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Thermoregulatory response of women to intermittent work in the heat

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DRINKWATER, BARBARA L., JOAN E. DENTON, PETER B. RAVEN, AND STEVEN M. HORVATH. *Thermoregulatory response of women to intermittent work in the heat.* J. Appl. Physiol. 41(1): 57–61. 1976.—Seven women worked intermittently in three randomly ordered sessions at 75% $\dot{V}O_{2\,max}$ at three temperatures, 28°C (45% rh), 35°C (65% rh), and 48°C (10% rh) and recovered in a cool environment (22°C) after each 6-min work period. Although T_{re} was higher in each successive work period, the ambient temperature had no effect on the cardiovascular or respiratory responses or on ΔT_{re}. In all conditions SV decreased with time with a concomitant increase in HR to maintain $\dot{Q}$. A fall in mean blood pressure from the initial to final measurement was due entirely to a decrease in diastolic pressure. The final T_{re} for these women was approximately equal to that previously reported for men working continuously for 1 h under conditions equivalent to time-weighted average of the thermal and metabolic loads during work and recovery in this study.

temperature regulation; heat stress; exercise in the heat

CARDIOVASCULAR AND RESPIRATORY responses to exercise differ considerably when the exercise is performed continuously or when the total work load is divided into alternating cycles of work and rest (1, 2). To accomplish the same amount of work in the same period of time, exercise during intermittent work must be performed at a higher, often supramaximal, metabolic rate. Although the demand on the muscular system may be extremely high, a proper ratio of work-rest time intervals allows the subject to perform the work without excessive strain on either the circulatory or respiratory systems (1). Several investigators (5, 9, 12) have hypothesized that the thermoregulatory system might also respond differently to work in hot environments if the work were performed intermittently rather than continuously. There are obvious practical implications to this approach since many jobs in hot industries do involve alternating periods of work and rest. In contrast to the usual protocol of laboratory studies in which subjects work and rest in the hot environment, workers tend to remove themselves from the source of heat and rest in a cool environment. Since alternating hot and cool environments as well as work-rest periods could be expected to affect thermoregulation, this study was designed to investigate this pattern of exposure.

METHODS

Seven healthy, unacclimatized female volunteers (Table 1) participated in this study during the spring and summer months when the range of ambient temperature in the Santa Barbara area was 18–23°C. Each subject was fully informed of the protocol and gave written consent according to the procedures established by the University of California Committee on Human Rights. The experimental protocol involved working under three different conditions, 28°C, 12.6 Torr vapor pressure (45% rh), 35°C, 28.0 Torr vapor pressure (65% rh), and 48°C, 8.7 Torr vapor pressure (10% rh), in an environmental chamber and recovering in a laboratory area at 22°C, 12.6 Torr (45% rh). At least 1 wk elapsed between tests on the same subject to minimize acclimatization effects, and each subject was advised not to change her level of physical activity during the series of tests.

During a preliminary session, subjects were screened for cardiac and pulmonary abnormalities using a resting 12-lead ECG and a standard series of pulmonary function tests and given instruction and practice in treadmill walking. Levels of aerobic power ($\dot{V}O_{2\,max}$) were determined during a second session by a modified Balke treadmill test (4) so that the work load during the heat exposure could be set at 75% of $\dot{V}O_{2\,max}$.

The subject arrived at the laboratory 2 h following a light lunch, weighed nude, inserted a copper-constantan rectal thermocouple to the depth of 12 cm, and dressed in a two-piece swimsuit, socks, and tennis shoes. ECG leads (modified V_4 position) were applied and seven skin copper-constantan thermocouples were attached to the subjects: 1, forehead; 2, arm; 3, finger; 4, thigh; 5, calf; 6, chest; and 7, abdomen. The relative contribution of each area was weighted in calculation of mean skin temperature as follows (10)

$$\bar{T}_{sk} = 0.21T_1 + 0.13T_2 + 0.06T_3 + 0.15T_4 + 0.08T_5 + 0.21T_6 + 0.17T_7$$

with T_1–T_7 as indicated above. Mean body temperature was calculated as: $\bar{T}_b + 0.65\ T_{re} + 0.35\bar{T}_{sk}$.

