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Age and temperature regulation of humans in neutral and cold environments

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WAGNER, J. A., S. ROBINSON, AND R. P. MARINO. *Age and temperature regulation of humans in neutral and cold environments.* J. Appl. Physiol. 37(4): 562–565. 1974.—Groups of male subjects (ages 10–13, 14–16, 20–29, and 46–67 yr) wearing only shorts and socks reclined for 60 min in a thermoneutral room (T_a 30°C; T_{wb} 15°C), immediately followed by 30 min in a cold environment (T_a 16–17°C, T_{wb} 10–12°C). In the thermoneutral environment, the age-group means of rectal temperature (T_{re}), mean skin temperature ($\bar{T}_{sk}$), metabolic rate (kcal/m²·h), and the coefficient of heat conductance of the subjects varied inversely with age. During the exposure to this environment the group means of T_{re} declined by 0.3–0.4°C and $\bar{T}_{sk}$ increased by 0.7–1.1°C, the changes in the groups following parallel courses. The older boys and young men had somewhat higher finger and forearm blood flows than the young boys and older men after 50 min in the thermoneutral room. The younger subjects reacted rapidly to the cold (16–17°C) by increasing metabolism and minimizing heat loss by cutaneous vasoconstriction, whereas older men showed little increase in metabolism and experienced greater reductions in their body heat stores. In the cold, the boys had lower heat conductance and their finger blood flows were reduced to much lower rates than rates observed in the men.

boys; men; thermoregulation; thermoneutral environment; cold exposure; finger blood flow; forearm blood flow

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WHEN UNACCLIMATIZED MEN are exposed to cold their initial reactions are general cutaneous vasoconstriction with a rapid fall in skin temperature, and increased muscle tension and shivering, causing a greater metabolic heat production. These responses may be modified by a number of factors, including acclimatization to cold (7, 14), the amount of body fat (6), relative humidity (5), wind speed (10), physical fitness (1), and age (2, 9, 11). Horvath et al. (9) observed that when young men were exposed to a cold environment their skin temperatures fell to low levels and they were able to prevent a fall in rectal temperature (T_{re}) by increasing their metabolic rates. However, older men showed a moderate decline in T_{re} because they did not increase their metabolic rates to the same extent as young men, and the fall in skin temperatures was less in older men than in young men. On the other hand, Krag and Kountz (11) observed that older people had an earlier and greater metabolic response to cold than young people, but rectal temperatures declined more in older people than in young people during cold exposure. Bernstein et al. (2) found a delay in the metabolic response to cold exposure in older women, but they maintained T_{re} as well as younger women. Some of these inconsistencies may have been sex differences, or they may have been due to differences in experimental conditions; however, more information was needed to establish the effect of age on the thermoregulatory responses to cold exposure. The thermoregulatory capabilities of children during cold exposure had not been defined and this information was necessary to broaden our knowledge of physiological aging. The following experiments were conducted to compare the thermoregulatory responses of boys and men (ages 10–67 yr) during short-term exposures to cold stress.

METHODS

Four groups of male subjects (ages 10–13, 14–16, 20–29, and 46–67 yr), dressed only in shorts and socks, reclined on a saran net bed for 1 h in a thermoneutral environment 30°C dry bulb (T_a), 15°C wet bulb (T_{wb}), and relatively still air. Immediately following this exposure, the room temperature was changed to T_a 16–17°C in 10–15 min and the subjects remained in the cold for 30 min following the change in room temperature. All of the subjects were partially heat-acclimatized, since the experiments were conducted during the months of July and August. The young and older men had been participating in competitive games of handball, paddle ball, and tennis during the summer months, and the boys were participants in the Bloomington summer recreation program. The physical characteristics of the subjects are given in Table 1.

