	A_D , m^2	A_D/wt , cm^2/kg	BF, %	$\dot{V}O_{2\max}$, l/min	$\dot{V}O_{2\max}$, $ml \cdot kg^{-1} \cdot min^{-1}$	HR_{\max} , beats/min	Activity, miles/wk
Young	9	21.2 \pm 2.4	173.1 \pm 3.8	76.3 \pm 6.6	1.90 \pm 0.08	250.2 \pm 12.9	14.7 \pm 4.9	4.036 \pm 0.50	52.9 \pm 5.2	197.2 \pm 5.6	4.6 \pm 8.0
Middle-aged	9	46.4 \pm 4.6	179.9 \pm 5.7	82.2 \pm 9.5	2.01 \pm 0.12	248.8 \pm 15.8	16.6 \pm 5.5	4.169 \pm 0.60	51.3 \pm 9.2	177.7 \pm 9.9	24.1 \pm 19.7
P		<0.01	<0.05	>0.05	>0.05	>0.05	>0.05	>0.05	>0.05	<0.05	<0.05
				(P = 0.17)	(P = 0.06)	(P = 0.61)	(P = 0.45)	(P = 0.69)	(P = 0.64)		

Values are means \pm SD. A_D , surface area; A_D/wt , surface area-to-weight ratio; BF, body fat; $\dot{V}O_{2\max}$, maximal O_2 uptake; HR_{\max} , maximal heart rate; Activity, weekly regular aerobic activity. Median ages for young and middle-aged groups are 21 and 46 yr, respectively.

min before sampling) in an antechamber (20°C T_a , 40% rh), and exercise blood samples were obtained ~25 min into each bout while the subjects continued to walk. Triplicate measurements were made of hematocrit, and duplicate measurements were made of all other blood variables. An automated system was used to measure hemoglobin (Hemoglobinometer, Coulter Electronics), whereas plasma osmolality was measured by a vapor pressure method (Wescor, no. 5500), and plasma sodium was determined by an ion-selective membrane method (Nova Biomedical). The percent changes in plasma volume from rest were calculated from the appropriate hemoglobin and hematocrit values (3).

Statistical analysis. A repeated-measures analysis of variance was used to compare the thermoregulatory and perceptual values. If significant F values were found, critical differences were determined by Tukey's procedures. Paired t tests were used to evaluate differences in the physical characteristics between the middle-aged and young subjects. All subjects completed the heat acclimation sessions, whereas two subjects from each group missed the comfortable environment evaluation due to illness, and only four subjects in each group volunteered for esophageal temperature measurements. Statistical significance was accepted at the $P < 0.05$ level.

RESULTS

No significant differences ($P > 0.05$) were observed between the middle-aged and young men (Table 1) for body weight, DuBois surface area (A_D), surface area-to-weight ratio (A_D/wt), percent body fat, and $\dot{V}O_{2\text{max}}$ (l/min or $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$). However, these groups differed ($P < 0.05$) in age, height, maximal heart rate (HR_{max}), and weekly aerobic activity. During these experiments there were no group differences ($P > 0.05$) in the relative exercise intensity ($\%\dot{V}O_{2\text{max}}$) associated with treadmill walking at 1.56 m/s, 5% grade [young men $43.8 \pm 5.6\%$ (SD), middle-aged men $44.4 \pm 8.6\%$ (SD)].

Even though not presented formally, metabolic rate (W or W/m^2) did not differ between days 1 and 10 of heat acclimation. Also, there were no differences between groups in metabolic rate on either the first or last acclimation day. For both groups, preexposure body weight did not change ($P > 0.05$) between days 1 and 10 of acclimation. Water consumption did not differ ($P > 0.05$) between groups on either day 1 or 10 of acclimation. Both groups completed the first and last acclimation sessions at $<2\%$ reduction in body weight [young men $-0.75 \pm 0.96\%$ (SD), middle-aged men $-1.56 \pm 1.05\%$ (SD)].