Each session consisted of an initial 5-min rest period followed by three alternating work (6 min) and recovery periods (20 min). Prior to the initial rest period, the subject sat in a semireclining position at room temperature (22°C) outside the chamber until heart rate, $\dot{V}O_2$, and T_{re} had stabilized. During the rest period, *min 4* and *5* of walk, and last 5 min of recovery, the metabolic, temperature, and heart rate data were recorded. In one subject a 12-ml venous blood sample was drawn during

TABLE 1. *Physical characteristics of subjects*

Age, yr	Wt, kg	Ht, cm	BSA, m^2	$\dot{V}O_{2\ max}$, l/min	75% $\dot{V}O_{2\ max}$, kcal/h
23.7 ± 4.3	62.5 ± 1.7	169.4 ± 3.3	1.72 ± 0.04	2.46 ± 0.15	550 ± 7

Values are means ± SE; $n = 7$.

rest, 4 min after each work period, and during the last 2 min of each recovery for analysis of blood lactate.

Oxygen and carbon dioxide were analyzed continuously using a paramagnetic oxygen analyzer (Servomex O.A. 137) and an infrared CO_2 analyzer (Beckman LB-1) which were calibrated before and after each test using calibration gases whose O_2 and CO_2 contents were checked periodically by Haldane analysis. The sample gas was drawn from a mixing chamber at a constant rate of 2.7 l/min. Respiratory minute volumes and respiration rates were measured on a Parkinson-Cowan dry gasometer. Skin and rectal temperatures were recorded during measurement periods using a multipoint recorder (Honeywell). All instruments were connected online with a PDP 12/40 computer. The electrocardiogram was monitored continuously on an oscilloscope (Tetronix) and heart rate was recorded on a strip chart during the last 10 s of each minute of data collection. Arterial blood pressure was measured during the 3rd min of the initial rest period and the 19th min of each recovery period by brachial auscultation. Cardiac output was determined by the modified acetylene method (15) during the 5th min of rest, the 6th min of the walks, and the last minute of each recovery period. The technique was modified during the walks to draw aliquots of expired air from the 1-liter bag at the 3rd and 6th s instead of the recommended 4th and 7th s. Prior to and following each exercise period, the subject was weighed (±10 g) inside the environmental chamber. She left the chamber after each walk period to resume the semireclining position for the 20-min recovery period. Fluid was not replaced during the experiment and at the conclusion a final nude weight was recorded.

The data were analyzed by a two-factor factorial analysis of variance with repeated measures across all experimental conditions, temperatures, and work-rest periods. Tests of significance were made at $P < 0.05$ in order to keep the power of the tests ≥ 0.90 for those variables of primary interest. When significant temperature by period interactions were observed, a test of simple main effects was used to determine at what levels significant differences between means were to be found. All a posteriori tests for significance between means were calculated using the Newman-Keuls test of ordered means (17) at the 0.05 level of significance.

RESULTS

Conditions within the environmental chamber, including conversions into some of the more commonly used Heat Stress Indices, are described in Table 2. In spite of the varied environmental conditions, there were no significant differences in cardiovascular response to the work in the three environments nor during the subsequent recovery periods. Oxygen consumption ($\dot{V}O_2$) averaged 29.5 ml $O_2/kg \cdot min^{-1}$ (75% $\dot{V}O_{2\ max}$) during work and 4.3 ml $O_2/kg \cdot min^{-1}$ during the last 5 min of recovery. Since the mean resting $\dot{V}O_2$ was 4.2 ml $O_2/kg \cdot min^{-1}$, it was evident that the subjects had returned to their resting metabolic level by the end of the recovery period. Ventilation volumes remained constant at all temperatures, averaging 53.3 l/min during work and 7.8 l/min by the end of recovery. The latter value did not differ from the mean resting volume of 7.6 l/min. The respiratory exchange ratio (R) was significantly higher during work and showed a significant decrement with time but was not affected by ambient temperature. R decreased from a peak value of 1.00 during the first walk to 0.93 and 0.92 for the second and third walks, respectively. A similar drop was observed following the initial rest period (R = 0.84) to the final recovery period (R = 0.79).