During each experiment, rectal temperature was recorded by a thermocouple in an indwelling catheter, inserted to a depth of 10 cm. Skin temperatures were obtained with thermocouples located on the finger pad, arm, back, chest, and leg just above the knee. Mean skin temperatures ($\bar{T}_{sk}$) were calculated by weighting the skin temperatures in the following manner: finger, 0.10; arm, 0.20; back, 0.15; chest, 0.15; and leg, 0.40. Mean body temperatures ($\bar{T}_b$), which were used in the estimation of body heat storage(s), were obtained by weighting: T_{re}, 0.65; and $\bar{T}_{sk}$, 0.35. Metabolic rates (MR) were determined by the open-circuit method between the 35th and 45th min of the exposures to the thermoneutral environment and 20–25 min after the beginning of the cold exposure. Expired air was collected in a Tissot spirometer and gas samples were analyzed for oxygen and carbon dioxide by use of a Beckman GC-4 chromatograph, which was frequently checked with a gas mixture carefully standardized with the Haldane apparatus. Evaporative (E), radiative (R), and convective (C)

heat loss were considered collectively as total heat loss, which was calculated from the partitional heat balance equation: $MR = E \pm R \pm C \pm K \pm W \pm S$ (12); conduction (K) and work (W) were assumed to be zero, the coefficient of heat conductance was calculated by dividing metabolic heat production, adjusted for stored and pulmonary heat loss, by the gradient between T_{re} and $\bar{T}_{sk}$.

TABLE 1. *Physical characteristics of subjects*

Group	Subj	No.	Age, yr	Ht, cm	Wt, kg	Surface Area, m²	m²/kg
1	Prepubertal boys	9	10-13	144.3±3.2	34.8±1.6	1.18±0.04	0.034
2	Postpubertal boys	7	14-16	165.2±1.9	50.9±4.1	1.54±0.07	0.033
3	Young men	10	19-26	177.5±2.7	76.7±3.5	1.94±0.05	0.026
4	Older men	7	46-67	179.6±2.0	81.4±2.2	2.00±0.04	0.025

Values are means ± SEM.

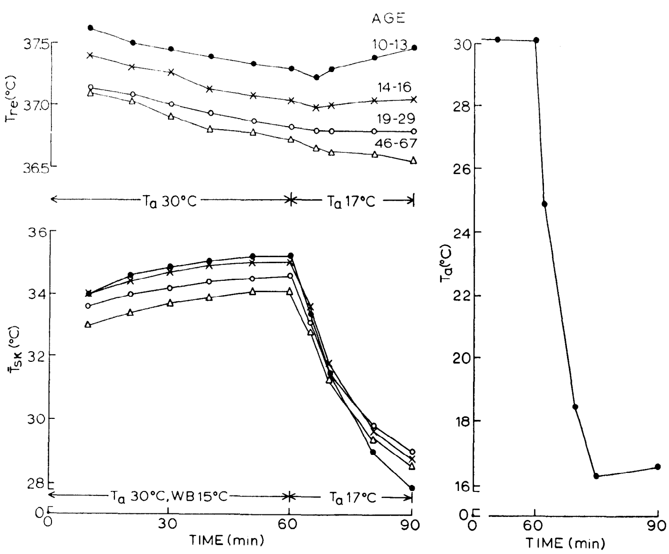

FIG. 1. Group means of rectal (T_{re}) and mean skin ($\bar{T}_{sk}$) temperatures of resting male subjects during 60-min exposures to thermoneutral (T_a = 30°C; T_{wb} = 15°C), followed by 30-min exposures to room temperatures falling to T_a = 16–17°C, T_{wb} = 10°C, as shown in panel at *right*.

Finger blood flow was measured 50 min after reclining in the thermoneutral environment and at 10-min intervals during the cold exposure. Blood flow was measured in the terminal phalanx of the middle finger using a modification of the venous occlusion plethysmographic techniques of Burton (3, 4) and Wilkins, Doupe, and Newman (17). A light-weight plastic finger cup was sealed on the finger using Kerr dental impression medium. The finger volume of each subject was determined prior to each experiment by dyeing 2–4 ml of the subject's finger tip in a small bottle containing diluted food coloring (18).

Forearm blood flow was measured 55 min after reclining in the thermoneutral environment and after 25 min of exposure to the cold environment. Forearm blood flow was measured by venous occlusion plethysmography (8, 19) using an air-filled plethysmograph. The plethysmograph consisted of a thin (0.38 mm) metal sleeve enclosing a thin-rubber, cloth-covered bag, both of which were wrapped around the arm, and the metal sleeve was fastened by adjustable clips (A. C. Burton, personal communication). The metal sleeve and cloth covering prevented expansion of the rubber bag during blood flow determinations. Forearm volume in the plethysmograph was determined by water displacement.

