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Sweating and Cardiovascular Responses of Aged Men to Heat Exposure

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In this study, 6 older and 10 younger Japanese men were exposed, while sitting, to 40 °C and 40% relative humidity for up to 130 min. All participants were heat unacclimatized. Physiological measurements included sweat responses, esophageal and skin temperatures, nonevaporative heat exchange, heart rate, cardiac output, blood pressure, forearm blood flow, and metabolic heat production. There was no significant difference in sweat rate or in onset of sweating between the older and younger men; however, esophageal temperature at the onset of sweating was greater in the older men. Changes in skin temperature, nonevaporative heat exchange, metabolic heat production, heart rate, and cardiac output were the same during heat exposure in both age groups. However, forearm blood flow before and after exposure to heat was significantly lower in the elderly group. These data suggest that the greater health risk posed to resting, yet healthy, aged men by hot environments is not a consequence of inadequate sweating but could be associated with retardation of the vasodilation reflex, which can prevent effective transfer of the body heat to its shell, thus resulting in greater heat storage.

INCREASED morbidity and mortality in the elderly population during heat waves have been well documented in several medical reports. [For a review see (1).] Yet, relatively few scientific studies have focused on the physiological basis of the aging process in thermoregulation, and the few existing studies have reported conflicting results. Some researchers have found older individuals to be less heat tolerant due to a delay in the onset of sweating (2–5). Other investigators, however, have found that older men and women do have adequate sweating mechanisms and have associated their low tolerance to heat stress with their decreased aerobic capacity and possible impairment of their cardiovascular systems (6–9).

Discrepancies in the literature probably are related to various differences in experimental protocols and conditions, such as the study participants' physical fitness levels, body compositions, and previous states and degrees of heat acclimatization. For example, accumulation of body fat is a consequence of aging; nevertheless, Minard et al. (10) found that among unacclimatized Marine recruits exposed to unexpected heat loads, heat stroke occurred mainly in obese individuals. A further delineation of age-related thermoregulatory function can be expected if the effect of adiposity is minimized among the participants of different ages. Further research is needed to test whether or not the greater health risk posed to aged persons by hot environments is a consequence of age per se. This study was designed to examine the age-related differences in thermoregulatory responses of healthy unacclimatized men to heat. The men who participated in the study were selected in such a way as to rule out the difference of skin fat thickness between the two groups by matching their skin fold thicknesses. A resting experimental protocol was chosen in order to eliminate the complex effects of exercise and differences in aerobic capacity between the age groups. The specific objectives were to examine the effects of short-term heat exposure on age-related differences in (a) onset of sweating and sweat rate, (b) heat balance, and (c) cardiovascular adjustments.

METHOD

Study participants. — Six men ranging in age from 61 to 73 (elderly group) and 10 men ranging in age from 21 to 39 (young group) volunteered for the study. The physical characteristics of all participants are summarized in Table 1. All of the volunteers received physical examinations, including blood pressure and electrocardiogram (ECG). The older participants were community-dwelling, nonsedentary men who worked daily as security guards. All of the older men were healthy and had no previous cardiovascular or respiratory complications. None were receiving any medications, and cardiovascular fitness was examined using a head-up tilt test (70°) as reported elsewhere (11). The younger volunteers were students or laboratory investigators who were nonsedentary but not athletes or regular participants in any sport. Each volunteer signed a consent form after receiving a detailed description of the procedure and the potential complications.

Body fat content was estimated from the skin fold thickness (SFT). SFT of 10 different skin areas was measured with a Lange caliper (Cambridge Scientific, Cambridge, MD), and the mean subcutaneous fat thickness was estimated according to the description by Allen et al. (12). Percentage of total body fat was calculated from the relationship between SFT and adiposity. Given that the physiological measurements were taken in winter (January to February), all of the participants, who were Japanese, were considered unacclimatized to heat, thus avoiding the con

Table 1. Physical Characteristics of the Study Participants

Participant	Age (years)	Height (cm)	Weight (kg)	Surface area (m^2)	Fat (%)	MFT (mm)
Elderly group (61 to 73 years of age)						
1	64	159	65.3	1.69	19.8	5.1
2	70	175	65.7	1.81	18.8	4.6
3	64	161	49.7	1.52	16.2	3.5
4	64	164	57.6	1.63	17.8	4.2
5	73	157	55.2	1.56	19.1	4.8
6	61	172	85.4	2.00	20.8	5.7
M	66.0	164.7	63.2	1.70	18.8	4.7
±*SEM*	1.8	3.0	5.1	0.07	0.7	0.3
Young group (21 to 39 years of age)						
1	39	165	59.2	1.66	18.4	4.5
2	36	169	59.8	1.70	15.6	3.2
3	32	180	73.4	1.94	17.1	3.9
4	32	165	66.0	1.74	19.7	5.3
5	24	164	59.4	1.65	19.5	5.4
6	22	173	74.3	1.90	22.2	6.5
7	21	172	62.1	1.75	16.6	3.7
8	22	168	61.7	1.71	14.4	2.8
9	21	170	79.7	1.93	22.7	6.7
10	21	166	70.6	1.80	23.4	7.2
M	27.0	169.2	66.6	1.78	18.9	4.9
±*SEM*	2.2	1.5	2.3	0.03	1.0	0.5