The heart rate response was consistent for all three environmental conditions (Table 3). There was a significant increase in heart rate following the first walk but no further rise from the second to the third work period. All recovery heart rates were significantly higher than the initial resting value but stabilized at a constant level for the three recovery periods. Cardiac output (Table 3) was similar in all three ambient temperatures during work ($\bar{X} = 13.7 \pm 0.7$) and during the recovery periods which followed ($\bar{X} = 5.2 \pm 0.4$). Regardless of the ambient environment, stroke volume (SV) decreased with time (Table 3). The 25% drop in SV from the preexposure rest to the final recovery period was matched by a 25% increase in heart rate for the same interval. The 5% increase in heart rate during work did not completely compensate for the 11% drop in SV, resulting in a nonsignificant 5% decrement in cardiac output from the first to the last work period. Mean blood pressure also decreased with time; the final recovery value of 82.4 Torr was significantly lower than the initial rest value of 87.2 Torr and the first recovery figure, 87.4 Torr. The decrease was completely dependent on a significant drop in diastolic pressure, from 77.4 Torr during rest to 72.8 Torr during the final recovery period. There was no significant change in systolic pressure.

Although mean skin temperature ($\bar{T}_{sk}$) was affected by the ambient temperature ($P < 0.01$), the increase in rectal temperature (ΔT_{re}) during work and recovery was the same for all environmental conditions (Fig. 1). The mean T_{re} during rest and the first walk were the same, 37.1°C. In all other periods T_{re} was significantly higher than this basal value. Another significant increase in T_{re} followed the second walk, but there were no further significant changes across the last three measurement periods. Final rectal temperatures averaged 37.7°C.

TABLE 2. *Work environment*

T_{db}, °C	28.0 ± 0.2	35.2 ± 0.2	47.8 ± 0.1
P_w, Torr	12.6	28.0	8.7
rh, %	45	65	10
T_{wb}, °C	20.0	29.4	23.3
WBGT, °C	22.4	31.1	30.7
T_{eff} (CET), °C	21.5	30.0	30.0

Although air movement within the chamber was 0.5 m/min, an effective air speed of 54 m/min was assumed for all treadmill walks.

