Heat acclimation, physical fitness, and responses to exercise in temperate and hot environments

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Heat acclimation, physical fitness, and responses to exercise in temperate and hot environments. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 43(4): 678-683, 1977. - Three groups of men with different \( \text{VO}_{2\text{max}} \) (60.1, 47.7, and 35.6 ml·kg\(^{-1}\)·min\(^{-1}\)) were administered two submaximal tests at 23°C, at 41 and 82 W, before and after 8 days of heat acclimation (3-h work at 41 W at 39.4°C dry bulb, 30.3°C wet bulb). A control group with \( \text{VO}_{2\text{max}} \) of 45.3 ml·kg\(^{-1}\)·min\(^{-1}\) was tested at 23°C and in heat before and after 6 days of exercise at 23°C. Trained subjects with the highest \( \text{VO}_{2\text{max}} \) showed the best responses, and the lowest \( \text{VO}_{2\text{max}} \) group showed the worst responses at 23°C and in heat (differences in heart rates and rectal temperatures but not in sweat rates and oxygen consumption responses). Heat acclimation resulted in substantial improvements in responses at 23°C and in heat of the acclimation groups, with very minor changes shown by the control group. Changes at 23°C were characterized by decreases in heart rate, rectal temperature (0.3-0.5°C), oxygen consumption, and sweat rate (25-30%), and increases of 13% and 29% in \( \text{VO}_{2\text{max}} \) in the groups with average and low \( \text{VO}_{2\text{max}} \), respectively. \( \text{VO}_{2\text{max}} \) correlated \( r = -0.62 \) and \( -0.65 \) with rectal temperatures at 23°C and in heat, respectively. It was shown that exercise rectal temperature at 23°C was mainly a function of heat acclimatization, as well as \( \text{VO}_{2\text{max}} \) and surface area/mass ratio, that heat acclimation presented an effective method of physical training, and that \( \text{VO}_{2\text{max}} \) was partially related to heat tolerance.

heat tolerance; \( \text{VO}_{2\text{max}} \); heart rate; rectal temperature; sweat rate; submaximal exercise

The relationship between heat tolerance and physical fitness has been investigated in several studies. Good heat tolerance was found in trained, but unacclimated, runners (9); highly trained men acclimated to heat rapidly (8); interval training resulted in substantial improvements in heat tolerance (4, 5); less strenuous training regimens resulted in significant, but minor, improvements in responses to heat (18-20); and rectal temperature responses in heat were found to be partially correlated with exercise tolerance (6) and \( \text{VO}_{2\text{max}} \) (4, 22, 24). Although there was some evidence that heat acclimation tended to cause an increase in \( \text{VO}_{2\text{max}} \) (20, 22), the relationship between heat acclimation and responses to exercise in temperate conditions was not clear, nor was there sufficient information about the effect of heat acclimation in men with different \( \text{VO}_{2\text{max}} \).

It has been shown that core temperature is related to the relative, rather than the absolute, work load (1, 10) during exercise in temperate conditions, and that training results in decreases in exercise rectal temperature (15, 17, 19, 20). It was not clear, however, if exercise core temperature in temperate conditions was a function of the percentage of \( \text{VO}_{2\text{max}} \) only.

The purposes of the present study were to compare the responses to exercise in temperate and hot environments of men with different \( \text{VO}_{2\text{max}} \), and to determine the effect of heat acclimation on these responses.

Methods

Subjects. The subjects were 26 healthy, unacclimated, young men. Their physical characteristics are shown in Table 1. The trained subjects (\( \text{VO}_{2\text{max}} \) of 57-65 ml·kg\(^{-1}\)·min\(^{-1}\)) had participated in regular training sessions of track, cross-country running, and occasional team games, at least three times a week for at least 1 yr before the experiment began. The untrained, unfit, and control subjects with \( \text{VO}_{2\text{max}} \) of 43-50, 29-38, and 41-49 ml·kg\(^{-1}\)·min\(^{-1}\), respectively, had engaged in mild recreational activities periodically but not in regular training programs. There were no significant differences in body weights among the groups. To minimize the possible effect of natural acclimatization to heat, the experiments were conducted during the fall and winter seasons (November-January).