Note. MFT stands for mean subcutaneous fat thickness of 10 skin sites. MFT = (10 skin fold thickness − 40 mm)/20.

founding effects of varying degrees or levels of acclimatization on their responses to heat.

Experimental protocol. — To control hydration state and avoid variability due to the circadian effects, the participants were asked to eat breakfast at 7:00 a.m. Participants arrived at the laboratory at 8:30 a.m. They were dressed in cotton underwear (shorts) in the climatic chamber where air temperature was kept constant at 26 °C with relative humidity at 40%. Each participant was harnessed with skin thermocouples (copper-constantan), heat flux transducers, esophageal probe, ECG electrodes, tape-on twin mylar electrodes for measuring cardiac output, a mercury-in-Silastic Whitney strain gauge, blood pressure cuff, and sweat capsules made of acryl resin. Preparation of each volunteer was completed within 30 min, after which time the participant maintained a sitting position on a comfortable wide-meshed chair for about 60 min (equilibrium period). After the equilibrium period, while the participant remained in sitting position, the room temperature was raised to 40 °C, at a constant rate (1 °C/min), and relative humidity was kept constant at 40%, except for a transient period for raising the temperature. Thus, the participant remained seated throughout the entire experimental period (up to 130 min). Sweat rate, esophageal temperature, and ECG were measured throughout the entire period, but skin temperatures and all cardiovascular parameters were monitored during the first 95 min only. The time remaining (about 35 min) in the hot room was used for measuring $\dot{V}O_2$, removing all monitoring attachments, and measuring the nude body weight.

Measurements. — Open-circuit spirometry was used to measure the $\dot{V}O_2$ of each participant at a temperature of 26 °C and again after 95 min of exposure to a temperature of 40 °C. Metabolic heat production (kcal/m^2/h) was calculated from $\dot{V}O_2$ and the respiratory quotient.

Measurements of skin temperature were obtained by 7-point thermocouples on forehead, hand, forearm, chest, thigh, leg, and foot. Mean skin temperature was calculated using the area weighting formula of Hardy and Dubois (13). Esophageal temperature was measured by a thermocouple that was swallowed to the level of the heart.

For measurement of heat exchange at the skin surface, a laboratory calibrated heat flux transducer (Thermonetics, HA-13-18-10P) was placed near each skin temperature thermocouple and secured with a water-vapor permeable surgical tape (Hogi Van, Tokyo, Japan). Skin nonevaporative heat exchange was calculated as the regional heat exchange of the seven sites times the weighted factor of each respective regional area as that used for skin temperature. Body temperatures, nonevaporative heat exchange, and heart rate were monitored continuously, and the data were stored every 15 sec on a data logger (7V07 San-ei Sokki, Tokyo) to be analyzed by a computer (M243, Sord, Tokyo, Japan).

Blood pressure was determined by sphygmomanometry in which a pressure transducer (Validyne DP15) was connected to an ordinary pressure cuff. Systolic and diastolic pressures were read from the pressure wave recorded on a chart. Cardiac output was estimated by impedance cardiography (Nihon-Kohden AI-601G, Tokyo, Japan) using the standard four-band electrode arrangement as described by Shiraki et al. (14). A Whitney mercury-in-Silastic circumference gauge was placed at the left midforearm for forearm blood flow, and a cuff was secured at the upper arm. Venous congestive pressure was 50 Torr, and forearm blood flow measurements were averaged for every 5 min. Blood pressure and cardiac output were measured once every 5 min during the experimental period. Total peripheral resistance was calculated by dividing the mean arterial pressure by cardiac output, where mean arterial pressure = 1/3 (pulse pressure) + diastolic pressure. Forearm vascular conductance was calculated as forearm blood flow/mean arterial pressure.

The capacitance hygrometry technique was used to measure local onset of sweating; capsules, each covering 15 cm^2 of a skin area, were attached to the forehead, right forearm, chest, abdomen, and thigh. Each capsule was ventilated with dry air, and the humidity of the effluent air was sensed with a capacitance hygrometer (Vaisala HMP23UTA, Helsinki, Finland). The data were stored in a computer (Sord 343) every 1 sec for later analysis. The onset of sweating for each skin region was determined as the time when sweat first appeared following heat exposure.

