Acclimatization of healthy young adult males to a hot-wet environment

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GARDEN, JOHN W., I. DODD WILSON, AND P. J. RASCH. *Acclimatization of healthy young adult males to a hot-wet environment.* J. Appl. Physiol. 21(2): 665–669. 1966.—Thirty-eight young adult males were exercised daily for 2 weeks during the winter and early spring months on a motor-driven treadmill at 3.5 mph located in a heat chamber maintained at 98 F dry bulb and 90 F wet bulb. Twelve subjects walked for 50 min followed by 10 min rest in the heat; 13 subjects walked 50 min, rested 10 min, walked 30 more min, and rested a final 10 min; 13 subjects walked 50 min, rested 10 min, walked 50 more min, and rested a final 10 min. A modified Balke performance test was administered before heat exposure and at the end of each week. Physiological parameters including rectal temperatures, heart rates, sweat loss and sweat electrolytes were used as measures of acclimatization. It was found that the daily exposure to heat for 2 hr and 1⅔ hr produced acclimatization. Daily exposure to heat for 1 hr resulted in significant alterations in sweat rate and sweat electrolytes but not in heart rate or body temperature. Several differences between physiologic adjustment to a hot-wet as contrasted with hot-dry climates were observed and are discussed.

exercise in hot-wet environment; acclimatization, minimal time for

THE ABILITY of the human organism to adjust physiologically to high environmental temperatures has been the subject of intense study for the past quarter of a century. This phenomenon has been of particular interest to the military services insofar as it is related to the performance of men in the field. Recently, increasing attention has been directed to the rate at which individuals can become acclimatized under various environmental conditions. Lind and Bass (6) have presented evidence that 90 min of work per day for 9 days provides the optimal laboratory exposure time for the development of acclimatization to hot-dry heat. This was shown by the way the rectal temperatures and heart rates plateau during the second half of the work period, indicating the establishment of a thermal equilibrium. It is the purpose of the present study to determine the optimal time for acclimatization to hot-wet conditions as judged by both physiological measurements and performance tests.

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Subjects

Thirty-eight young adult male Marines served as volunteer subjects. Each was given a careful physical examination and an electrocardiogram. Subjects were excluded on the basis of medical conditions existing at the time of examination, emotional problems that could lead to uncooperativeness during the study, or a past record of repeated infractions of military discipline. All subjects were given a single practice training period of treadmill walking at room temperatures (72–78 F). They were then tested by use of a modified Balke treadmill test, which has been shown to have a good correlation with the military task of running 3 miles with combat equipment (7), and divided into three matched groups. All studies were performed between the 1st week in January and the 1st week in April. No subject was used who had been exposed to a hot environment within 3 months of the experimental period.

PROCEDURE

The Naval Medical Field Research Laboratory's climatic heat chamber was held at a constant temperature of 98 F dry bulb and 90 F wet bulb, which gives a relative humidity of 74%. Airflow was maintained at approximately 200 ft/min. Each subject was requested to refrain from coffee drinking or smoking for 2 hr prior to entering the heat chamber.

Group I (1 hr heat exposure) walked in a chamber on a level treadmill at 3.5 mph for 50 min, and then rested on a chair in the heat chamber for 10 more min.

Group II (1⅔ hr heat exposure) walked 50 min, rested on a chair in the chamber for 10 min, and then walked another 30 min. This was followed by a 10-min rest period before leaving the chamber.

Group III (2 hr heat exposure) walked 50 min, rested on a chair in the chamber for 10 min, walked a second 50 min, and rested another 10 min before leaving the chamber.