Procedure. The experimental period lasted 10 days. The trained, untrained, and unfit subjects were administered three exercise tests in a temperate environment before and after undergoing 8 days of heat acclimation. The control group was administered the tests in the temperate environment on the 1st day and were exposed to heat on the 2nd day. This was followed by 6 days of exercise in a temperate environment and a repetition of the tests in the temperate and hot environments on days 9 and 10.

The tests in the temperate environment (23°C dry bulb, 16°C wet bulb, and wind speed less than 0.2 m·s\(^{-1}\)) were as follows: the subjects reported to the laboratory at 8:00 a.m., rested for at least 30 min, after which they performed bench stepping at a rate of 12 steps·min\(^{-1}\) for 60 min. The height of the benches was 30 cm, which gave an average work load for the subjects.
HEAT ACCLIMATION, \( V_{O_2 \text{max}} \), AND RESPONSES TO EXERCISE

TABLE 1. Physical characteristics of subjects

<table>
<thead>
<tr>
<th>Group</th>
<th>Age, yr</th>
<th>Ht, cm</th>
<th>Wt, kg</th>
<th>Surface Area, m²</th>
<th>( V_{O_2 \text{max}} )</th>
<th>1 min⁻¹</th>
<th>ml·kg⁻¹·min⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trained</td>
<td>19.7</td>
<td>177.1</td>
<td>69.2</td>
<td>1.86</td>
<td>4.16</td>
<td>0.16</td>
<td>60.1</td>
</tr>
<tr>
<td>(N = 7)</td>
<td>±1.3</td>
<td>±3.9</td>
<td>±4.14</td>
<td>±0.07</td>
<td>±0.16</td>
<td>±0.7</td>
<td></td>
</tr>
<tr>
<td>Untrained</td>
<td>21.3</td>
<td>175.9</td>
<td>71.0</td>
<td>1.87</td>
<td>4.41</td>
<td>0.34</td>
<td>41.7</td>
</tr>
<tr>
<td>(N = 7)</td>
<td>±1.5</td>
<td>±5.7</td>
<td>±11.7</td>
<td>±0.17</td>
<td>±0.36</td>
<td>±3.6</td>
<td></td>
</tr>
<tr>
<td>Unfit</td>
<td>19.0</td>
<td>176.0</td>
<td>69.6</td>
<td>1.85</td>
<td>9.48</td>
<td>3.7</td>
<td>35.7</td>
</tr>
<tr>
<td>(N = 7)</td>
<td>±0.6</td>
<td>±3.8</td>
<td>±3.9</td>
<td>±0.06</td>
<td>±0.02</td>
<td>±0.8</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>20.4</td>
<td>172.2</td>
<td>69.7</td>
<td>1.85</td>
<td>3.16</td>
<td>45.3</td>
<td></td>
</tr>
<tr>
<td>(N = 5)</td>
<td>±2.7</td>
<td>±5.9</td>
<td>±10.5</td>
<td>±0.16</td>
<td>±0.49</td>
<td>±5.4</td>
<td></td>
</tr>
</tbody>
</table>

Data are means ± SD.

of 41 W. After 30-45 min of rest, the subjects performed bench stepping again on the same benches at a rate of 24 steps·min⁻¹ for 15 min. This constituted an average work load of 82 W. The purpose of these tests was to determine responses to submaximal exercise in a temperate environment, and therefore only 15 min of exercise were performed at 82 W, since some unfit subjects had been found to exhibit near maximal heart rates at 23°C. During heat exposures and exercise training in the control group, sweat rate was determined each hour in the manner described above, with corrections made for water intake and for urine output. Oxygen consumption was determined by collecting the expired air in Douglas bags and analyzing the gases with a paramagnetic \( O_2 \) analyzer (Beckman EB) and an infrared \( CO_2 \) analyzer (Beckman LB).

RESULTS

Responses to exercise at 23°C and in heat before acclimation. The trained subjects showed the lowest heart rate and rectal temperature values and the unfit subjects showed the highest values at rest and during exercise at 41 and 82 W at 23°C (Table 2). Differences in heart rate responses were of a higher magnitude than differences in rectal temperature responses. There were no significant differences in sweat rate and oxygen consumption responses among the groups. \( V_{O_2 \text{max}} \) differed significantly among the groups, except between the untrained and the control groups. There were no significant differences among the groups in skin temperature at 23°C, which ranged from a mean of 30.8°C in the trained group to a mean of 31.1°C in the unfit group.