The diffused water loss from the skin was measured by subtracting respiratory water loss plus the weight difference between CO_2 and O_2 of the respiratory gas from total body weight loss. The body weight loss was measured as the difference of body weight before and after the equilibrium

period using a platform scale (Kobe Koki, Japan) with a sensitivity of ± 1.0 g. The water loss from the respiratory tract (m_{res}) was estimated using the equation described by Mitchell et al. (15). The weight difference between CO_2 and O_2 in the respiratory gas was calculated by the following equation:

$$d(CO_2 - O_2) = 1.964 \times \dot{V}CO_2 - 1.429 \times \dot{V}O_2\,(g/min) \quad (1)$$

Where $\dot{V}CO_2$ is CO_2 output, and $\dot{V}O_2$ is O_2 consumed (1/min standard temperature pressure, and dryness); 1.964 and 1.429 are constants.

Sweat volume was determined as the difference in nude body weight before and after exposure to heat. Corrections were made for differences between weight of water vapor in expired and inspired air, in weight of CO_2 produced and O_2 consumed, and for water that diffused through the skin. Sweat rate (g/m²/min) was calculated by dividing the sweat volume by the actual sweating period determined from the actual onset of sweating.

Statistical analysis. — Steady-state measurements during the equilibrium period were compared with values measured during the course of heat exposure by using the repeated-measures analysis of variance (ANOVA). Significant differences were tested further using the simultaneous multiple-comparisons method of Bonferroni (16). Student's *t* test was used to compare the mean values of the elderly group with those of the young group during the course of the experiment. In all statistical tests a value of $p < .05$ was accepted as indicating significance.

RESULTS

Sweating Mechanism

The average onset of sweating at different skin sites is summarized in Table 2. A considerably wide individual variation in the time of sweat burst was observed in both age groups. The average value of the time required for onset of sweating was not greatly different from one site to another. The average onset of sweating at each skin site was longer for the elderly group, but the difference was not significant between both age groups, with one site exception, the abdomen ($p < .05$). At the onset of sweating, threshold esophageal temperature was significantly higher ($p < .05$) in the elderly group than in the young group (Table 2). Initiation of sweating in most of the younger participants occurred at an esophageal temperature below its average value before heat exposure, but that of the older participants was slightly higher than the control level. Insensible water loss, sweat volume, and sweat rate (g/m²/min) were not significantly different between age groups (Table 3).

Heat Balance

Body temperatures. — The skin temperature was not significantly different at thermoneutrality in either group. Heat exposure increased all regional skin temperatures; hence, mean skin temperature reached a plateau level at 65 min after heat exposure (Figure 1, top). The rate of increase in mean skin temperature of both groups was identical during heat exposure. Changes in the esophageal temperature of both age groups during the first 90 min of heat exposure are shown in Figure 1 (bottom). The average esophageal temperature at 90 to 95 min of exposure and that after 125 to 130 min are summarized in Table 4. The average esophageal temperature at the equilibrium period was not significantly different in either group, being 36.79 ± 0.04 and 36.72 ± 0.09 (*M* ± *SEM*), in the young and elderly groups, respectively. Upon exposure to heat, esophageal temperature decreased initially and then began to rise after 30 min. It exceeded its preheat exposure value after 40 min in the

Table 2. Variables Associated With the Onset of Sweating

	Onset of sweating (min)		Threshold Tes (°C)	
Sites	Elderly	Young	Elderly	Young
Forehead	55.3 ± 6.9	38.2 ± 5.2	36.95 ± 0.07	36.65 ± 0.06**
Chest	55.7 ± 7.0	44.2 ± 5.2	36.97 ± 0.07	36.73 ± 0.05*
Forearm	58.7 ± 5.1	47.2 ± 4.1	36.98 ± 0.04	36.73 ± 0.06*
Abdomen	60.2 ± 5.4	39.5 ± 5.3*	36.98 ± 0.05	36.67 ± 0.05**
Thigh	51.6 ± 8.4	37.7 ± 4.5	36.98 ± 0.03	36.65 ± 0.06**
Mean	57.3 ± 5.8	41.4 ± 4.5	36.97 ± 0.05	36.69 ± 0.06**

Note. Values are means plus or minus standard errors of the means. Threshold Tes is the esophageal temperature at which sweating begins. Mean is the overall average of the five sites measured. For Tes value before heat loading, see Table 4. Men ranged in age from 61 to 73 in the elderly group and 21 to 39 in the young group.

*$p < .05$, **$p < .01$ between groups.