The following physiological measurements were

TABLE 1. *Mean scores for the modified Balke treadmill test, in minutes*

Group	Pre-Training	1 Week Training	Diff*	Signif of Within-Group Diff	2 Weeks Training	Diff Between 1 Week and 2 Weeks	Signif of Within-Group Diff
I (1 hr) N = 12	6.79	8.02	1.23	Signif† (t = 2.75)	8.75	0.73	NS (t = 1.25)
II (1⅔ hr) N = 13	6.69	8.83	2.14	Signif (t = 6.41)	8.13	−0.70	Signif (t = 1.83)
III (2 hr) N = 13	6.92	8.81	1.89	Signif (t = 3.01)	8.87	0.06	NS (t = 0.29)
Signif of between-group diff	NS‡ (F = <1 with 2 and 35 df)		NS (F = 1.665 with 2 and 35 df)				

* Diff = difference. † Signif = significant. ‡ NS = not significant.

TABLE 2. *Mean rectal temperatures at the pre-exercise period and range of temperature change after 50 min of exercise, in degrees centigrade*

Group	Day 2		Day 9		Difference, Day 9–Day 2			
	Pre-exercise	Increase after 50 min exercise	Pre-exercise	Increase after 50 min exercise	Pre-exercise	Signif of within-group diff	Increase after 50 min exercise	Signif of within-group diff
I (1 hr) N = 12	37.28	1.07	37.10	1.20	−0.18	NS (t = 1.05)	0.13	Signif (t = 2.44)
II (1⅔ hr) N = 13	37.21	1.06	36.90	1.18	−0.31	Signif (t = 3.75)	0.12	NS (t = 1.58)
III (2 hr) N = 13	37.19	1.20	36.87	1.29	−0.32	Signif (t = 5.07)	0.09	NS (t = 0.94)
Signif of between-group diff	NS (F = <1 with 2 and 35 df)				NS (F = <1 with 1 and 24 df)*			

* Since groups II and III showed a significantly lower pre-exercise rectal temperature on *day 9*, an analysis of variance was run to check for any differences between these two groups.

obtained before the start of exercise, and at 10-min intervals during exercise:

1) Rectal temperature, as determined by an indwelling rectal thermistor inserted to a depth of 7 cm from the external sphincter and recorded by an Airborne Instruments Laboratory multichannel temperature programmer. Diurnal temperature variations were minimized by arranging the training schedule so that the same number of individuals from each group exercised at any given hour of the day.

2) Heart rates, as counted on each subject from an exercise electrocardiogram through a Sanborn model 150 recorder. The exploring electrodes were placed in the V2 and V5 precordial positions and the indifferent electrode lateral to the lower thoracic spine. On occasion, it was necessary to count heart rates from the radial pulse.

3) Sweat rates were calculated from nude weights before and after heat exposure. Each subject was instructed to void prior to being weighed initially. After exercising in the heat, the subject showered, toweled dry, and was reweighed. The difference between the initial weight and final weight was taken as the total amount of sweating during the exposure period. Since water was allowed ad libitum during the rest period, accurate intake records were kept and the weight loss was corrected for the weight of ingested water. Each subject was asked not to void until the final weights had been tabulated.

The arm-bag method of sweat collection was used. The left arm of each subject was cleaned with bland soap, thoroughly washed with tap water, rinsed with distilled, ion-free water, and blotted dry with absorbent paper towels. The arm bag was fastened by means of elastic bands below the axilla and at the wrist. Between each usage, each arm bag was throughly washed and rinsed with distilled, ion-free water. Sweat samples were collected, frozen and stored in polyethylene bottles until they could be analyzed.

Sweat sodium and potassium determinations were performed on a Baird-Atomic flame photometer (5), and sweat chlorides were determined on a Cotlove chloride titrator (1).

After all groups had exercised in the heat, the chamber was cooled to room temperature and subjects from groups I and II walked on the treadmill until their total exercise time was equal to that of the 2-hr group. The time of the work task was thus held constant, while the amount of exposure to heat was varied. No physiological measurements were recorded during the latter period. Each subject was performance-tested (modified Balke test) the week prior to walking in the heat, walked from Monday through Friday in the heat, and was again perform-