Figure 1 contrasts the performance time (min) between the young and middle-aged men in the comfortable environment (C) and during heat acclimation. In the comfortable environment, all subjects ($n = 7$, each group) completed the 120-min exposure. In contrast, performance time for the young men was shorter ($P < 0.05$) on the first day of heat acclimation compared with all other acclimation days. In all instances, performance time was limited because rectal temperature exceeded 39.5°C . Performance time did not differ ($P > 0.05$) across acclimation days for the middle-aged men. When performance

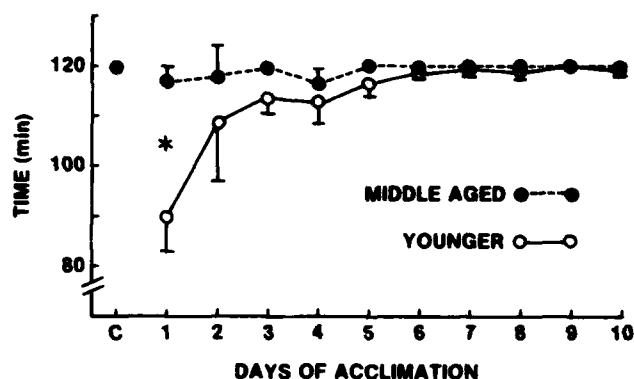


FIG. 1. Comparison of performance time between middle-aged and young men during control (C) day and during each of 10 exercise-heat acclimation days. All subjects from both groups completed 120-min exposure during control day. Values are means \pm SE. * Significant difference ($P < 0.05$).

time between groups was contrasted, the middle-aged men averaged a 27-min longer exposure on the first day of acclimation ($P < 0.05$), but performance time did not differ significantly between groups during the remaining days of acclimation ($P > 0.05$).

Figure 2 presents the final rectal temperature (T_{re}), final mean-weighted skin temperature (T_{sk}), final HR and final \dot{M}_{ow} for the young and middle-aged men during the comfortable environment evaluation and 10 days of heat acclimation. For the young men, final T_{re} decreased ($P < 0.01$) from a mean value of $39.4 \pm 0.1^{\circ}\text{C}$ (SE) for day 1 to $38.7 \pm 0.2^{\circ}\text{C}$ for day 10. Respective values for the middle-aged men were $39.0 \pm 0.1^{\circ}\text{C}$ (day 1) and $38.5 \pm 0.1^{\circ}\text{C}$ (day 10, $P < 0.05$). For both groups differences in the T_{re} responses between days 8, 9, and 10 were not significant ($P > 0.05$). Even though final T_{re} did not differ ($P > 0.05$) between groups in the comfortable environment, final T_{re} was higher ($P < 0.05$) for the young men during each of the first four acclimation days but was not different during the remaining acclimation days ($P > 0.05$).

Final T_{sk} decreased ($P < 0.01$) for the young men from a mean value of $37.8 \pm 0.2^{\circ}\text{C}$ on day 1 to $36.7 \pm 0.2^{\circ}\text{C}$ on day 10. None of the differences in final T_{sk} for the young men between days 8 and 10 was significant. For the middle-aged men, final T_{sk} did not differ across acclimation days. In the comfortable environment, the final T_{sk} did not differ between groups, but final T_{sk} was higher ($P < 0.01$) for the young men only during the first 3 acclimation days.

Final HR decreased ($P < 0.05$) for both the young and middle-aged men from mean values of 164 ± 5 and 148 ± 5 beats/min on day 1 to 139 ± 4 and 129 ± 5 beats/min on day 10, respectively. No differences in final HR were observed between days 8 and 10 for both groups. Final HR was higher ($P < 0.05$) for the young men in the comfortable environment and for days 1, 2, 4, 5, and 7 of heat acclimation.