TABLE 3. *Physiological responses to intermittent work in three environments*

		Rest	Work			Recovery		
			1	2	3	1	2	3
$\dot{V}_{E_{BTPS}}$, l/min	A	7.4 ± 0.1	54.8 ± 3.8	53.5 ± 3.5	54.4 ± 4.1	7.6 ± 0.4	7.6 ± 0.4	8.4 ± 0.5
	B	7.1 ± 0.2	53.7 ± 4.1	53.0 ± 3.8	53.6 ± 4.1	7.9 ± 0.6	7.4 ± 0.2	7.5 ± 0.4
	C	8.2 ± 0.3	52.5 ± 3.3	52.5 ± 3.5	52.5 ± 3.5	8.2 ± 0.4	8.0 ± 0.5	7.8 ± 0.2
$\dot{V}o_2$, ml/kg·min^{-1}	A	4.2 ± 0.2	29.9 ± 1.5	30.3 ± 1.4	30.8 ± 1.6	4.4 ± 0.2	4.2 ± 0.2	4.4 ± 0.2
	B	4.2 ± 0.2	28.5 ± 1.4	29.1 ± 1.6	29.2 ± 1.6	4.6 ± 0.3	4.4 ± 0.2	4.4 ± 0.2
	C	4.1 ± 0.2	28.7 ± 1.8	29.6 ± 1.2	29.6 ± 1.2	4.3 ± 0.2	4.2 ± 0.2	4.2 ± 0.2
HR, beats/min	A	67.6 ± 4.7	167.6 ± 3.9	174.3 ± 3.3	175.3 ± 3.2	82.4 ± 4.5	85.0 ± 5.4	87.1 ± 4.8
	B	70.6 ± 5.4	169.3 ± 4.1	176.7 ± 3.8	179.0 ± 3.6	82.0 ± 5.4	84.4 ± 5.4	85.0 ± 5.9
	C	65.3 ± 5.0	167.0 ± 3.7	175.3 ± 3.5	178.6 ± 3.4	80.6 ± 6.2	82.9 ± 6.2	83.9 ± 5.9
T_{re}, °C	A	37.1 ± 0.1	37.2 ± 0.1	37.5 ± 0.1	37.6 ± 0.1	37.5 ± 0.1	37.7 ± 0.1	37.7 ± 0.1
	B	37.2 ± 0.2	37.3 ± 0.1	37.6 ± 0.1	37.7 ± 0.1	37.5 ± 0.2	37.8 ± 0.1	37.8 ± 0.1
	C	37.0 ± 0.1	37.0 ± 0.1	37.4 ± 0.1	37.5 ± 0.1	37.4 ± 0.1	37.6 ± 0.1	37.7 ± 0.1
$\bar{T}_{sk}$, °C	A	32.0 ± 0.3	32.4 ± 0.3	32.6 ± 0.3	32.6 ± 0.2	32.6 ± 0.3	32.8 ± 0.2	32.8 ± 0.2
	B	32.3 ± 0.2	34.9 ± 0.2	35.2 ± 0.2	35.2 ± 0.2	33.0 ± 0.3	33.1 ± 0.2	33.1 ± 0.3
	C	32.1 ± 0.2	36.6 ± 0.2	36.8 ± 0.2	36.8 ± 0.2	33.1 ± 0.3	33.5 ± 0.3	33.5 ± 0.3
$\bar{T}_b$, °C	A	35.3 ± 0.2	35.5 ± 0.1	35.8 ± 0.2	35.8 ± 0.2	35.8 ± 0.2	36.0 ± 0.1	36.0 ± 0.1
	B	35.5 ± 0.2	36.4 ± 0.1	36.8 ± 0.2	36.8 ± 0.1	35.9 ± 0.2	36.2 ± 0.2	36.1 ± 0.2
	C	35.3 ± 0.1	36.8 ± 0.1	37.2 ± 0.1	37.3 ± 0.1	35.9 ± 0.1	36.2 ± 0.2	36.2 ± 0.1
$\dot{Q}$, l/min	A	5.2 ± 0.4	14.2 ± 0.9	13.9 ± 0.6	13.9 ± 1.2	5.5 ± 0.4	5.1 ± 0.4	5.3 ± 0.5
	B	5.1 ± 0.3	14.1 ± 0.6	13.6 ± 0.9	13.7 ± 0.7	5.7 ± 0.6	5.2 ± 0.4	5.1 ± 0.5
	C	5.8 ± 0.3	13.9 ± 1.2	13.0 ± 1.0	13.7 ± 0.6	5.0 ± 0.5	4.9 ± 0.5	4.6 ± 0.5
SV, ml/beat	A	78.5 ± 8.9	86.1 ± 6.9	79.5 ± 4.4	76.2 ± 6.3	66.9 ± 3.4	61.4 ± 7.5	61.8 ± 7.4
	B	74.0 ± 6.1	84.2 ± 2.9	77.4 ± 6.9	73.7 ± 5.8	71.1 ± 8.8	62.9 ± 5.9	61.2 ± 6.2
	C	89.8 ± 8.9	84.5 ± 7.9	73.7 ± 5.8	78.4 ± 4.0	62.7 ± 6.1	60.2 ± 6.9	59.9 ± 7.7
Evap wt loss, g/min	A		6.4 ± 0.7	5.2 ± 0.9	5.2 ± 1.1	1.6 ± 0.5	1.6 ± 0.3	2.2 ± 0.4
	B		5.9 ± 1.2	6.4 ± 1.6	6.4 ± 1.2	1.6 ± 0.4	2.4 ± 0.5	3.3 ± 0.9
	C		9.5 ± 0.6	10.9 ± 0.8	10.7 ± 1.6	2.9 ± 0.6	2.6 ± 0.5	2.8 ± 0.3

Values are means ± SEM. Environments: A = 28°C; B = 35°C; C = 48°C; subsequent recovery in a cool environment (22°C).