All trained subjects completed the 3-h heat exposure on day 2, with relatively low heart rate and rectal temperature responses (Table 3). One untrained subject, three unfit subjects, and one subject in the control group did not complete the 3-h exposure because of rectal temperatures above 39.6°C and subjective exhaustion. Table 3 shows that the unfit subjects showed the highest heart rate, rectal temperature, and skin temperature responses. There were no significant differences in sweat rates and oxygen consumption responses among the groups.

Effect of heat acclimation on responses at 23°C and in heat. Heat acclimation resulted in the usual exponential decreases in heart rates and rectal temperatures and increases in sweat rates in the three experimental groups. The subjects in these groups who had not completed the 3-h exposure on day 2 completed it during the last 4 days of acclimation. The subject who had not completed the first heat exposure in the control group was able to complete the 3-h exposure after training, but with a rectal temperature of 39.6°C.

Table 2 shows that heat acclimation resulted in significant decreases in resting and exercise rectal temperatures at 23°C. Final exercise values at 41 W for the trained, untrained, and unfit subjects decreased 0.3, 0.4, and 0.4°C, respectively. Heart rates decreased in the untrained and unfit subjects but not in the trained...
Subjects. Sweat rates decreased 25-30% in these three groups, and oxygen consumption decreased 8-13%. Similar changes were noticed during exercise at 82 W. The control groups showed a significant decrease in heart rate and nonsignificant changes in rectal temperature, sweat rate, and oxygen consumption. \( VO_{2\max} \) after heat acclimation showed a very small and nonsignificant reduction shown by the control group was in a decrease in heart rate, cons, rate, cons, ml kg\(^{-1}\) = 0 1 2 3 min\(^{-1}\) 1 2 3.

Table 2. Responses to exercise at 23°C before and after acclimation.

<table>
<thead>
<tr>
<th>Group</th>
<th>Heart rate, beats min(^{-1})</th>
<th>Rectal temp, °C</th>
<th>Sweat oxygen cons, ml m(^{-2}) h(^{-1})</th>
<th>Oxygen cons, ml m(^{-2}) min(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 30 60</td>
<td>0 30 60</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trained</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>73°±6.6</td>
<td>97°±9.7</td>
<td>36.9±0.19</td>
<td>37.7±0.37</td>
</tr>
<tr>
<td>A</td>
<td>70°±9.9</td>
<td>96°±7.7</td>
<td>36.7±0.19</td>
<td>37.1±0.16</td>
</tr>
<tr>
<td>Untrained</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 7)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>B</td>
<td>81°±2.6</td>
<td>119°±8.7</td>
<td>37.1±0.13</td>
<td>38.0±0.16</td>
</tr>
<tr>
<td>A</td>
<td>77°±10.1</td>
<td>101°±10.2</td>
<td>36.7±0.11</td>
<td>37.6±0.77</td>
</tr>
<tr>
<td>Unfit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>89°±11.0</td>
<td>120°±16.2</td>
<td>37.2±0.25</td>
<td>38.1±0.20</td>
</tr>
<tr>
<td>A</td>
<td>80°±10.0</td>
<td>119°±10.2</td>
<td>36.8±0.25</td>
<td>37.7±0.37</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>(N = 5)</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>75°±5.8</td>
<td>102°±7.0</td>
<td>37.0±0.25</td>
<td>37.9±0.37</td>
</tr>
<tr>
<td>A</td>
<td>75°±6.6</td>
<td>102°±7.0</td>
<td>36.8±0.20</td>
<td>37.7±0.37</td>
</tr>
</tbody>
</table>

Table 3 shows that heat acclimation resulted in significant decreases in heart rates and rectal temperatures in the trained, untrained, and unfit subjects during exercise in heat. The decreases for final mean values were 12, 23, and 32 beats min\(^{-1}\) and 0.4, 0.7, and 0.8°C, respectively. In these groups, heat acclimation resulted in significant decreases in skin temperatures and oxygen consumption (11-14%) and increases in sweat rates (15-25%), although in several cases these increases were not significant. The only significant change shown by the control group was a decrease in heart rate (Table 3).

