Physiological responses of aged men to head-up tilt during heat exposure

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Physiological responses of aged men to head-up tilt during heat exposure. J. Appl. Physiol. 63(2): 576–581, 1987.—The effects of age on cardiovascular and thermoregulatory responses to passive tilting were investigated using six old (61–73 yr) and 10 young (21–39 yr) unacclimatized men. Experiments were carried out at 26°C and after exposure to 40°C and 40% relative humidity for 105 min. Continuous measurements of esophageal (Tes) and mean skin (Tsk) temperatures and heart rate (HR) were recorded. Other variables studied included blood pressure (BP), forearm blood flow (FBF), and cardiac output (CO), which were measured at 4- to 5-min intervals. Measurements were made in the supine position and after 70° head-up tilt for 15 min. Cardioacceleration during the tilt test was greater in the young than in the old. Other cardiovascular responses of the old men to orthostatism were qualitatively similar to that of the young except for FBF and forearm vascular conductance. The old men did not show significant changes in FBF during tilting, suggesting a deterioration in the sympathetic nervous reflex in the aged. However, other circulatory adaptations seemed to overcome this deficiency resulting in orthostatic tolerance similar to that of the young. During head-up tilt at 26 and 40°C, Tes of both age groups increased. This may reflect a decrease in conductive heat transfer presumably due to diminished blood flow to the periphery.

orthostatism; cardiac output; forearm blood flow; total peripheral resistance; vascular conductance; esophageal temperature

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TOLERANCE to orthostatic provocation has been studied during acute heat exposure in unacclimatized subjects, (2, 10, 11, 25, 26) and heat-acclimatized subjects (1, 13, 16). On exposure to heat, unacclimatized individuals showed poor orthostatism, a response that was improved on acclimatization. In all of these studies, only young men and women participated as subjects, and the eldest subjects used were 46 (13) and 47 (16) yr old. No reports have been found on orthostatic heat tolerance of old men or women. As a matter of fact, a literature search revealed only a few studies dealing with the influence of age on cardiovascular responses to tilting (4, 15, 21). In the study by Lee et al. (15) tilt-table tests (45°) were performed on old volunteers (age 47–82, mean age 63.0 yr) who were domiciliary care patients at the Baltimore City Hospital, and no significant differences in response to tilt were observed between young and old subjects.

Since the severity of a stress is, most likely, dependent on the intensity of the stimulus, it is uncertain if the adequate cardiovascular compensatory adjustments made by old men to 45° head-up tilt (15) can be duplicated when the orthostatic position increases and when acute heat stress is superimposed. Fiorica and Kem (9) concluded that cardioacceleration and regulation of blood pressure can be altered in a graded fashion by changing the position of the body on a tilt table. In a previous paper (unpublished observations), we reported that sweating sensitivity and activity were not diminished by aging per se, but the impairment of thermoregulatory function, if any, was attributed to a retarded response of the peripheral vascular system during exposure to heat. One important manifestation of dysfunction in the autonomic nervous system is orthostatic hypotension, a function of presoreceptor activity, which seems to deteriorate in many elderly people. Orthostatic hypotension is likely to be a significant factor in predicting the loss of thermoregulatory efficiency, since it correlates with abnormal patterns of peripheral blood flow (6).

This study is concerned with the effects of age on cardiovascular and thermoregulatory responses to passive tilting performed in a comfortable environment and during acute heat exposure.

METHODS

Subjects

Six male elderly subjects, with age ranging from 61 to 73 yr (63.2 ± 5.1 kg body wt) and 10 young men ranging from 21 to 39 yr (66.2 ± 2.3 kg) volunteered for the experiment. The body fat content averaged 18.8 ± 0.7% in the elderly and 18.9 ± 1.0% in the young subjects. All subjects received physical examinations, including blood pressure and electrocardiography (ECG). Elderly subjects were nonsedentary and actively worked daily. Young subjects were students or laboratory investigators. Permission was obtained for the study from each subject after he was given a detailed description of the procedure and the potential complications. As experiments were carried out in winter (January to February), all subjects were considered unacclimatized to heat, avoiding the confounding effects of various degrees or levels of acclimatization of their responses to heat.