TABLE 3. *Mean heart rates, beats/15 sec*

Group	Pre-Exercise				50 Min of Exercise and Heat Exposure				90 Min of Exercise and Heat Exposure				110 Min of Exercise and Heat Exposure			
	Day 2	Day 9	Diff	Signif of within-group diff	Day 2	Day 9	Diff	Signif of within-group diff	Day 2	Day 9	Diff	Signif of within-group diff	Day 2	Day 9	Diff	Signif of within-group diff
I (1 hr) N = 12	23.3	23.3	0	NS (t = 0.11)	36.6	36.7	0.1	NS (t = 0.15)								
II (1⅔ hr) N = 13	24.3	23.0	−1.3	Signif (t = 2.62)	36.9	34.4	−2.5	Signif (t = 5.35)	39.4	35.1	−4.3	Signif (t = 4.34)				
III (2 hr) N = 13	23.3	22.5	−0.8	NS (t = 0.84)	36.9	35.5	−1.4	Signif (t = 2.06)	39.1	36.6	−2.5	Signif (t = 3.65)	40.5	38.1	−2.4	Signif (t = 2.22)
Signif of between-group diff	NS (F = 1 with 2 and 35 df)				NS (F = <1 with 1 and 24 df)*				NS (F = 2.39 with 1 and 23 df)*							

* Since groups II and III showed significantly lower heart rates at these periods on *day 9*, an analysis of variance was run to check for any differences between these two groups.

ance-tested on the Saturday of each week for a period of 2 weeks.

A test of the significance of differences between the means for correlated data (one-tailed Student's t score) on *day 2* and *day 9* was applied to each physiologic parameter to determine within-group changes. Between-group differences were tested using the one-way analysis of variance method (F scores) (3). No statistic was accepted as significant unless the chance probability of such a statistic was 0.05 or less. *Day 2* was used as the investigators observed differences between *day 1* to *day 2* which suggested an anticipatory response was influencing the data. Due to instrumentation problems on *day 10*, *day 9* was used as the final period.

RESULTS

Performance Test

The mean scores for the modified Balke treadmill tests are shown in Table 1. When the pretraining means were compared with those at the end of the 1st week of exercise in the heat, all three groups had significantly improved their performance. No further improvement was noted in groups I and III and a significant decline was noted in group II when the means at the end of the 1st week were compared with those at the end of the 2nd week. Furthermore, differences could not be demonstrated between the three groups on any of the test days.

Physiological Parameters

1) Temperatures. The mean rectal temperatures at the pre-exercise period and the range of rectal temperature increase after 50 min of exercise for *day 2* and *day 9* are shown in Table 2. There were no significant differences in the pre-exercise temperatures on *day 2* for any of the three groups, or between *day 2* and *day 9* for group I (1 hr). On *day 9*, the pre-exercise temperatures for both group II (1⅔ hr) and group III (2 hr) were lower than on *day 2*. There were no significant differences in the range of temperature change from the control to the 50-min exercise period on *day 2* and *day 9* for group II or group III, but there was an increase on *day 9* for group I.

The curve representing the mean change in rectal temperature at each period for all three groups on *day 2* and *day 9* is shown in Fig. 1. There is no significant change in the shape or slope of this curve. The rectal temperatures after 90 min of exercise for group II and after 90 and 110 min of exercise for group III remained significantly lower on *day 9*, but no significant differences were

TABLE 4. *Mean sweat loss, in pounds*

Group	Day 2	Day 9	Diff	Signif of Within-Group Diff
I (1 hr) N = 11	2.12	2.47	0.35	Signif (t = 3.29)
II (1⅔ hr) N = 12	3.32	4.01	0.69	Signif (t = 4.17)
III (2 hr) N = 13	4.39	5.49	1.10	Signif (t = 6.48)