For the young men, final \dot{M}_{ow} was lower ($P < 0.01$) on day 1 of acclimation ($581 \pm 29 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$) than on day 10 ($744 \pm 22 \text{ g}\cdot\text{m}^{-2}\cdot\text{h}^{-1}$). No differences in final \dot{M}_{ow} were observed for these young men during days 8 to 10 of acclimation. Final \dot{M}_{ow} for the middle-aged men was

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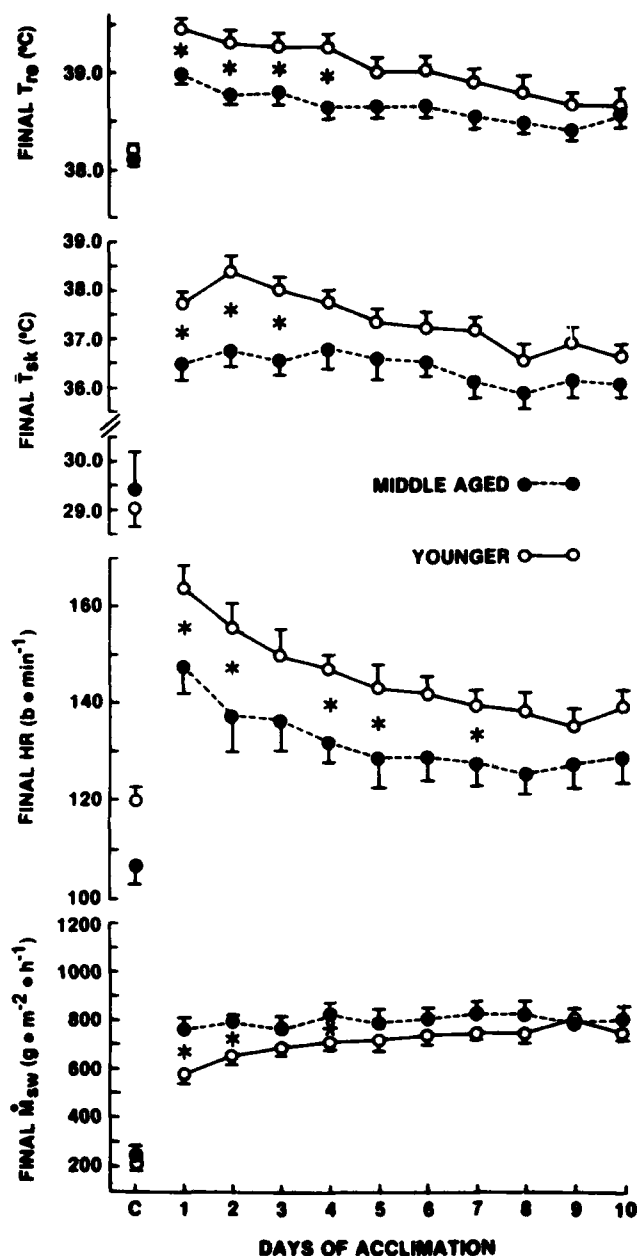


FIG. 2. Comparison of final rectal temperature (T_{re}), mean skin temperature (T_{sk}), heart rate (HR), and total body sweat loss (\dot{M}_{sw}) between middle-aged and young men during control (C) day and during each of 10 days of exercise-heat acclimation. Values are means \pm SE. * Significant difference ($P < 0.05$).

not different across acclimation days. Although final \dot{M}_{sw} did not differ between groups in the comfortable environment, final \dot{M}_{sw} was higher ($P < 0.05$) for the middle-aged men during days 1, 2, and 4 of heat acclimation.

Table 2 shows the mean \pm SE values for sweating sensitivity or slope of the \dot{m}_e -oesophageal temperature (T_{es}) relationship, T_{es} at sweating onset (threshold), and the sweating onset time (min) contrasting these two groups on the first and last heat acclimation day. Measurements were made during the first 30 min of these

exercise-heat exposures. For the young men, both T_{es} at sweat onset (threshold) and the sweating onset time (min) were lower ($P < 0.05$) on day 10 compared with day 1. For the middle-aged men, sweating onset time was lower ($P < 0.05$) on day 10 compared with day 1. When these two groups were compared, no differences were observed for either the slope, threshold, or onset time on the first or last day of heat acclimation.