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Experimental Protocol

For the experimental sessions, each subject arrived at the laboratory at 0830 h. He was dressed in cotton underwear in a climatic chamber in which air temperature (T_a) was kept constant at 26°C with relative humidity (rh) at 40%. Each subject was harnessed with skin thermocouples (copper-constantan), esophageal and rectal probes, ECG electrodes, a tape-on twin mylar electrodes for measuring cardiac output, a mercury-in-Silastic Whitney strain gauge, and a blood pressure cuff. Preparation of the subject was completed within 30 min and the subject maintained a sitting position on a comfortable wide-meshed chair for ~60 min before any measurements were taken (equilibrium period). After the equilibrium period, the subject lay on a tilt table in the climatic chamber. Both arms rested at the heart level on shelves fastened to the tilt platform. Securing straps on the arms, chest, and thighs allowed the subject to remain passive when changing from one position to another. During the first 15 min on the tilt table when the subject lay supine, blood pressure (BP), heart rate (HR), cardiac output (CO), and forearm blood flow (FBF) were measured every 5 min. Skin (Tsk), esophageal (Tes), and rectal (Tre) temperatures were monitored continuously throughout the experimental period. The tilt table was raised at 70° within 3 s and maintained at that position for 15 min (head-up tilt) unless syncope occurred. During the period of head-up tilt, starting at the first minute, BP, HR, FBF, and CO were measured every 4 min. Care was taken to ensure that the subjects were completely relaxed during the tilting period by instructing them not to use their leg muscles at all during tilt. On completion of the tilt test at 26°C, the subject again sat on the chair. The T_a of the chamber was raised at a constant rate (1°/min) to 40°C, and rh was kept constant at 40% except for a transient period for raising T_a. The subject remained seated for 105 min at 40°C (heat exposure period) and then lay on the table while the same tilt procedure and measurements were conducted. A physician was always in attendance during the tilt test. The ECG was continuously monitored and displayed on an oscilloscope, and recordings were obtained on a San-ei Recti Horiz-8K eight-channel polygraph.

Measurements

Measurements of mean skin temperature (Tsk) were obtained by seven-point thermocouples on the forehead, hand, forearm, chest, thigh, leg, and foot. Tsk was calculated using the area weighting formula of Hardy and DuBois (12). The Tes was measured by a thermocouple (copper-constantan) that was swallowed to the level of the heart, and Tre was measured by a thermocouple probe inserted ~10 cm into the rectum. Body temperatures and HR were monitored continuously and the data were stored every 15 s on a data logger (7V07 San-ei Sokki, Tokyo) to be analyzed by a computer (M243, Sord, Tokyo). BP 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. CO was estimated by impedance cardiography (Nihon-Kohden AI-601G, Tokyo), using the standard four-band electrode arrangement, as described elsewhere (24). A Whitney mercury-in-Silastic circumference gauge was placed at the left midforearm for FBF, and a cuff was secured at the upper arm. Venous congestive pressure was 50 Torr. Total peripheral resistance (TPR) was calculated by dividing mean arterial pressure (MAP) by CO, where MAP = ½(pulse pressure) + diastolic pressure. Forearm vascular conductance (FVC) was calculated as FBF/MAP.

Statistical Analysis

Steady-state measurements during the supine period were compared with values measured during the course of head-up tilt using analysis of variance. Significant differences for the analysis of variance were further tested using the Bonferroni simultaneous multiple comparisons (18). Paired t test was used for comparing intraindividual changes between the thermoneutral and heat exposure periods and Student's t test for comparing mean values of the elderly with those of the young. Data are expressed as means ± SE, with a value of P < 0.05 considered significant.

RESULTS

At 26°C when tilted, none of the subjects showed any signs or symptoms of syncope. After exposure to 40°C, one subject (24 yr) showed syncopeal signs at the last minute of the tilting test when all measurements were completed. In this case the tilt table was immediately returned to the horizontal position, and all signs and symptoms quickly disappeared. We did not detect any abnormal parameters in this particular subject before the syncopic episode. The effects of orthostatic provocation on HR and BP are presented in Table 1.

Cardiovascular Responses

Heart rate. The average HR during supine position at thermoneutrality (T_a = 26°C) was about the same in both age groups (Table 1). It increased within the first minute after the head-up tilt and remained at a higher level until the termination of the test. However, a significant cardioacceleration in the orthostatic position was observed only in the young group.

Heat exposure significantly increased (P < 0.05) HR in both groups. The head-up tilt increased HR promptly and it remained significantly higher (P < 0.05) until the termination of the test. However, the magnitude of the HR response was higher in the young, although not significant.