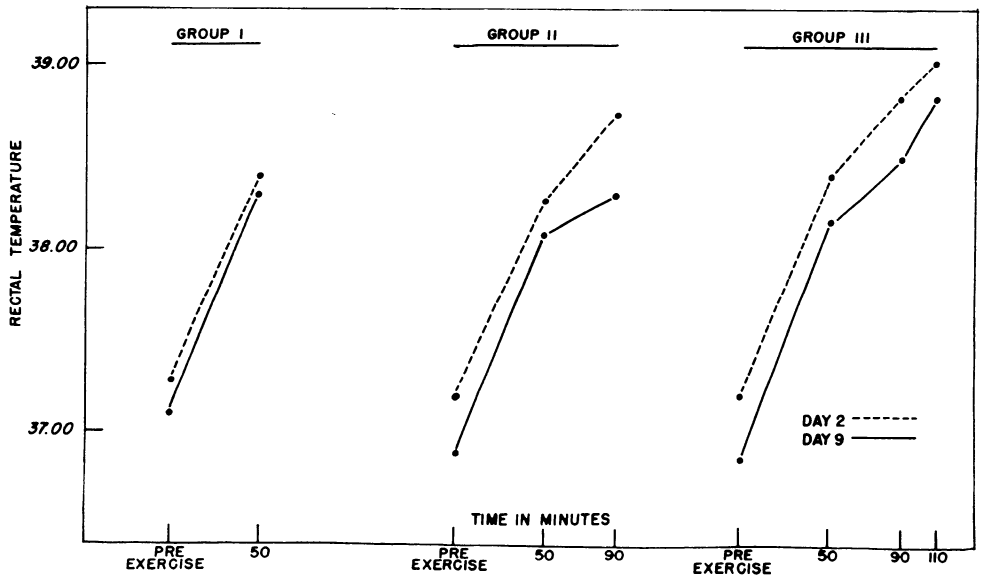

FIG. 1. Mean rectal temperatures, degrees centigrade, during exercise in the heat.

TABLE 5. *Mean concentration of sodium and chloride in sweat, meq/liter*

Group	Sodium				Chloride			
	Day 2	Day 9	Diff	Signif of within-group diff	Day 2	Day 9	Diff	Signif of within-group diff
I (1 hr) N = 10	69.7	56.5	−13.2	Signif (t = 2.22)*	61.8	49.0	−12.8	Signif (t = 2.48)
II (1⅔ hr) N = 13	58.1	34.0	−24.1	Signif (t = 5.24)	51.4	34.3	−17.1	Signif (t = 3.55)
III (2 hr) N = 11	61.4	45.3	−16.1	Signif (t = 3.56)	57.8	40.4	−17.4	Signif (t = 6.31)

* Only eight subjects were available in this group of which seven decreased and one increased from *day 2* to *day 9*.

found in the range of temperature change. At the 110-min period, the average rectal temperature for nine subjects was used for comparison between *day 2* and *day 9*. Four subjects were stopped prior to that time, upon reaching the upper safety limits used at the heat chamber (rectal temperature = 39.40 C or heart rate = 180 beats/min).

2) *Heart rates.* Table 3 shows the mean heart rates for all three groups on *day 2* and *day 9*. In group I there were no significant differences between *day 2* and *day 9*. In group II a significant decrease was noted at the control period, but this was not seen in group III. In groups II and III the mean heart rates were lower at all subsequent periods on *day 9*.

3) *Sweat loss.* The mean sweat loss for all three groups is shown in Table 4. All three groups had a significantly elevated sweat loss on *day 9*.

4) *Sweat electrolytes.* The mean sweat electrolytes for all three groups are shown in Table 5. The sodium and chloride concentrations in all three groups were significantly lower on *day 9*.

DISCUSSION

The performance of all three groups as measured by the modified Balke treadmill test improved during the 1st week of heat exposure, but failed to show subsequent further improvement. The high degree of correlation of the modified Balke test with the ability to run 3 miles with the combat pack (r = 0.76) (7) suggests that the modified Balke test is a measure of cardiovascular conditioning. This indicates that the improvement in cardiovascular response to work in the heat occurred primarily during the 1st week.