**Table 3. Responses to exercise in heat before and after acclimation.**

<table>
<thead>
<tr>
<th>Group</th>
<th>Heart Rate, beats min(^{-1})</th>
<th>Rectal Temp, °C</th>
<th>Skin Temp, °C</th>
<th>Oxygen Cons, ml m(^{-2}) min(^{-1})</th>
<th>Sweat Rate, ml m(^{-2}) h(^{-1})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0 30 60</td>
<td>0 30 60</td>
<td>0 30 60</td>
<td>0 30 60</td>
<td>0 30 60</td>
</tr>
<tr>
<td>Trained</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>121°±22.7</td>
<td>38.0±10.7</td>
<td>60.1°±2.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>115°±9.9</td>
<td>37.5±6.0</td>
<td>61.7°±0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Untrained</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(N = 7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>114°±6.1</td>
<td>38.1±6.6</td>
<td>65.6°±0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>112°±7.2</td>
<td>37.2±6.7</td>
<td>65.3°±0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unfit</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>(N = 7)</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>124°±10.1</td>
<td>38.1±6.4</td>
<td>63.5°±0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>122°±9.2</td>
<td>37.8±6.0</td>
<td>63.2°±0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
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</tr>
<tr>
<td>(N = 5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>118°±9.0</td>
<td>38.3±6.7</td>
<td>60.5°±0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>116°±8.8</td>
<td>37.9±6.4</td>
<td>60.2°±0.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data are means ± SD. B = before, and A = after acclimation or training. 0, 30, 60 are minutes of exercise. *P < 0.01 compared with unfit group; **P < 0.05 compared with trained and unfit groups; *P < 0.05 compared with untrained and unfit groups; **P < 0.05 compared with trained group. Effects of acclimation or training (+4 tests for dependent groups) are indicated by *P < 0.05 and **P < 0.01.

Footnotes and statistical analyses are as in Table 2. Preacclimation 3rd-h responses of the untrained, unfit, and control groups are of 6, 4, and 4 subjects, respectively, who completed the exposure.
HEAT ACCLIMATION, \(\text{VO}_2\text{max}\), AND RESPONSES TO EXERCISE

FIG. 1. Relationships between \(\text{VO}_2\text{max}\) and rectal temperatures in temperate and hot environments. Rectal temperatures are final values for 3 h of exercise in heat, and after 1 h of exercise at 23°C. \(\bigcirc\) = trained; \(\triangle\) = untrained; \(\square\) = unfit, and \(\bigtriangleup\) = control groups before acclimation. Respective symbols after acclimation are \(\bigcirc\), \(\triangle\), \(\square\), and \(\bigtriangleup\). Correlation coefficients and regression equations for \(\text{VO}_2\text{max}\) vs. rectal temperature in heat: \(r = -0.65\); \(y = -0.03 x + 40.15\). For \(\text{VO}_2\text{max}\) vs. rectal temperature at 23°C; \(r = -0.62\); \(y = -0.016 x + 38.76\).

groups (except between the untrained and control groups), rectal temperature responses show substantial intergroup variability.

DISCUSSION

\(\text{VO}_2\text{max}\) and responses to exercise in temperate conditions. The observations of Astrand (1) and of Saltin and Hermansen (11) that core temperature was dependent on the relative, rather than the absolute, work load can explain in part the findings that trained men had lower rectal temperatures than untrained men when exercising at fixed work loads (8, 14, 15, 17, 18, 19). Table 2 and Fig. 1 also show that \(\text{VO}_2\text{max}\) is related to rectal temperature responses at 23°C. However, Table 2 shows significant differences in rectal temperature only between the trained and unfit subjects, and Fig. 1 shows substantial intergroup variability in rectal temperature responses among the groups. The correlation coefficient of \(-0.62\), found between \(\text{VO}_2\text{max}\) and rectal temperature at 23°C, suggests that \(\text{VO}_2\text{max}\) accounts for less than 40% of the variability which determines the level of rectal temperature during exercise in temperate conditions. Why is rectal temperature partially dependent upon \(\text{VO}_2\text{max}\)? One possible reason is that trained men, as compared with untrained ones, show a higher sensitivity of sweating (7). In the present study also the trained subjects had an advantage over the unfit ones at 23°C in that trained subjects had equal sweat rates at lower rectal temperatures (Table 2). Other possible reasons are a superior cardiovascular system, which results in more efficient dissipation of stored body heat, and lower resting rectal temperatures (Table 2). The correlation coefficient between resting and exercise rectal temperatures at 41 W at 23°C was 0.58. The ratio of surface area to mass, which substantially affects rectal temperature responses in temperate conditions (16), was not related at all to \(\text{VO}_2\text{max}\) in the present study (Table 1), but the correlation coefficient between surface area-to-mass ratio and rectal temperature responses at 41 W at 23°C was \(-0.69\). Under ambient conditions in which skin temperature is substantially higher than air temperature, men with a larger surface area-to-mass ratio can dissipate relatively more heat than men with a small ratio, which results in lower core temperatures.