Arterial blood pressure. The average MAP of the elderly at 26 and 40°C was significantly higher (P < 0.05) than that of the young (Table 1). Heat exposure significantly decreased MAP of both age groups (P < 0.05) during the supine period. No tilt-related changes in MAP were observed in either age group.

Changes in systolic and diastolic BP to supine and head-up tilt at 26 and 40°C in both age groups are shown.
in Table 1. In the supine position, the older men had a higher BP than the younger group at 26 and 40°C. At 26°C head-up tilt significantly decreased systolic pressure in the young group. However, the old group did not show a significant decline in systolic pressure at either Tₜₐ. Diastolic blood pressure was not affected by the upright position at either Tₜₐ in either age group.

Cardiac output. Acute heat exposure slightly increased CO for both age groups (Table 2). This was attributed to an increase in HR to compensate for a slight reduction of stroke volume (SV). Orthostatic provocation at 26 and 40°C had no significant effect on CO of either age group. In the young men, CO was maintained by holding the SV to that of the supine position when HR was not remarkably increased (Table 2).

Responses of Vascular State

At thermoneutrality, the levels of FBF and FVC during the supine position were similar in both groups (Table 2). Although these values decreased significantly (P < 0.05) during the head-up tilt in the young, no changes were observed in the elderly. At 40°C, the head-up posture significantly decreased FBF and FVC in the young. On the other hand, the elderly showed, although not significantly, an increase in FBF and FVC. The average TPR in the supine position became significantly lower (P < 0.05) in both groups in the hot environment. At 26°C, head-up tilt caused no significant changes in TPR.

TABLE 2. Response of cardiovascular parameters to head-up tilt and acute heat exposure in young and old men

<table>
<thead>
<tr>
<th>Measurements</th>
<th>Tₜₐ °C</th>
<th>Age Group</th>
<th>Supine Values</th>
<th>Tilt Period, min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Stroke volume, ml</td>
<td>26</td>
<td>Old</td>
<td>66±3</td>
<td>57±3+6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>68±4.2</td>
<td>59±3.2</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Old</td>
<td>67±5.3</td>
<td>56±4.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>60±3.2</td>
<td>46±2.6*</td>
</tr>
<tr>
<td>Cardiac output, l/min</td>
<td>26</td>
<td>Old</td>
<td>4.0±0.2</td>
<td>4.0±0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>4.1±0.2</td>
<td>4.1±0.1</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Old</td>
<td>4.5±0.3</td>
<td>4.3±0.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>4.4±0.3</td>
<td>4.2±0.3</td>
</tr>
<tr>
<td>Forearm blood flow, ml·100 ml⁻¹·min⁻¹</td>
<td>26</td>
<td>Old</td>
<td>2.0±0.6</td>
<td>2.1±0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>2.3±0.2</td>
<td>1.1±0.2*</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Old</td>
<td>5.1±0.7†</td>
<td>6.6±1.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>10.2±1.4†‡</td>
<td>4.8±0.8*‡</td>
</tr>
<tr>
<td>forearm vascular conductance, ml·100 ml⁻¹·min⁻¹·mmHg⁻¹×100</td>
<td>26</td>
<td>Old</td>
<td>2.1±0.6</td>
<td>2.3±0.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>2.8±0.3</td>
<td>1.4±0.2*</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Old</td>
<td>6.0±0.9†‡</td>
<td>8.3±2.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>13±5.19†‡</td>
<td>6.9±1.2†‡</td>
</tr>
<tr>
<td>Total peripheral resistance, mmHg·l⁻¹·min⁻¹</td>
<td>26</td>
<td>Old</td>
<td>24±7.1</td>
<td>24±5.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>20±5.1</td>
<td>19±3.0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>Old</td>
<td>20±3.1†‡</td>
<td>17±9.0†‡</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Young</td>
<td>17±8.10†‡</td>
<td>16±6.9†‡</td>
</tr>
</tbody>
</table>

Values are means ± SE. Head-up tilt was performed at 70°. Supine values are the averages during pretilt supine period. * P < 0.05 compared with thermoneutrality [air temperature (Tₐ) = 26°C]. † P < 0.05 compared with elderly group.
in either age group. In the hot environment, TPR tended to decrease during tilt in the elderly, but did not change in the young.