Table 3 presents a comparison of the hematological data for the young and middle-aged men during the first and last day of heat acclimation. When no group differences were found, the two groups were combined to assess other treatment effects (acclimation and pre- and postacclimation). The percent change in plasma volume from rest to exercise did not differ between groups or with acclimation. Osmolality and Na^+ values were lower ($P < 0.05$) for the young compared with middle-aged men on day 1 (preacclimation) and on day 10 (postacclimation). Osmolality and Na^+ did not differ between day 1 and 10 of acclimation. For the young men, osmolality and Na^+ did not change during exercise. For the middle-aged men, however, osmolality was higher ($P < 0.05$) post- compared with preacclimation on day 10.

Figure 3 contrasts the final rated perceived exertion (RPE) and final thermal sensation (TS) between these groups in the comfortable environment and also during the 10 days of acclimation. Both final RPE and final TS did not differ across these 10 acclimation days for either the middle-aged or young men. Final RPE and TS also did not differ between groups in the comfortable environment. However, final RPE was higher ($P < 0.05$) for the young men on all acclimation days except for day 7 ($P = 0.06$). Although final TS appears higher for the young men throughout these 10 acclimation days, it was only statistically higher ($P < 0.05$) on day 1.

DISCUSSION

In the summary of their recent review, Kenney and Gisolfi (15) concluded that "when rigid criteria are applied to the relatively few studies which have addressed the issue of how age affects temperature regulation, the concept that heat tolerance and thermoregulatory function are compromised with advancing age is not supported. A comprehensive well-controlled study which screens for disease and normalizes for differences in aerobic power, body composition, body weight/surface area ratio, and state of acclimation is required to answer the questions posed at the beginning of this review." By matching the middle-aged and young men in our study for body weight, A_D , A_D/wt , body fat, and $\dot{V}O_{2max}$ (l/min and $ml \cdot kg^{-1} \cdot min^{-1}$) we have attempted to fulfill this requirement through an evaluation of the acute exercise-heat tolerance and rate and degree of heat acclimation for these individuals.

The acute exercise-heat tolerance of the middle-aged men was greater than that of the young men. Average performance time was 27 min longer during the first day of exercise in the heat for the middle-aged men, whereas final T_{re} , T_{sk} , and HR were lower, and final \dot{M}_{sw} was higher compared with the young men. These thermoregulatory advantages for the middle-aged men persisted for

TABLE 2. Slope, threshold, and time of sweating onset on first and last day of heat acclimation

	n	Slope, mg·cm ⁻² ·min ⁻¹ ·°C ⁻¹		Threshold, °C		Onset Time, min	
		Day 1	Day 10	Day 1	Day 10	Day 1	Day 10
		Young	4	0.50±0.06	0.59±0.02	36.99±0.09	36.67±0.08*
Middle-aged	4	0.47±0.09 (P = 0.78)	0.63±0.10 (P = 0.70)	36.79±0.12 (P = 0.23)	36.64±0.07 (P = 0.75)	6.25±1.44 (P = 0.86)	2.00±1.00* (P = 0.83)

Values are means ± SE. Slope, sweating sensitivity; threshold, esophageal temperature at sweating onset. * Significant difference ($P < 0.05$) from day 1 to day 10.