Table 3. Insensible Water Loss From the Skin, Sweat Volume, Sweat Duration, and the Sweat Rate for Both Groups

	Age groups	
Measurements	Elderly (61 to 73)	Young (21 to 39)
Insensible water loss (g/m²/min)	0.35 ± 0.04	0.38 ± 0.03
Sweat volume (g/m²)	120.0 ± 9.8	142.4 ± 9.6
Sweat duration (min)	78.0 ± 6.6	90.1 ± 4.5
Sweat rate (g/m²/min)	1.60 ± 0.14	1.60 ± 0.10

Note. Values are means plus or minus standard errors of the means. $n = 6$ in the elderly group and 10 in the young group. Corresponding values between groups are not significantly different at $p < .05$.

Table 4. Esophageal Temperature Before and After Exposure to Heat for 90 to 95 Min and 125 to 130 Min

	Age groups	
Exposure times	Elderly (61 to 73)	Young (21 to 39)
Control (before exposure)	36.72 ± 0.09	36.79 ± 0.04
90 to 95 min after exposure	37.31 ± 0.04	37.03 ± 0.05*
125 to 130 min after exposure	37.58 ± 0.06	37.36 ± 0.04*

Note. Values are means plus or minus standard errors of the means. Values for the control are the averages of the last 5 min at the equilibrium period. Values for heat exposure are the averages of the last 5 min (90 to 95 min and 125 to 130 min) of heat exposure. $n = 6$ in the elderly group and 10 in the young group. Esophageal temperature is measured in °C.

*$p < .01$ between groups.