On *day 2* all groups were homogeneous for resting rectal temperatures. By *day 9*, the resting rectal temperature was unchanged in group I, but lower than *day 2* in both groups II and III. This is consistent with the hypothesis of a lower setting of the body thermostat (9). The rectal temperature for all subsequent periods in groups II and III remained lower after heat exposure, while the range of temperature change between subsequent periods remained unchanged. While the magnitude of increase in rectal temperature did not change with repeated hot-wet exposure, a consistently lower temperature at any given time was observed. The mean rectal temperatures at 110 min were slightly low, due to the exclusion of subjects who reached the upper limits of either heart rate or temperature measurements. No plateau effect was seen, as the internal temperature continued to rise until the subject was removed from the heat. Thus, in hot-wet environments a thermal equilibrium similar to hot-dry conditions as observed by Lind and Bass (6) was not achieved.

The pre-exercise heart rates show no consistent pattern between *day 2* and *day 9*, since group II was significantly

lowered but groups I and III showed no change. Since measurements were not taken at absolute rest, it is difficult to interpret this finding. However, in groups II and III heart rates at successive periods were lower on *day 9*, which indicates cardiovascular acclimatization. Brouha et al. (2) have recently shown that heart rate is a sensitive indicator of "the total strain induced by the simultaneous action of work and heat." This implies that less "total strain" was being imposed on the subjects in groups II and III on *day 9*. Both the lower rectal temperatures and the improved cardiovascular conditioning as shown by the modified Balke test substantiate this suggestion.

The improvement in the Balke test in group I without changes in heart rates or rectal temperatures might be explained in several ways. It is possible that the body temperature is far more important in regulating heart rate in extremely hot-wet conditions than is cardiovascular conditioning. Also, psychogenic influences such as the anticipatory reflex may have affected the initial Balke test in much the same manner as they appeared to affect our 1st day of work in the heat. An improvement due to training effect probably was not a factor since each subject had a practice walk on the treadmill before the study began (4).

After the 50-min period on both *day 2* and *day 9*, the heart rate changes between successive periods became much less marked. Thus a "plateau effect" for heart rates is seen on both *day 2* and *day 9*. The failure of the heart rate to increase with the rectal temperature following the initial 50-min exercise period may represent the achievement of a level at which the cardiovascular response is limited. In hot-wet environments, "plateauing" seems to be an index of cardiovascular adjustment to a single, continuous environmental stress rather than an index of acclimatization.

The increase in sweat rates over the 9-day period in all groups suggests that the eccrine sweat gland is somewhat more sensitive to short periods of heat exposure than either the body thermostat or the cardiovascular system. It is notable that the mean values for sodium and chloride in sweat tended to fall in all groups, but it must also be accepted that interpreting arm-bag sweat as indicative of total-body sweat may not be entirely valid (8).

Three conclusions seem justified from this investigation: First, it appears that adaptation to hot-wet environments is different from that to hot-dry conditions. In a hot-wet climate, the evaporative heat loss is a limiting factor. However, the eccrine gland continues to produce sweat, resulting in the needless depletion of body stores of essential substances. One compensatory mechanism is the lowering of the resting body temperature. This allows the acclimatized individual to work for a longer period in the heat before a critical temperature is reached. In hot-dry conditions, a thermal equilibrium may be reached as evaporative loss compensates for heat load but under hot-wet conditions average body temperatures continue to rise during heat exposure. Second, 1⅔ hr of daily heat exposure for 10 days consisting of 80 min of exercise and 20 min of rest at each period is the minimum requirement in this study for the adaptation of the cardiovascular, thermoregulatory, sweat-producing, and salt-conserving systems to a hot-wet environment. One hour of exposure under identical conditions failed to produce cardiovascular or thermoregulatory adjustments but did produce an increased sweat volume and salt conservation. Improved performance on the modified Balke test in the 1-hr group indicates cardiovascular adjustment to work but not necessarily to hot-wet environments. Therefore, in the strictest sense, only the 1⅔- and 2-hr groups can be considered to be "acclimatized." Finally, since physiologic adjustments to a hot-wet climate were noted in the 1-hr group, we feel that the term "acclimatization" should be clearly defined and used only when the component environmental and physiologic factors are precisely stated.

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