**Body Temperature Responses**

**Mean skin temperature.** The average value of $T_{sk}$ at 26°C was $32.0 \pm 0.2°C$ and $31.9 \pm 0.1°C$ in the elderly and young, respectively. At 40°C it increased ($P < 0.001$) to $36.6 \pm 0.1$ and $36.6 \pm 0.1°C$ in the elderly and young, respectively. There were no age-dependent changes of $T_{sk}$ during the tilt test under either environmental condition.

**Esophageal temperature.** Changes in $T_{es}$ in the young and elderly during the tilting test are shown in Fig. 1. The average $T_{es}$ during the period of supine position at 26°C was not significantly different in either group, being $36.60 \pm 0.08°C$ and $36.69 \pm 0.04°C$ in the old and young groups, respectively. In both age groups, $T_{es}$ had a tendency to decrease during the supine position at 26°C. Then $T_{es}$ began to increase immediately after head-up tilting with a faster rate at the beginning, reaching a plateau level after the 10th min of the head-up tilt. The rate of increase was higher in the young; consequently their $T_{es}$ became higher, though not significantly, than that of the elderly at the termination of the test, being $36.68 \pm 0.09°C$ and $36.77 \pm 0.05°C$ in the elderly and young, respectively. At 40°C, the average $T_{es}$ was significantly higher ($P < 0.05$) in the elderly. The head-up tilt increased $T_{es}$ of both age groups ($P < 0.05$) with a faster rate at the beginning and kept increasing until the end of the experiment. The rate of increase was the same in both age groups, subsequently the average increment of $T_{es}$ between the first and the last minute during the head-up tilt period was the same in both age groups.

![FIG. 1. Responses of esophageal ($T_{es}$) and mean skin ($T_{sk}$) temperatures to head-up tilt (70°) and acute heat exposure in young and old men. (Open area with solid line, means ± SE of $T_{es}$ for young; shaded area with dashed line, means ± SE of $T_{es}$ for elderly. Lines for $T_{es}$ represent mean values for corresponding groups. $T_{es}$ of old group at 40°C is significantly higher ($P < 0.05$) compared with that of young group throughout period. Note a difference in scale for $T_{es}$ and $T_{sk}$.)](http://jap.physiology.org/)

**DISCUSSION**

Acute heat stress has been shown to cause syncopal episodes in 25–30% of unacclimatized subjects (13, 16, 25). However, in this study none of the elderly men fainted, and only 1 of 10 young men showed symptoms of heat syncope. It is difficult to explain the reduced incidences of heat syncope among our subjects, especially since they were exposed to heat for a longer time period (105 min before tilting) than the subjects used by the other workers quoted (13, 16, 25). Also they were tilted for 15 min rather than 5 min as used by Lind et al. (16). A possible explanation for the observed low incidence of heat syncope may be related to differences in physical fitness of the subjects used in these studies. The subjects used in earlier studies (13, 16, 25) may have been in excellent physical condition as compared with our subjects. Lind et al. (16) attributed the high frequency of fainting episodes to the excellent physical fitness of the subjects, who were mine rescue personnel. The measured cardiovascular and thermoregulatory responses in the syncopal subject in our experiment at 40°C provided no clues for the possible occurrence of syncope. The fainting episode was not related to failure in the thermoregulatory responses, a finding that supports the work of Lind et al. (16) who found that many heat-fainting episodes occurred at normal rectal temperatures.

The circulatory adjustments in response to a rise in body temperature by external heating are known to involve a redistribution of blood flow away from the splanchnic, renal, and muscle vascular beds (22). Thus maintenance of blood pressure in our subjects during heat stress while in the supine position may have been caused by a decrease in the splanchnic and renal blood flows as a result of sympathetic vasoconstrictor mechanism as reported previously (7). However, it is not clear whether the similar tolerance to orthostatism in old and young men was a result of the same cardiovascular adjustments during heat exposure.

In general, the cardiovascular responses of young men to the 70° head-up tilt at 26°C followed a similar pattern to that described by others (9). During the period of head-up tilt there were no changes in CO due to a significant reduction in SV (Table 2) and an increase in HR (Table 1). Other cardiovascular measures showed no significant changes in MAP and TPR and a significant reduction in FBF and FVC. The decrease in FBF is presumably the result of vasoconstriction that was stimulated by increased sympathetic discharge in response to head up tilt. Activation of the sympathetic nervous system is known to accompany postural changes as a compensatory mechanism for regulation of blood pressure (9, 29).