TABLE 3. Comparison of hematological data for young and middle-aged men during first and last day of heat acclimation

	Day 1		Pre (D ₁) - Pre (D ₁₀)	Day 10		Significant Differences		
	Pre	Post		Pre	Post	Y - MA	Acclimation	Pre - Post
ΔPV, %								
Y	Base line	7.3±2.8	8.0±2.2	Base line	3.8±0.6			
MA	Base line	3.7±1.5	5.1±2.6	Base line	3.7±1.8	NS	NS	NS
Osmolality, mosmol/kg								
Y	279±1	280±1		279±1	277±1	Pre (D ₁)*	NS	NS
MA	283±1	284±2		281±1	285±1	Post (D ₁₀)*	NS	D ₁₀ *
Sodium, meq/l								
Y	142.7±0.4	142.5±0.4		142.8±0.4	42.0±0.5	Post (D ₁)*	NS	NS
MA	143.5±0.4	144.5±0.5		143.4±0.4	45.0±0.5	Post (D ₁₀)*	NS	NS

Values are means ± SE for 1st and 10th days of acclimation period (D₁ and D₁₀) and difference between preexposure on day 1 and preexposure on day 10 [Pre (D₁) - Pre (D₁₀)] for young men (Y) and middle-aged men (MA) both preexposure (Pre) and postexposure (Post). ΔPV, change in plasma volume. In significant differences columns, * $P < 0.05$; D₁ > D₁₀, values for D₁ are significantly ($P < 0.05$) higher than those of D₁₀; Y - MA, difference between young men and middle-aged men; NS, not significant.

the first few days of exercise-heat acclimation. By the end of this 10-day heat acclimation period, no thermoregulatory differences or differences in performance time were observed between these groups. Both groups demonstrated most of the classical physiological changes associated with acclimation, which are heightened sweating response and lowered HR, T_{re} , and T_{sk} during exercise in the heat. The acclimation process was considered virtually complete for both groups by the documentation of nonsignificant changes in final T_{re} , T_{sk} , HR, and \dot{M}_{sw} during the last 3 days (days 8-10) of the acclimation period.

Our observations of better thermoregulatory performance for the middle-aged than young men during an acute exercise-heat exposure (first day of heat acclimation) are inconsistent with several reports (5, 25, 30). Thermoregulation during the initial day of exercise-heat exposure has been shown to be either the same (25) or poorer (5, 30) for middle-aged compared with young individuals. When thermoregulatory responses were contrasted postacclimation, Robinson et al. (25) showed that middle-aged and young men acclimated to about the same degree, which is in agreement with the findings of the present study, whereas Wagner et al. (30) reported the postacclimation thermoregulatory responses to be poorer for his middle-aged men. However, it must be remembered that none of these reports normalized middle-aged and young subjects for any pertinent morphological factors and/or maximal aerobic power.

We believe that the initial thermoregulatory advantage seen in our middle-aged men during the first few days of exercise-heat acclimation was associated with their significantly greater ($P < 0.05$) regular weekly aerobic ac-

tivity (see Table 1). Our middle-aged men averaged nearly 20 miles/wk more aerobic activity than their younger counterparts. Most authors have reported that physical training in a cool environment improves exercise-heat tolerance and/or the rate of acclimation (8-10, 18, 23, 24). Maintenance of an enhanced sweating response similar to that seen for our middle-aged men with little further change during heat acclimation has been reported previously for fit young men (8, 24). Several authors (10, 23, 24) have suggested that physically trained individuals showed many of the characteristics of heat-acclimated individuals while performing exercise in the heat and "behaved as though they were acclimated to the heat" (24). Enhanced regular aerobic activity on the part of our middle-aged men appears to have offset any impairment of their thermoregulatory systems if, indeed, aging per se affects thermoregulation. However, one could also interpret that the more active lifestyle of our middle-aged men may have masked any true age-related effects on their thermal tolerance.