Finger and forearm volume changes resulting from venous occlusion (60 mmHg) were recorded using Grass PT5A volumetric low-pressure transducers, amplified and recorded on a Honeywell multichannel Visicorder. The finger and forearm blood flow values reported in Fig. 3 represent averages of five serial determinations separated by 30-s intervals. Finger and forearm blood flows were expressed as ml/min · 100 ml of the respective finger and arm volumes.

Analysis of variance and the Student t test were used to test for statistical significance. The null hypothesis was rejected at the 5% level.

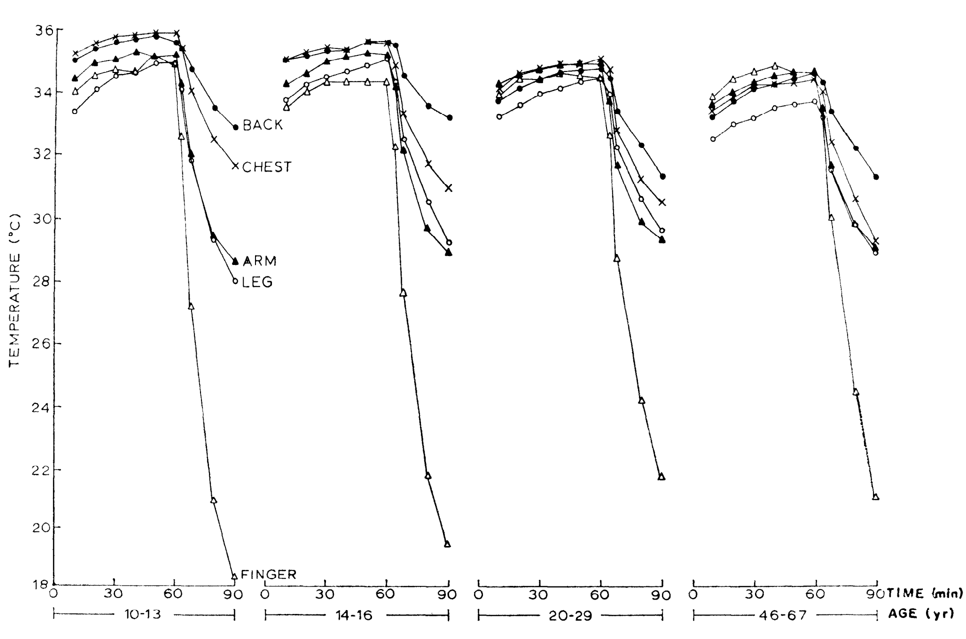

FIG. 2. Group means of skin temperatures of the resting male subjects during 60-min exposures to thermoneutral (T_a = 30°C, T_{wb} = 15°C), followed by 30-min exposures at room temperatures falling to T_a = 16–17°C, T_{wb} = 10°C, as shown in Fig. 1.

RESULTS AND DISCUSSION

Rest in the thermoneutral environment (30°C) resulted in significant decreases in the rectal temperatures (T_{re}) and increases in the mean skin temperatures ($\bar{T}_{sk}$) of all subjects (Fig. 1). The changes in $\bar{T}_{sk}$ were more rapid early in the exposure than toward the end when the subjects were approaching thermal equilibrium, and the mean rates of change were similar for all groups of subjects. Since $\bar{T}_{sk}$ rose about twice as much as T_{re} declined, mean body temperatures changed very little during the 60-min exposure to the thermoneutral environment. Rectal temperatures were highest in the prepubertal boys and successively lower in the older boys, young men, and older men. Throughout the exposures the temperatures at each of the skin areas except the finger were highest in the two groups of boys and lowest in the older men (Fig. 2); consequently, $\bar{T}_{sk}$ was lower with increasing age (Fig. 1). The age-related differences in rectal and mean skin temperatures were associated with the progressively lower metabolic rates in relation to age (Table 2).