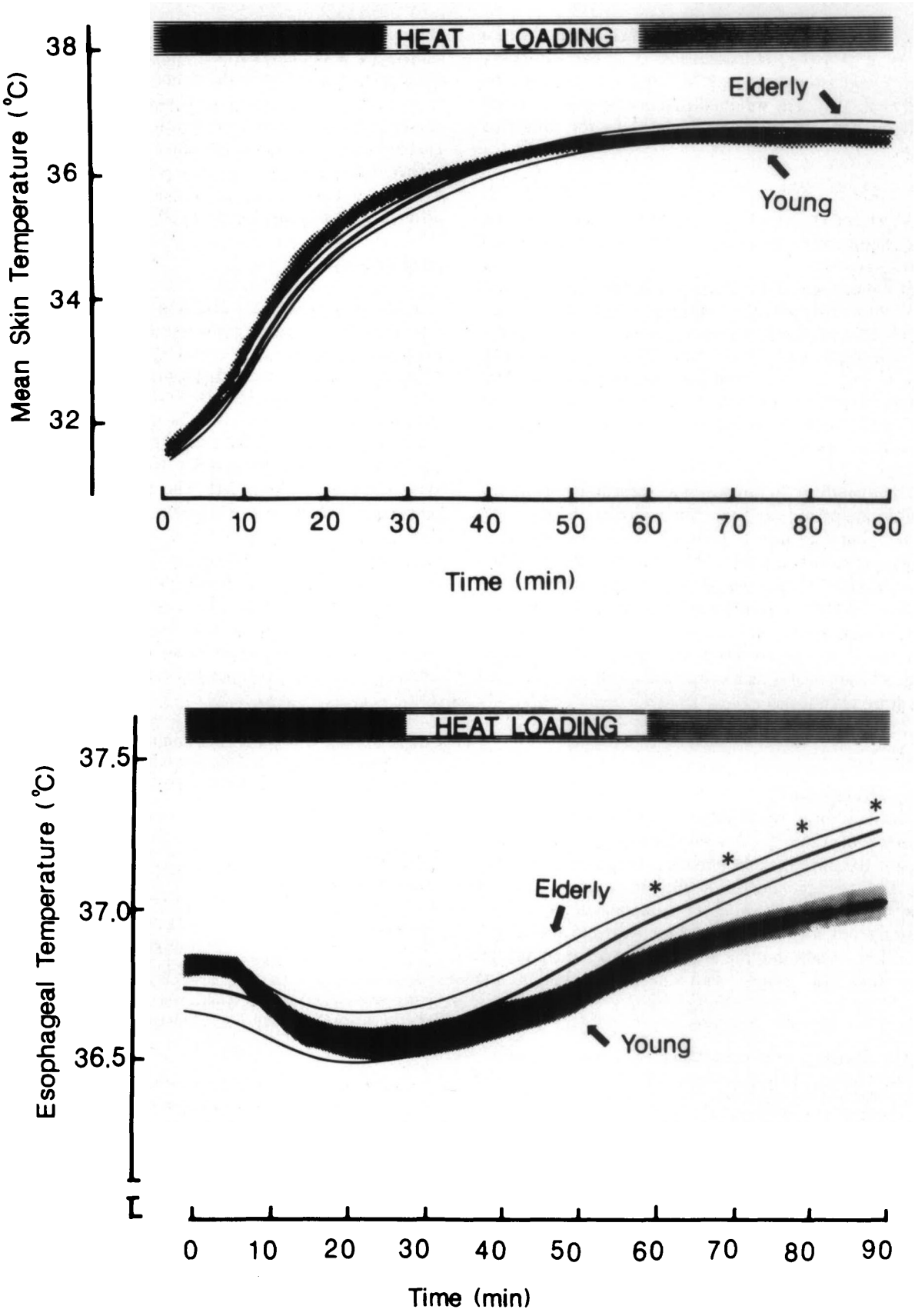

Figure 1. Overall changes in mean skin (top) and esophageal (bottom) temperatures of the elderly and young groups during exposure to heat. Open area with solid line represents the means and standard errors of the means of the elderly group; shaded area with broken line represents the means and standard errors of the means of the young group. *Significant difference ($p < .05$) between average values of every 10 min of the elderly group and corresponding averages of the young group.

elderly group and after 55 min in the young group. Accordingly, the esophageal temperature in the elderly group became significantly higher ($p < .05$) than that in the young group after 63 min. The average esophageal temperature at 85 to 90 min of heat exposure was 37.31 ± 0.04 °C and 37.03 ± 0.05 °C in the elderly and the young groups, respectively ($p < .01$). The average esophageal temperature at the termination of heat exposure (125 to 130 min) was 37.58 ± 0.06 in the elderly group and 37.36 ± 0.06 in the young group ($p < .01$).

Metabolic heat production ($\dot{M}$). — The average values of resting metabolic heat production in the elderly group were the same as in the young group (38.2 ± 2.0 vs. 39.1 ± 1.4 kcal/m²/h) at the equilibrium period (temperature = 26 °C). Metabolic heat production increased significantly ($p < .01$) to 42.1 ± 1.7 for the elderly group and 42.5 ± 1.1 kcal/m²/h for the young group after heat exposure.

Nonevaporative heat exchange ($\dot{H}$). — Heat loss from the skin surface (negative heat exchange) was identical in both groups, being 62 kcal/m²/h at thermoneutrality, and it decreased proportionally as the temperature rose. After 15 min of heat exposure, nonevaporative heat exchange reached a level of 40 kcal/m²/h, a heat gain from the environment, which was maintained throughout the experimental period.

Heat storage (S). — Cumulative heat storage (the amount of energy stored during the whole period) can be calculated from the cumulative $\dot{M}$ (kcal/m²) and cumulative $\dot{H}$ (kcal/m²) by the following equation: $S = \dot{M} - E - \dot{H}$, where E (kcal/m²) is cumulative evaporative heat loss via the skin and respiratory tract. However, in the present study it was not appropriate to estimate the cumulative heat storage from this equation or from a conventional equation with a constant weighting factor of esophageal and mean skin temperatures because we neither estimated an effective sweat rate, nor did we know the changes of the weighting factors during the transient course of the heat exposure. However, we could estimate roughly that heat storage of the elderly group increased more than that of the young group because esophageal temperature was higher in the elderly group, whereas metabolic heat production, mean skin temperature, nonevaporative heat exchange, and sweat volume were the same as for the young group.

Cardiovascular Responses

Heart rate. — The average heart rate of both groups before heat exposure was about the same (Table 5). By raising the room temperature, heart rate continued to increase in both groups, and values became significantly higher ($p < .01$) at 15 min in the elderly group and at 20 min in the young group.

Mean arterial pressure. — The average mean arterial pressure of the elderly group at the equilibrium period (temperature = 26 °C) was significantly higher than that of the young group ($p < .05$), and it remained higher throughout the experimental period. Mean arterial pressure of the elderly group decreased significantly ($p < .01$) at 10 min after exposure and remained lower until the end of the exposure period. However, the decrease in mean arterial pressure of the young group was slight and not as consistent as that observed in the elderly group.