Our findings on the impact of aerobic fitness or $\dot{V}O_{2\max}$ on exercise-heat tolerance are also worthy of comment. Henane et al. (14) evaluated the sweat loss during passive heating (55°C dry bulb, 40°C wet bulb) of six skiers (66.5 ml·kg⁻¹·min⁻¹, $\dot{V}O_{2\max}$) compared with four swimmers (65.8 ml·kg⁻¹·min⁻¹, $\dot{V}O_{2\max}$). The $\dot{V}O_{2\max}$ and A_D/wt did not differ between these groups, but the skiers displayed a higher level of heat tolerance and higher sweating rate and were better heat acclimated than the swimmers (14). These authors concluded that the reduced heat acclimation observed in the swimmers could be ascribed to a smaller increment in deep body temperature while training in cold water (14). Avellini et al. (2)

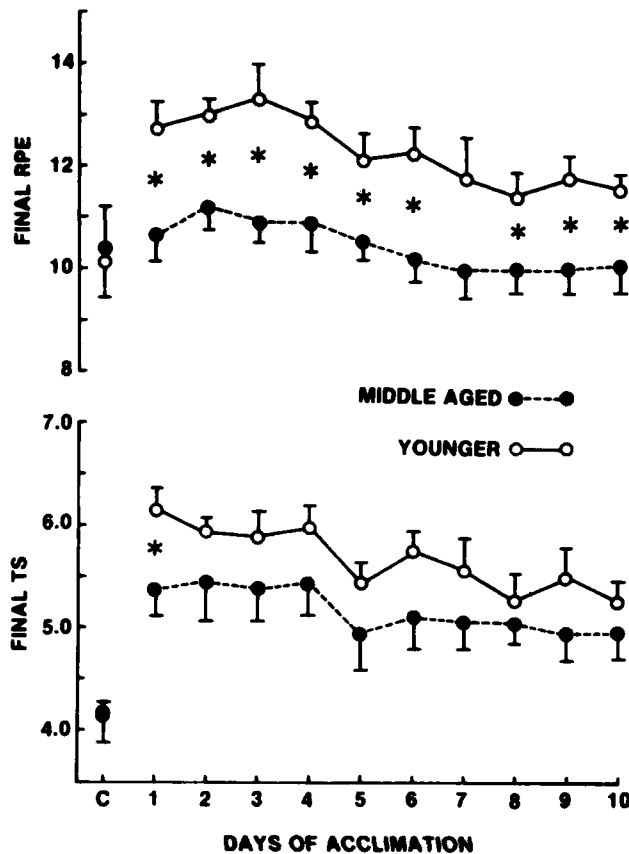


FIG. 3. Comparison of final rated perceived exertion (RPE) and thermal sensation (TS) between middle-aged and young men during control (C) day and during each of 10 days of exercise-heat acclimation. Values are means \pm SE. * Significant difference ($P < 0.05$).

showed that 4 wk of training in cold water (20°C) improved $\dot{V}O_{2\max}$ by ~15% but did not enhance exercise-heat tolerance; in fact, final T_{re} and T_{sk} were higher after training. During training in cold water, T_{re} and M_{tr} did not change. These authors concluded that core temperature must increase during exercise training to stimulate sweating for physical training to improve exercise-heat tolerance (2). Unlike the young men, our middle-aged men achieved and/or maintained their level of aerobic fitness through regular physical training. These findings support the contention that $\dot{V}O_{2\max}$ per se may not be as important in determining exercise-heat tolerance as the thermal adaptations associated with attaining the fitness level (9, 20, 21).

Core temperature at sweating onset (sweating threshold) and/or sweating rate have been compared between young and middle-aged individuals either during passive heating (4, 12, 28) or while exercising in the heat (5, 6, 16). Sweating rate has been reported to be lower (5, 16, 25, 28, 30) or the same (4, 6, 12) for middle-aged individuals, whereas sweating threshold did not change with age (4, 6, 12). In addition, Hellon and Lind (12) demonstrated that the onset of sweating during passive heating took twice as long (delayed 15 min) for their middle-aged men. This reduced or "sluggish" sweating response of middle-aged individuals has been attributed by some to neural

degeneration and/or a decline in the functional ability of their sweat glands (12, 28, 30).