Mean skin temperature clearly reflected the ambient temperature of the environment where the measurements were taken (Table 3). During work $\bar{T}_{sk}$ was significantly higher in 48°C than in 35 or 28°C and significantly higher in 35 than in 28°C. There were no differences between resting levels of $\bar{T}_{sk}$ preceding the three experiments nor during the first recovery period. Following the 48°C walks $\bar{T}_{sk}$ was significantly higher during the final two recovery periods than after 28°C walks. In the 35 and 48°C environments $\bar{T}_{sk}$ during work was significantly higher than during the recovery periods. No such increase was observed during the walks at 28°C. For all three temperature conditions the $\bar{T}_{sk}$ was higher in the recovery periods than during the initial rest. Following the 28 and 35°C exposures $\bar{T}_{sk}$ stabilized after the first recovery period; at 48°C, after the second recovery period.

Changes in mean body temperature reflected both T_{re} and $\bar{T}_{sk}$ (Table 3). No significant differences due to environmental conditions were observed during the rest or recovery periods. However, during the work periods $\bar{T}_b$ did increase significantly as the ambient temperature increased. The contribution of T_{re} to $\bar{T}_b$ resulted in a significant rise in $\bar{T}_b$ between the first and second walks and from the pretest rest to the first and second recovery periods. No change in $\bar{T}_b$ occurred between walks 2 and 3 or between the second and third recovery period. The calculated increase in body heat content for the 95-min experimental period was 33, 36, and 48 kcal for the 28, 35, and 48°C exposures.

The evaporative weight loss (g/min) was significantly higher during work in the 48°C environment than at 28 or 35°C (Table 3). However, in the recovery periods the weight loss was similar following walks in all three ambient conditions. Only in the 48°C environment was the loss higher during work than during recovery. When evaporative sweat loss for each period of the test was correlated with rectal and mean skin temperature

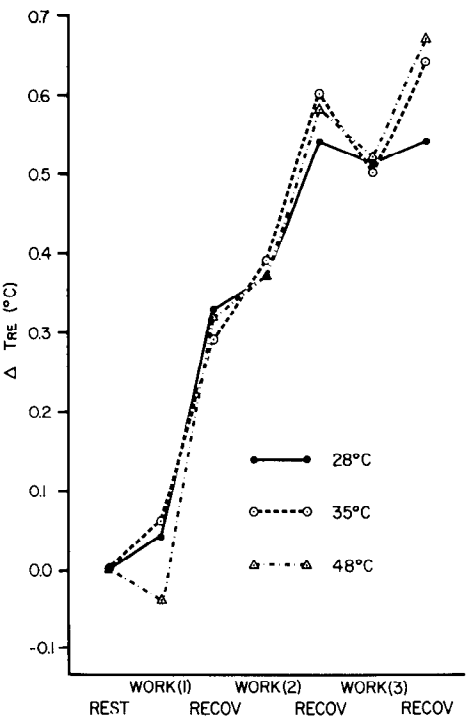

FIG. 1. Changes in rectal temperature (T_{re}) from resting values at 22°C to work (5th and 6th min $\bar{X}$) in and recovery (15–20 min $\bar{X}$) following 28, 35, and 48°C exposures.

for that period, the correlations were r = 0.87 with $\bar{T}_{sk}$ and r = −0.42 with T_{re}. Total sweat loss for all three sessions was less than 1% of the nude body weight.