TABLE 2. *Thermoregulatory responses of resting men and boys during acute exposures to thermoneutral and cold environmental temperatures*

	Group			
	1, 10–13 yr	2, 14–16 yr	3, 20–29 yr	4, 46–67 yr
Thermoneutral environments, T_a = 30°C; T_{wb} = 15°C				
Metabolic rate, kcal/m²·hr	48.9 ±1.6[c,e]	47.7 ±1.6[b,e]	41.1 ± 2.1	36.0 ±2.0
Heat storage, kcal/m²·h[a]	−3.0 ±1.4	−5.8 ±1.0	−5.6 ±1.1	−4.8 ±2.9
Total heat loss, kcal/m²·h	51.9 ±2.2[d]	53.5 ±2.2[e]	46.7 ±2.5	40.8 ±3.5
$T_{re} - \bar{T}_{sk}$, °C	2.3 ±0.1[d]	2.3 ±0.2[d]	2.5 ±0.2	2.9 ±0.1
Heat conductance, kcal/m²·°C($T_{re} - \bar{T}_{sk}$)	18.7 ±0.7[d]	21.3 ±2.2	17.3 ±1.6[d]	12.3 ±1.5[b]
Cold environment, T_a = 16–17°C				
Metabolic rate, kcal/m²·h	55.2 ±1.7[b,e,f]	53.8 ±1.0[e,g]	47.9 ±2.7	39.2 ±3.6
Heat storage, kcal/m²·h[a]	−63.2 ±6.6[g]	−58.6 ±9.1[g]	−69.7 ±6.5[g]	−77.7 ±8.0[g]
Total heat loss, kcal/m²·h	118.4 ±6.3[g]	112.4 ±9.4[g]	117.6 ±5.6[g]	116.9 ±9.7[g]
$T_{re} - T_{sk}$, °C	8.6 ±0.2[c,d,g]	7.6 ±0.3[g]	7.1 ±0.3[g]	7.4 ±0.5[g]
Heat conductance, kcal/m²·°C($T_{re} - T_{sk}$)	12.8 ±0.8[b,g]	13.7 ±1.3[g]	15.6 ±0.8	15.0 ±1.0

All parameters were measured during the second 30 min of a 60-min exposure to a thermoneutral environment and during the final 15 min of a 30-min exposure to a cold environment. Heat loss is the sum of radiation, convection, and evaporation, calculated by the partitional heat balance equation (12). Values are means ± SEM. [a] Heat storage with a negative sign means that T_b has decreased and a loss of stored body heat has occurred during the period of observation (12). [b] $P < 0.05$, compared with young men. [c] $P < 0.01$, compared with young men. [d] $P < 0.05$, compared with older men. [e] $P < 0.01$, compared with older men. [f] $P < 0.05$, compared with mean value in the thermoneutral environment. [g] $P < 0.01$, compared with mean value in the thermoneutral environment.

The combined rate of heat loss by radiation, convection, and evaporation was greater in the boys than in the adults as a result of their higher skin temperatures. The boys maintained higher skin temperatures ($\bar{T}_{sk}$) by greater metabolic rate and cutaneous blood flow; the latter being indicated by coefficients of tissue heat conductance averaging 63 % higher than in the older men (Table 2).

In the thermoneutral environment, the young men had significantly higher finger blood flows than the prepubertal boys and slightly higher finger blood flow than the older men (Fig. 3). Ring et al. (13) observed lower finger blood flows in older subjects than in young subjects in a thermoneutral environment, and finger blood flows have been shown to be lower in older men than in young men in a hot environment (16). The results of these studies indicate that aging is accompanied by a reduction in functional, if not anatomical, cutaneous vascularization. Forearm blood flow was higher in the postpubertal boys and young men than in older men and prepubertal boys. These differences may be due to greater forearm muscle mass relative to total forearm mass in the older boys and young men, or to a greater circulation to their forearm muscle, or both.

In the cold environment (16–17°C), the rectal temperatures of the younger boys declined initially for 6 min and increased thereafter until the experiment was terminated (Fig. 1). In the older boys, rectal temperature also declined initially, then rose slightly and leveled off in the last 10 min in the cold room. T_{re} of the young men remained about constant, whereas in the older men it decreased throughout the cold exposure. The pre- and postpubertal boys showed declines in mean skin temperature of 7.2°C and 6.3°C, respectively, as compared with declines of 5.5°C and 5.4°C for the young and older men. These differences were largely due to greater declines in the temperatures of the appendages in the boys than in the adults, while the temperatures of the back and chest areas of the adults declined more in the cold environment than those of the boys (Fig. 2). In the cold room the boys' rates of heat loss by radiation, convection, and evaporation were about the same as the adults', but they maintained their core temperatures (Fig. 1) and body heat stores more effectively with higher metabolic rates (Table 2) and greater cutaneous vasoconstriction than the adults (Fig. 3).