The most important factor affecting submaximal rectal temperature responses in temperate conditions is heat tolerance, or the condition of heat acclimatization or the lack of it in an individual; this is only partially related to \(\text{VO}_2\text{max}\) (discussed below). As showed in Table 2, exercise rectal temperatures are substantially lower after acclimation than before acclimation, and Fig. 1 shows clearly that most of the unacclimated subjects had rectal temperatures above 38.0°C at 23°C, and almost all acclimated subjects had rectal temperatures below this value. The correlation coefficient between final rectal temperatures at 23°C and in heat was 0.83. It should also be noted that resting rectal temperature is affected by heat acclimation more than by physical training (14, 15, 17). Since all the above mentioned factors that are related to rectal temperature responses in temperate conditions (with the possible exception of surface area-to-mass ratio) are interrelated, it is difficult to determine from the present data the relative contribution of each factor to exercise rectal temperature. The present results, however, suggest that heat acclimatization presents the dominant factor affecting rectal temperature responses in temperate conditions (possible reasons are discussed below), and that \(\text{VO}_2\text{max}\) and surface area-to-mass ratio constitute less important factors in this respect.

\(\text{VO}_2\text{max}\) and responses to exercise in heat. Piwonka and Robinson (8) showed that highly trained men were partially heat acclimated, and Gisolfi and Robinson (5) and Gisolfi (4) found that strenuous training regimens resulted in substantial improvements in heat tolerance. Strydom et al. (20) and Strydom and Williams (19) showed that moderately severe training resulted in
minor or moderate improvements in heat tolerance, and Shvartz et al. found that mild-to-moderate training resulted in minor (18) or no (17) improvements in heat tolerance. Although the degree of effectiveness of training as a method of heat acclimation may be argued, it is clear that fitness is related to heat tolerance. Wyndham et al. (24) found a correlation coefficient of \(-0.345\) between \(V_{O_2\max}\) and 2nd-h rectal temperatures in heat, and in another study (22), correlation coefficients of \(-0.50\) and \(-0.41\) for \(V_{O_2\max}\) vs. 3rd-h rectal temperatures in heat for data recorded before and after acclimation, respectively. Gisolfi (4) found a similar, but nonsignificant, relationship between \(V_{O_2\max}\) and final rectal temperatures in heat. The results of the present study show that the relationship between \(V_{O_2\max}\) and heat tolerance is higher than those shown by the above-mentioned studies (Fig. 1). These results suggest that, as is the case in a temperate environment, \(V_{O_2\max}\) accounts for about 40% of the variability which determines the level of rectal temperature during exercise in heat. There are several possible reasons for the partial dependence of heat tolerance on \(V_{O_2\max}\). The effects of training on the cardiovascular system, resulting in increases in blood volume and stroke volume (2, 3, 10), are similar to that achieved by heat acclimation (12, 13, 21), which are reflected in lower exercise heart rates in heat as shown in the present study in the trained subjects (Table 3), as well as in similar studies (4, 5, 8, 9, 18-20). Unlike responses in a temperate environment, the ratio of surface area to mass constitutes a minor factor during exercise in heat (16) since ambient temperatures are usually higher than skin temperature (the correlation coefficient between surface area-to-mass ratio and rectal temperatures in heat was \(-0.20\)). There is no evidence that trained men sweat more in heat than untrained ones. Although Gisolfi and Robinson (5) found that trained runners showed slightly higher sweat rates in heat than untrained men and that interval training resulted in a 7.3% increase in sweat rate in heat, in a following study Gisolfi (4) failed to see these changes occurring during several weeks of interval training. Similar lack of increase of sweat rate in heat after training in cool conditions was also shown by other investigators (17, 18, 19, 20). Table 3 also shows no significant differences in sweat rate responses in heat among the groups before acclimation, but the trained subjects showed lower rectal temperatures than the other subjects. The sensitivity of sweating to the rise in rectal temperature was therefore higher in the trained subjects than in the other subjects. However, the lack of differences in absolute sweat rates in heat among men with different \(V_{O_2\max}\) is probably the major reason why heat tolerance is only partially related to \(V_{O_2\max}\). Only heat acclimation can result in substantial increases in sweat rates of trained, as well as untrained, men with the corresponding decreases in heart rates and rectal temperatures (Table 3).