Table 5. Effect of Heat Exposure on Hemodynamics

Age groups	Heat exposure periods: Control	Onset of sweating	At 95 min
Heart rate (bpm)			
Elderly	63.8 ± 3.9	73.7 ± 5.1^{+}	79.0 ± 4.5^{+}
Young	64.5 ± 2.7	74.3 ± 2.6^{+}	79.1 ± 3.3^{+}
Mean arterial pressure (Torr)			
Elderly	98.2 ± 5.8	89.1 ± 4.9^{+}	89.5 ± 5.2
Young	84.5 ± 2.4*	82.9 ± 1.9	81.6 ± 1.8
Cardiac output (l/min)			
Elderly	3.9 ± 0.2	4.8 ± 0.2^{+}	5.2 ± 0.3^{+}
Young	3.8 ± 0.2	4.4 ± 0.2^{+}	4.8 ± 0.3^{+}
Forearm blood flow (ml/100ml/min)			
Elderly	1.3 ± 0.2	6.0 ± 1.7	4.6 ± 0.7^{+}
Young	2.6 ± 0.4*	7.2 ± 0.9^{+}	8.7 ± 1.4$^{*,+}$
Total peripheral resistance (Torr/l/min)			
Elderly	25.6 ± 2.3	18.7 ± 1.5^{+}	17.5 ± 1.5^{+}
Young	21.7 ± 1.2	19.4 ± 1.2^{+}	17.1 ± 1.0^{+}
Forearm vascular conductance (ml/100ml/min/Torr × 100)			
Elderly	1.3 ± 0.2	7.2 ± 2.4^{+}	5.2 ± 0.7^{+}
Young	3.0 ± 0.5*	9.3 ± 1.0$^{*,+}$	12.2 ± 1.9$^{*,+}$

Note. Values are means plus or minus standard errors of the means. An * indicates significant difference ($p < .05$) between the young and elderly groups, and a + indicates significant difference ($p < .05$) between control and heat exposure. No significant difference was detected in each value between onset of sweating and 95 min. Onset of sweating was taken at the mean time on five skin sites: forehead, chest, forearm, abdomen, and thigh. Men in the elderly group ranged in age from 61 to 73, and men in the young group ranged in age from 21 to 39.

Cardiac output. — Cardiac output averages were similar in both groups at thermoneutrality. Heat loading increased cardiac output of both groups, but there was no age-related difference.

Responses of vascular state. — A significant increase in the forearm blood flow and a decrease in total peripheral resistance with a concomitant increase in forearm vascular conductance clearly indicated a vasodilation during heat exposure in both groups. The magnitude of the increase in forearm blood flow and forearm vascular conductance was significantly higher ($p < .05$) in the young group than in the elderly group, but the change in total peripheral resistance was similar in both groups.

Relationship between blood flow and core and skin temperatures. — Changes in forearm blood flow were plotted against corresponding changes in forearm skin temperature

(Figure 2, top). A similar curvilinear relationship between the forearm skin temperature and forearm blood flow was observed in both the young and elderly groups; however, the response of forearm blood flow to the increase in forearm skin temperature was significantly higher ($p < .05$) in the young group, suggesting a sluggish response for the vasodilation reflex to heat exposure in the elderly group. Similarly, changes in forearm blood flow were plotted against corresponding changes in esophageal temperature (Figure 2, bottom). To avoid confusion due to the initial fall of core temperature (see Figure 1), all values during the preheat equilibrium period were excluded. The forearm blood flow increased after esophageal temperature exceeded 36.8 °C in the young group, but not in the elderly group. The difference between the two groups increased significantly ($p < .05$) thereafter. The sluggish vasodilation in the elderly group might cause an accumulation of heat in the shell due to a possible decrease in effective transfer of the internal body heat to the shell, resulting in a higher core temperature.