Total body sweat loss was greater ($\sim 178 \text{ g} \cdot \text{m}^{-2} \cdot \text{h}^{-1}$) for our middle-aged than young men during acute exercise-heat exposure probably because of their more regular and intensive weekly aerobic activity. Interestingly, our local sweating measures did not reflect this whole-body value. Perhaps this was due to the differences known to exist between local sites of sweating (4). Local sweating from the upper arm and the more rapidly responding T_{re} were employed in our study to evaluate sweating sensitivity (slope), T_{re} at sweating onset (threshold), and time of sweating onset (min) on the first and last day of heat acclimation for matched subjects ($n = 4$, each group). The T_{re} threshold at sweating onset did not differ between our middle-aged and young men during acute exercise-heat exposure (day 1 of acclimation), which is in agreement with previous reports using T_{re} (4, 6, 12); however, our findings showed no differences between groups after 10 days of heat acclimation. We have also shown that the sweating sensitivity or m_s -to- T_{re} response and onset time for sweating did not differ between groups either pre- or postacclimation. Sweating onset time was reduced for both groups from days 1 to 10 of acclimation, whereas T_{re} threshold for sweating onset was reduced significantly only for the young men during acclimation. However, T_{re} threshold was initially (day 1) somewhat lower (0.20°C) for the middle-aged men. Reductions in the core temperature threshold at sweating onset and the sweating onset time have been used as classic signs of heat acclimation. When taken collectively, these findings would challenge the hypothesis that aging per se is related to reduced sensitivity and capacity of the sweating mechanism (5, 12, 16, 25, 28) at least for physically trained middle-aged men.

Our young men were probably slightly hyperhydrated as suggested by the osmolality and Na^+ data. The ingestion of more hypotonic fluids, as water, would result in this small osmolal dilution. Because hyperhydration (vs. euhydration) does not modify thermoregulatory responses (26), this small difference did not influence these results. In fact, preacclimation in the young men, despite lower osmolality and Na^+ concentration, had higher T_{re} responses than their middle-aged male counterparts. Finally, the osmolality and Na^+ data indicated that these subjects maintained a fairly constant hydration status with each of the exercise-heat exposures. The hemodilution associated with treadmill exercise was not different between groups. Because the groups were matched for aerobic fitness and thus relative exercise intensity, this finding is not surprising because the transcappillary oncotic and hydrostatic pressures would not be expected to be different.

Final RPE was generally higher for the young men during these 10 days of heat acclimation. Although relative exercise intensity ($\% \dot{V}O_{2\max}$) may provide an important sensory cue to RPE (19), $\% \dot{V}O_{2\max}$ was the same for both groups and these differing RPE values must be attributed to other factors. Except for HR, none of the other physiological responses evaluated in this study is thought to strongly influence RPE (19). When final HR

was computed as a percentage of maximum HR during the first and last days of acclimation, none of the differences (83.0% young, 82.7% old, day 1; 70.8% young, 72.3% old, day 10) was significant ($P > 0.05$), which suggests that the different RPE values between groups must be associated with other sensory cues. Final TS was higher for the young men on the first day of acclimation with a trend for higher values compared with the middle-aged men throughout the acclimation period. Thermal sensation may be influenced by T_{sk} , but also to a lesser degree by other cues such as core temperature (22, 33). Final TS was found to be moderately correlated ($r = 0.42$) with final T_{sk} ($P < 0.01$) throughout acclimation. Thus our physically trained middle-aged men appear to be at a perceptual as well as physiological advantage.

In conclusion, the greater regular weekly aerobic activity of our middle-aged men was probably responsible for the better initial performance of these individuals while exercising in the heat; however, heat acclimation negated this advantage. These findings for middle-aged men demonstrated the importance of aerobic training on their thermoregulatory responses during exercise-heat stress. Finally, the results indicated that the hypothesis that aging per se impairs the thermoregulatory system at least through the fifth decade of life should be reconsidered.

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