DISCUSSION

The addition of an environmental heat load to the metabolic requirements of prolonged exercise increases the total heat load on the body. When this load becomes severe, marked alterations occur in the cardiovascular and thermoregulatory responses as the body attempts to balance heat gain and heat loss (13, 16, 18). If the exercise is brief, 4–6 min, and the metabolic cost moderate to severe, the cardiovascular response is determined primarily by the work load and is not affected by the ambient environment (3, 13). However, differences in central and peripheral adjustments have been noted between normothermic and preheated subjects subjected to a combined thermal and metabolic stress (6, 13). Therefore, it had been anticipated that the cardiovascular responses to intermittent work under three thermal loads might differ if the exercise resulted in a cumulative increase in body heat content. Such was not the case under the protocol used in this study. Although T_{re} was successively higher in each exercise period, the ambient temperature had no effect on the cardiovascular responses during work or recovery nor was there any cumulative effect of the combined stressors across time. During the first cycle of work and recovery, HR, $\bar{T}_{sk}$, and $\bar{T}_{b}$ had already reached 95–99% of their final values. Apparently the 20-min recovery period in a cool environment enabled these women to perform repeated bouts of hard work in a hot environment without objective or subjective signs of discomfort. It has been suggested that the dramatic decrease in heart rate upon exposure to cool air is a result of cutaneous venoconstriction causing a shift of blood flow to the central blood volume and therefore an increase in stroke volume (13, 14). This was not the case in this situation, as the decrease in heart rate following exercise at 28°C T_a, when $\bar{T}_{sk}$ was actually lower than during recovery, was the same as that following the 35 and 48°C exercise periods, when $\bar{T}_{sk}$ was significantly elevated during work. Under all three conditions the pattern of stroke volume change was the same, reaching a plateau of ~65 ml during the final two recovery periods. Apparently, Rowell's (13) observation that external heat load is not a factor in cardiovascular response during a brief exposure to work in high ambient temperatures also holds true during the recovery period. The similar stroke volume in the three conditions would suggest that no extreme shifts in blood volume from core to periphery had occurred in the 6 min of work as a result of thermal stress. Undoubtedly some increase in cutaneous circulation occurred during the 48°C exposure. The drop in T_{re} during the first exercise period was most likely due to a sudden increase in blood flow to the skin. In addition, lactate values were higher during the first two walks at 48°C for the one subject who agreed to permit serial samples (Fig. 2), suggesting a shift in blood flow from the active muscles to the skin. It seems clear, however, that the primary stimulus to the physiological responses to both work and recovery in this study was the metabolic work load. The obvious question is at what ratio of work to rest time does the thermal load make itself felt?

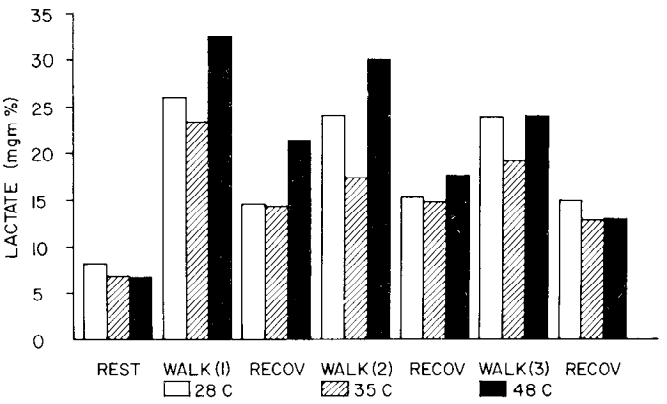

FIG. 2. Lactate (mg/100 ml) values for a single subject obtained 4 min postexercise and during the final 2 min of rest and recovery.

Under less severe environmental conditions, the body regulates its internal temperature in relation to the metabolic rate independent of ambient temperature for extended periods (8, 11, 12). The upper boundary of this "prescriptive zone" (8) depends on the rate of work and degree of acclimatization of the subject as well as the dry and wet bulb temperatures. For two healthy young men working at 420 kcal/h this upper limit was found to be 26.9°C CET (corrected effective temperature) (8). Defining the limits for intermittent work in different environments is more difficult, since both the metabolic rate and CET vary throughout the experimental period. In this study the women worked at ~550 kcal/h in two environments where the CET was equal to the limit proposed for mild work (30°C CET) and recovered in a cool area (<20°C CET) at ~77 kcal/h. For industrial applications a time-weighted mean has been suggested as the most accurate method of describing both the environmental and the metabolic cost of the job to the worker (7). Combining rest, work, and recovery periods the time-weighted average metabolic rate was 180 kcal/h and 20.3, 22.2, and 22.2°C CET for the 28, 35, and 48°C conditions, respectively. Under these conditions the rectal temperature would be predicted to reach an equilibrium during an hour of continuous work (8). The lack of a significant difference in T_{re} during the final three measurement periods suggests that these women had reached equilibrium in spite of minor fluctuations due to the work-rest cycle. The final work period mean T_{re} of 37.6°C was approximately the same as that reported by Lind (8) as the equilibrium value for men working continuously at 180 kcal/h within the "prescriptive zone" for 1 h. If indeed the response to intermittent work is an integration of the metabolic requirements and environmental conditions of the work-rest cycles, it should be possible to predict the ratio of work-rest periods for various combinations of work and heat stress which will minimize or prevent the additive effects of thermal heat load.