Postural change from supine to upright during acute heat exposure in young men was accompanied by cardiovascular changes that were similar qualitatively but not quantitatively to those described at thermoneutrality (26°C). The quantitative differences, such as greater rise in HR, gradual increase in TPR, and the return of MAP
to supine values, were necessary to offset the additional stress of heat and thus maintain adequate blood flow to vital organs. The significant decrease in vasodilation (decreased FBF) confirms the work of Lind et al. (16). The reduced FDF and FVC (a reciprocal of forearm vascular resistance) and no change in CO and TPR during tilt suggest vasoconstriction of the periphery and perhaps increased blood flow to visceral and other vital organs. The increase in $T_m$ during the head-up tilt may also support this kind of redistribution of blood flow.

The cardiovascular responses of old men to orthostatism were qualitatively similar to those of the young men except for FBF and FVC. The CO did not change during the tilting test at either $T_m$ because at $26^\circ$C there were no changes in both SV and HR, and at $40^\circ$C a slight reduction in SV was well compensated by an increase in HR. However, the increase in HR was less remarkable compared with that of the young men. It has been suggested that cardioacceleration associated with tilting results more from activation of the sympathetic nervous system than from inhibition of the parasympathetic system (9). Thus the diminished rise in HR of the elderly may be associated with decreased adrenergic input to the heart and/or diminished sensitivity of the pressoreceptors (5). Studies on humans have demonstrated that adrenergic receptor responsiveness and pressoreceptor functions are reduced with aging (8, 14, 20, 28). The vasodilation response of the elderly at $40^\circ$C was significantly lower than that of the young group, and FBF did not change in response to a postural change from supine to upright. Skin blood flow is known to be under pressoreceptor influence; thus the inability of the aged to vasoconstrict the skin and to override heat-induced vasodilation is an indication of decreased sensitivity of the pressoreceptors. Since active vasoconstrictor reflexes have been demonstrated during postural changes in humans (3), the unchanged FBF at $26^\circ$C and its increase at $40^\circ$C may reflect a defect in the sympathetic nervous reflexes in the aged. Additionally, the different response of FBF in young and old subjects during the tilt may be associated with loss of elasticity in the arterial system and compliance in the capacitance system as previously reported by Newberry and Bryan (19). Although postural changes in the aged at $40^\circ$C were accompanied by a slight decreased in TPR and vasodilation, MAP and CO were maintained and all subjects managed the orthostatic maneuvers without syncope. The fact that exposure to heat increased FBF of the aged only 2.6-fold, compared with 4.4-fold in the young, may have resulted in greater venous return, which contributed to maintenance of blood pressure.

None of the studies dealing with orthostatism and heat stress have reported changes in the core body temperature during the tilt test. In this study, $T_m$ was shown to increase in both age groups at 26 and $40^\circ$C. Since $T_m$ has been shown to accurately reflect blood temperature in humans (23), its immediate rise on tilting may reflect a decrease in conductive heat transfer, presumably due to diminished blood flow to the periphery, a redistribution of blood flow on tilting. It may be argued that the increased $T_m$ during tilt is related to redistribution of blood flow in the lung where apical regions are less well perfused than the basal ones while standing (27). However, $T_m$ measured during tilting in the present experiment also showed an increase with a delay time of $3.6 \pm 0.5$ min (the data are not shown in the text). Thus the rise in $T_m$ is probably a reflexion of blood redistribution as well as an increase in blood temperature. The $T_m$ tended to decrease, though not significantly, during the tilt test in agreement with another report (17). The increase in $T_m$ during tilting may be used as an index to evaluate the redistribution of blood flow and hence a contributing factor for the orthostatic tolerance.

In conclusion, unacclimatized healthy young and old men can manage orthostatic maneuvers with few incidences of heat syncope. Orthostatic tolerance in thermoneutrality and during acute heat exposure was not significantly influenced by age. However, the compensatory mechanisms of the cardiovascular system to maintain or regulate HP and CO differed between young and old men. The peripheral vascular responses to postural change was qualitatively and quantitatively different in both age groups. The data suggest that aging may result in sluggish or inadequate sympathetic nervous reflex. However, the elderly individual seems to develop a circulatory adaptation either peripherally and/or centrally to overcome the loss of the autonomic nervous control and thus tolerate orthostatism in heat.

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