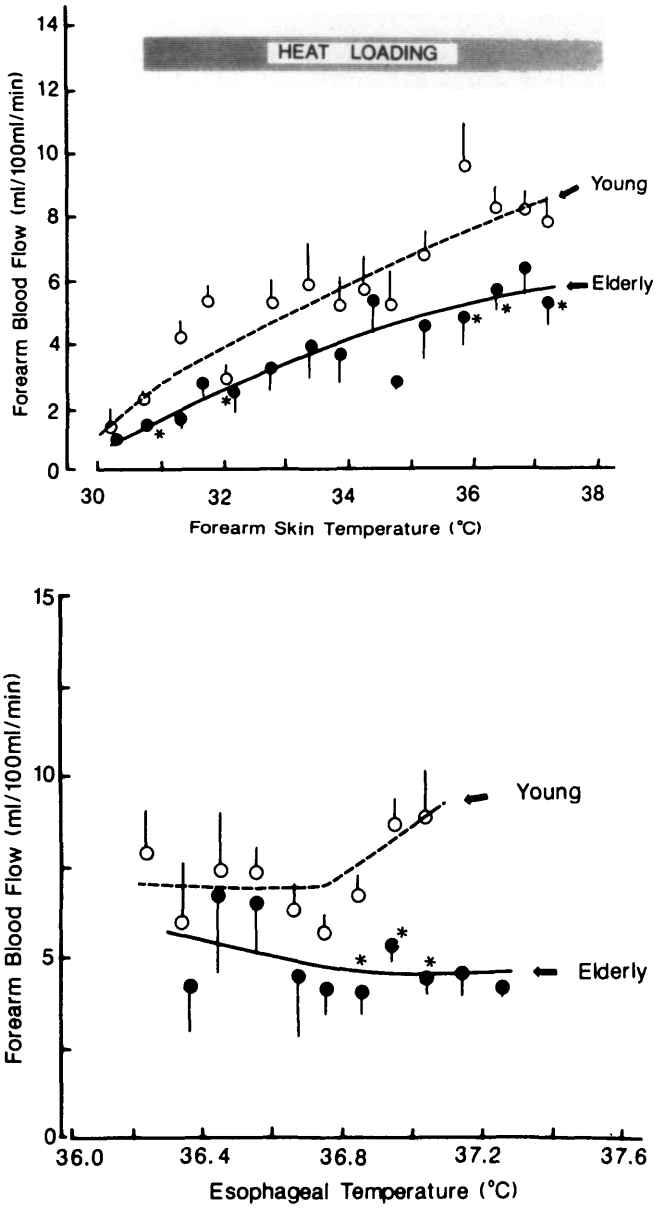

Figure 2. Relationship between changes in forearm skin temperature (Tsk-forearm) and changes in forearm blood flow (FBF) (top) and changes in esophageal temperature (Tes) and FBF (bottom). Open circles represent the young participants; closed circles represent the elderly participants. Each point with a bar represents average FBF ± SEM in 0.5 °C interval of Tsk-forearm and in 0.1 °C interval of Tes. Solid-line (elderly group) and broken-line (young group) curves were drawn by inspection. *Significant difference ($p < .05$) between values of the elderly group and corresponding values of the young group.

Discussion

A review of the literature revealed only a few studies that have dealt primarily with thermoregulatory responses of elderly men and women to heat exposure. The results of these studies were often in disagreement, and most men described as aged were, in fact, in their mid-years rather than in their elderly years, as the World Health Organization has designated persons aged 45 to 59 as being middle aged, 60 to 74 as being elderly, 75 to 89 as being old, and 90 and older as being very old. In the present study only men above the age of 61 were included in the elderly group.

Although the time required for the onset of sweating and the order of sweat recruitment patterns in hot environments have been described and documented in young study participants (17–19), only two such studies have dealt with elderly men and women (2,7). Hellon and Lind (2) revealed sluggishness of the sweat glands in older men (47.5 years of age) in response to heat load for 150 min at 38 °C. Within each age group the chest and scapula broke sweat at about the same time, but the forearm took a significantly longer time. In the study by Drinkwater et al. (7), among women who rested for 2 hr in a 40 °C environment, the onset of sweating was similar in both the young and old groups, and sweat appeared on the abdominal region earlier than at the forearm. In our study, however, neither age group showed consistency in the order of onset of sweating among the five skin sites. With the exception of the abdomen, no significant difference was detected in the time required for onset of sweating between age groups. However, in our unacclimatized participants the average onset of sweating was consistently higher in the elderly group. Our finding that the overall mean was not significantly different between age groups might be related, in part, to the considerable individual variations and to the relatively small sample number. However, in an earlier study when heat-acclimatized men were exposed to heat, the variations were reduced, and the onset of sweating was similar in both young and old men (20). We have no reasonable explanation for a significantly delayed ($p < .05$) onset on the abdomen in the elderly group.

In our study (Table 2), sweating began in the young and elderly groups after a much longer time than was reported by Hellon and Lind (2) and Drinkwater et al. (7); however, our values for the onset of sweating were similar to data reported by Wurster et al. (19). The data on our participants do not support the conclusion of Randall and Hertzman (18) that sweat recruitment is in the order of caudal-to-rostral upon heating of the body. Perhaps the discrepancy is related to the experimental protocols of the studies, that is, our participants sitting in a semireclining position as compared to theirs reclining in a supine position.

In the present study, the sweat volume was similar for both age groups, a finding that is in agreement with the report on women by Drinkwater et al. (7). However, Hellon and his colleagues (21) found that elderly men had a higher sweat production than young men during rest periods and that the reverse was true during work periods. In general, our data and that of Drinkwater et al. (7) support the hypothesis that aging per se does not significantly diminish the functional activity of the sweat glands of healthy elderly men and women during acute exposure to heat. A similar conclusion was reported when elderly men and women walked for 1 hr under desert conditions (9). The average esophageal temperature at the onset of sweating for our elderly group (36.97 °C) was significantly higher ($p < .01$) than that for the young group (36.69 °C) (see Table 2). Thus, the threshold of sweating for the elderly group was higher than that for the young group. However, once sweating began, the sweat rates were the same in both age groups (Table 4). At the termination of heat loading (130 min) esophageal temperature rose to 37.58 °C for the elderly group and 37.36 °C for the young group. During the sweating period, the rise in esophageal temperature was almost identical: 0.61 °C for the elderly group and 0.67 °C for the young group, which had the same sweat rate (see Table 4). Therefore, the identical sweat rate and rate of rise in esophageal temperature in both age groups support the conclusion that the functional activity of the sweat gland is not related to aging per se.