**Heat acclimation and responses to exercise in a temperate environment.** Our findings show that heat acclimation results in improvements in responses to exercise in temperate conditions that are similar to those achieved by strenuous training regimens. The improvements were characterized by decreases in heart rates, rectal temperature, oxygen consumption values and sweat rates, and increases in \(V_{O_2\max}\). The decreases in heart rates and rectal temperatures are similar to those found by Shvartz (14) in six acclimated Bantu subjects exercising at 35 W at 21°C. The decreases of 25-30% in sweat rates (Table 2) were larger than those found after training in cool conditions (15) and were partially related to the decreases in rectal temperatures (the correlation coefficient between changes in sweat rate and rectal temperature on acclimation was 0.69). The 13% and 23% increases in \(V_{O_2\max}\) in the untrained and unfit groups, respectively, are similar to those following strenuous training regimens (3, 15). Wyndham et al. (22) and Strydom et al. (20) also found increases of 17% and 19%, respectively, in \(V_{O_2\max}\) on acclimation. The increases in \(V_{O_2\max}\) in the present study were not caused by the exercise used per se (41 W) but by exercise in heat, because the control group did not show significant changes on training except for a decrease in heart rate (Table 2). The increases in \(V_{O_2\max}\) corresponded well with the decreases in heart rates and oxygen consumption measurements at 41 and 82 W.

Before acclimation, the trained subjects had an advantage over the other subjects during exercise at 41 W at 23°C, mainly because of relatively low resting rectal temperatures (36.9°C) and a superior cardiovascular system. These characteristics, and sweat rates which did not differ from sweat rates in the other groups, allowed them to maintain a heart rate of 98 beats·min\(^{-1}\) and reach a rectal temperature of 37.9°C after 60 min of exercise (Table 2). The unfit subjects, who started exercising at a rectal temperature of 37.2°C and maintained a heart rate of over 120 beats·min\(^{-1}\), reached a rectal temperature of 38.3°C. How then were such relatively large decreases in exercise rectal temperatures as 0.3-0.5°C possible after acclimation (Table 2) despite 25-30% decreases in sweat rates? This was caused by decreases in resting rectal temperatures (0.2, 0.4, and 0.4°C in the trained, untrained, and unfit groups, respectively) and heat production (corresponding decreases of 18, 30, and 28 W·m\(^{-2}\), and an increase in heat loss by radiation and convection as a result of an increase in skin temperature. Since skin temperature after acclimation was recorded only in the untrained group, we calculated heat balances and conductance for this group only, in the manner described elsewhere (15). The 30 W·m\(^{-2}\) decrease in heat production in the untrained group corresponded to an increase of 12 W·m\(^{-2}\) in heat loss through radiation and convection, due to a 0.8°C increase in skin temperature, a decrease of 12 W·m\(^{-2}\) in heat storage, and therefore a decrease of 30 W·m\(^{-2}\) in evaporation, which corresponded well with the decrease in sweat rate. Since heat production decreased and skin temperature increased, conductance did not change on acclimation, and values of approximately 30 W·m\(^{-2}·°C^{-1}\) were found before and after acclimation. The decrease in heart rates in the untrained and unfit groups were probably related to the increase in stroke volume which occurs during acclimation (12, 13, 21). Thus, when heat-acclimated men exercise in a temperate environment
they are able to maintain low heart rates, rectal temperatures, and sweat rates because of low resting rectal temperatures, efficient cardiovascular systems, low heat production values, and sufficient amounts of heat being conducted to the skin.

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The authors thank Dr. A. Lev for his valuable assistance.

This research was supported, in part, by a grant from the United States-Israel Binational Science Foundation (BSF), Jerusalem, Israel.

Received for publication 29 December 1976.