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REFERENCES

1. ÅSTRAND, I., P.-O. ÅSTRAND, E. H. CHRISTENSEN, AND R. HEDMAN. Intermittent muscular work. *Acta Physiol. Scand.* 48: 448–453, 1960.
2. CHRISTENSEN, E. H., R. HEDMAN, AND B. SALTIN. Intermittent and continuous running. *Acta Physiol. Scand.* 50: 269–286, 1960.
3. DAMATO, A. N., S. H. LAU, E. STEIN, J. I. HAFT, B. KOSOWSKY, AND S. I. COHEN. Cardiovascular response to acute thermal stress (hot dry environment) in unacclimatized normal subjects. *Am. Heart J.* 76: 769–774, 1968.
4. DRINKWATER, B. L., AND S. M. HORVATH. Detraining effects on young women. *Med. Sci. Sports* 4: 91–95, 1972.
5. EKBLOM, B., C. J. GREENLEAF, J. E. GREENLEAF, AND L. HERMANSEN. Temperature regulation during continuous and intermittent exercise in man. *Acta Physiol. Scand.* 81: 1–10, 1971.
6. GISOLFI, C., AND S. ROBINSON. Central and peripheral stimuli regulating sweating during intermittent work in men. *J. Appl. Physiol.* 29: 761–768, 1970.
7. HORVATH, S. M., AND M. O. COLWELL. Heat stress and the new standards. *J. Occupational Med.* 15: 524–528, 1973.
8. LIND, A. R. A physiological criterion for setting thermal environmental limits for everyday work. *J. Appl. Physiol.* 18: 51–56, 1963.
9. LIND, A. Physiological effects of continuous or intermittent work in the heat. *J. Appl. Physiol.* 18: 57–60, 1963.
10. NADEL, E. R., J. W. MITCHELL, AND J. A. J. STOLWIJK. Differential thermal sensitivity in the human skin. *Pfluegers Arch.* 340: 71–76, 1973.
11. NIELSEN, B. Thermoregulatory responses to arm work, leg work, and intermittent leg work. *Acta Physiol. Scand.* 72: 25–32, 1968.
12. NIELSEN, M. Heat production and body temperature during rest and work. In: *Physiological and Behavioral Temperature Regulation,* edited by J. D. Hardy, A. P. Gagge, and J. A. J. Stolwijk. Springfield, Ill.: Thomas, 1970.
13. ROWELL, L. B. Human cardiovascular adjustments to exercise and thermal stress. *Physiol. Rev.* 54: 75–159, 1974.
14. ROWELL, L. B., J. A. MURRAY, G. L. BRENGELMANN, AND K. K. KRANING. Human cardiovascular adjustments to rapid changes in skin temperature during exercise. *Circulation Res.* 24: 711–724, 1969.
15. SIMMONS, R., AND R. J. SHEPHARD. Measurements of cardiac output in maximum exercise. Application of an acetylene rebreathing method to arm and leg exercise. *Intern. Z. Angew. Physiol.* 29: 159–172, 1971.
16. WILLIAMS, C. G., G. A. G. BREDELL, C. H. WYNDHAM, N. B. STRYDOM, J. F. MORRISON, J. PETER, P. W. FLEMING, AND J. S. WARD. Circulatory and metabolic reactions to work in heat. *J. Appl. Physiol.* 17: 625–638, 1962.
17. WINER, B. J. *Statistical Principles in Experimental Design.* New York: McGraw, 1971.
18. WYNDHAM, C. H. The physiology of exercise under heat stress. *Ann. Rev. Physiol.* 35: 193–220, 1973.