Throughout the cold exposure, finger blood flows were lowest in the boys, intermediate in young men, and highest in the older men. These results indicate that age is accompanied by a decrease in the peripheral vascular reactivity to cold stress. Spurr et al. (15) and Yoshimura and Iida (20) have also shown a similar insensitivity of older subjects to local cold stress as indicated by the Lewis "hunting phenomenon." The young men and boys all showed reduced coefficients of heat conductance in the cold as compared with the values observed in the neutral environment. On the other hand, heat conductance of the older men in the cold was actually somewhat higher than in the neutral environment. The unexpected increase in conductance, with a great loss of stored heat (Table 2), resulting in a marked fall in body temperature (Fig. 1), and their relatively high finger blood flows in the cold (Fig. 3), all combine to indicate reduced ability of the older men to rapidly reduce heat loss by cutaneous vasoconstriction in response to cold. The

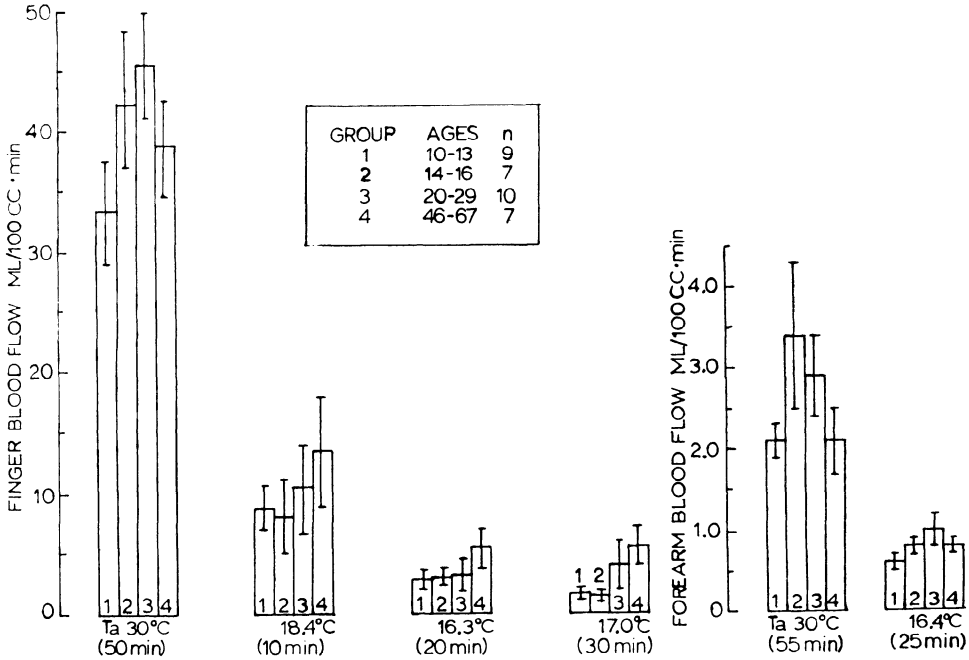

FIG. 3. Finger and forearm blood flow in resting male subjects during 60-min exposures to thermoneutral (T_a = 30°C, T_{wb} = 15°C), followed by 30-min exposures to room temperatures falling to T_a = 16–17°C, T_{wb} = 10°C. Values are means ± SEM.

older men were also much less responsive metabolically than the boys and the young men in the cold (Table 2). More prolonged exposures to cold, and subcutaneous temperature measurements of the thickness of the insulative outer shell, would have helped to clarify these age differences, but they were not feasible with the subjects involved in the study.

In conclusion, the thermoregulatory mechanisms in the thermoneutral and cold environmental temperatures were significantly affected by age. In the thermoneutral environment (30°C), rectal temperatures and mean skin temperatures decreased with advancing age due to lower metabolic rates, since lower levels of heat conductance also occurred with age. Younger subjects rapidly reacted to cold stress by increasing their metabolic rates and minimizing peripheral heat loss by rapid cutaneous vasoconstriction, whereas older men did not increase their metabolic rates to the same extent as younger subjects, and they were less able to maintain their body heat stores by cutaneous vasoconstriction.

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