The present data showing a greater rise in esophageal temperature in the elderly group confirm data on responses of tympanic temperature of old men exposed to passive heating (22). On the other hand, measurements of rectal temperature during acute exposure of old men and women to heat did not show a significant rise when compared to the young groups (4,7,21). The discrepancy between our esophageal temperature data and reported data on rectal temperature might be explained by a delayed response of rectal temperature to a rise in blood temperature during acute heat exposure (23). The higher esophageal temperature in the elderly group was not due to any of the following reasons: a decrease in sweat rate, increased insulative value caused by fat layer in the skin, a greater convective or radiant heat gain, or greater heat production, as skin temperature, skin fold thickness, nonevaporative heat exchange, and metabolic heat production were the same in both age groups. Perhaps it is related to a decreased coefficient of heat conductance because the thermal gradients between the core and the skin became significantly smaller in the elderly group as heat exposure continued (Figure 1); a lower cutaneous blood flow in the elderly group (Figure 2 and Table 5) supports this speculation.

The greater heat strain of elderly men and women working in a hot environment has been ascribed to a decreased aerobic capacity and inadequate cardiovascular response (7,9,24). In our study, aerobic capacity was not measured; thus, it is difficult to compare the physical fitness levels of both the younger and older participants. It would be inappropriate to rule out that some of the differences between age groups may be related, at least in part, to dissimilarity in fitness level. However, the possible role of fitness inequality between groups shown in the data was minimized by the choice of a resting experimental protocol as used previously by other investigators (7).

Our data (Table 5) show that the levels and responses of heart rate and cardiac output before and during exposure to heat were similar in both age groups. The forearm blood flow before and during heat exposure was significantly higher in the young group than in the elderly group (Table 5). However, the percentage increase in forearm blood flow was similar for the young group (235%) and the elderly group (254%), a finding that is in agreement with data on women where the percentage increase in forearm blood flow during heat exposure was the same in both age groups (7). In one study that reported on men resting in heat, forearm blood flow tended to be higher in the elderly men before exposure, and no differences were observed in the first 70 min after exposure (3). However, between 90 and 150 min after exposure, the elderly men maintained consistently higher forearm blood flow than the young men. Other studies involving protocols of rest/work combinations or exercise in hot environments have reported a greater increase in forearm blood flow in elderly men (3,4,5,21).

The age-related differences in our data on forearm blood flow before exposure to heat are not related to differences in cardiac output or heart rate, but they might be associated with the greater total peripheral resistance of men in the elderly group, although not significant. However, during exposure to heat, total peripheral resistance decreased at a greater rate in the elderly group and became identical to that of the young group. The increase in forearm blood flow in all participants was observed after 5 min of exposure to heat. The increase in forearm blood flow might reflect local active vasodilation rather than an increase in perfusion pressure, as mean arterial pressure was maintained in the young group, but it decreased in the elderly group (Table 5).

The primary difference in cardiovascular responses of aged persons to heat is probably related to cutaneous blood flow and its controlling mechanisms. The retarded vasodilation of aged persons could diminish the flow of metabolically produced heat from core to shell, resulting in greater heat strain. The question of whether or not the lower forearm blood flow and forearm vascular conductance in elderly men before and after exposure to heat is related to the diminished response of their vasomotor system to both central and peripheral drives remains open for further investigation. Also, the fact that cardiac output was similar in both age groups and that forearm blood flow was lower in the elderly group might represent greater ability among the young men to vasoconstrict the visceral blood flow as compared to the elderly men.

In conclusion, although the threshold esophageal temperature for sweating was higher in the elderly group, the sweating mechanism of healthy elderly men can keep pace with the demands for evaporative cooling during acute exposure to heat. The greater heat strain exhibited by elderly men might be related primarily to an inability of their vasomotor system to maintain cutaneous blood flow at the same level as that in younger men. The impairment of their vasomotor system in transferring heat was supported by our matching the insulative values of the fat layer in the skin of both age groups. However, it should be pointed out that

adiposity was assessed in our participants by measuring skin fold thickness, a method that might not reliably measure adiposity in elderly individuals.

The impairment of the vasomotor function in aged persons is not related to inadequate cardiac response but is perhaps associated with insufficient vasoconstriction of the blood supply to the viscera, resulting in less blood being shunted to the skin. This suggestion is probable because, in old age, the responsiveness of the circulatory system to adrenergic nerve control is known to decrease (25). Therefore, in elderly individuals, a decreased response to beta stimulation could explain the impaired vasodilatory responses, and a lowered response to alpha stimulation could be the underlying mechanism for diminished vasoconstriction in the viscera.

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