Response of unacclimatized males to repeated weekly bouts of exercise in the heat

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The purpose of the present study was to determine if there is an acclimation effect when unacclimatized males exercise in the heat at weekly intervals. Five subjects performed four exercise bouts, each lasting 1 h at 55% VO\textsubscript{2} max. The first trial was in moderate conditions (mean(s.d.) temperature (T\textsubscript{a}) = 22.0(0.8)°C; mean(s.d.) relative humidity (rh) = 67(6)% and the subsequent three trials were carried out at weekly intervals in the heat (mean(s.d.) T\textsubscript{a} = 34.6(0.6)°C; mean(s.d.) rh = 60(7)%). There were no significant differences between trials in the heat for heart rate, rectal temperature, skin temperature or VO\textsubscript{2} (repeated measures analysis of variance), and total sweat loss (one-way analysis of variance). As changes in these variables are seen with heat acclimation it was concluded that there was no heat acclimation effect and separating exercise bouts by 1 week was a valid method for comparing the effects of different treatments on unacclimatized males during exercise in the heat.

Keywords: Heat acclimation, exercise, thermoregulation

It is generally considered that dehydration results in impairment of temperature regulation and decreased exercise performance\textsuperscript{1}. It follows that minimizing dehydration and its associated effects is an important consideration for optimum performance during prolonged exercise in the heat. Finding the best method for doing this requires the comparison of various interventions such as manipulating plasma volume by intravenous infusion, oral rehydration or dehydration\textsuperscript{2-4}. Administration of fluids of differing composition\textsuperscript{1} or manipulating diet\textsuperscript{5} may also influence the cardiovascular and metabolic response to exercise.

A commonly used method for comparing treatment interventions during exercise is to separate treatments by 1 week, thus allowing time for recovery between exercise bouts, and also attempting to minimize the effects of variations in lifestyle\textsuperscript{2-4}. When studies of exercise in the heat are carried out on individuals who are resident in temperate zones, this presumes that this interval will result in no training effect carrying forward from one exercise bout to the next. When an unacclimatized individual exercises in the heat on a daily basis there is an acclimation effect which is apparent within 3–4 days\textsuperscript{6}. The purpose of the present study was to investigate whether adaptation to heat exposure occurred when three exercise bouts were carried out in the heat at weekly intervals, and thus look at the validity of this method for comparing the effect of treatment interventions on the performance of unacclimatized subjects in the heat.

Methods

Five unacclimatized male subjects, whose physical characteristics are shown in Table 1, participated in this study. All subjects were relatively fit and took part in regular exercise in the weeks before and during the study, but none was highly trained. The study took place in northern Scotland during the months of July and August. The monthly mean temperatures for May to August were 9.7, 11.9, 13.9 and 14.3°C. Any natural heat acclimatization, therefore, was unlikely. Informed consent was obtained from each subject before participation and the study was approved by the local ethics committee.

Maximum oxygen uptake (VO\textsubscript{2} max) was determined on an electrically braked cycle ergometer using a discontinuous exercise protocol. Expired air was analysed by an online computerized system with data recorded at 20-s intervals and averaged over each minute. Data obtained during this protocol were also used to compute a regression equation from which the workload to elicit the required intensity for the exercise bouts was calculated. On the second visit to the laboratory subjects first performed a verification

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean(s.d.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>25.6(4.3)</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>70.7(7.8)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>175(3)</td>
</tr>
<tr>
<td>VO\textsubscript{2} max (ml kg\textsuperscript{-1} min\textsuperscript{-1})</td>
<td>58.9(7.2)</td>
</tr>
<tr>
<td>Workload during trials (W)</td>
<td>171(27)</td>
</tr>
</tbody>
</table>
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of \( \dot{V}O_{2\text{max}} \). After a short warm-up, subjects cycled for 3 min or to volitional fatigue, whichever was reached first, at 25 W below and 25 W above the previous \( \dot{V}O_{2\text{max}} \) workload. Only one subject achieved a higher \( \dot{V}O_{2} \) during the second visit (1.8 ml kg\(^{-1}\) min\(^{-1}\) higher) and no subject completed 3 min at the higher workload. After 20 min rest, subjects rode for 20 min at a workload calculated to elicit a \( \dot{V}O_{2} \) of 55% maximum. This workload was adjusted at 5-min intervals when necessary based on measured \( \dot{V}O_{2} \) and the workload for the subsequent prolonged exercise trials was thus determined.

All subjects undertook four trials (mean(s.d.) \( \dot{V}O_{2\text{max}} = 55.3(3.8) \)). No fluids were given during the trials. The first trial (TA) was in moderate conditions (mean(s.d.) temperature (\( T_{a} \)) = 22.0(0.8)\( ^{\circ}\)C; mean(s.d.) relative humidity (rh) = 67(6)% and the following three trials (TH1, TH2, TH3) in hot, moderately humid conditions (mean(s.d.) \( T_{a} \) = 34.6(0.6)\( ^{\circ}\)C; mean(s.d.) rh = 60(7)%). All trials took place on the same day of the week at the same time of day. All trials in the heat were held on consecutive weeks, but for two subjects the trial in moderate conditions and the first trial in the heat were separated by 2 weeks.

Subjects were requested to consume approximately 500 ml of tap water before retiring the night before each trial to avoid arriving for the trials in a dehydrated state. Subjects reported to the laboratory in the morning after an overnight fast. Nude body weight was recorded to the nearest 0.01 kg and a rectal thermometer inserted to a depth of approximately 12 cm. Subjects, dressed in shorts, socks and shoes, were fitted with electrocardiogram electrodes and skin thermocouples while seated comfortably in a room at approximately 20\( ^{\circ}\)C. Skin temperature was measured at four sites (chest, upper arm, thigh and calf) and the weighted mean skin temperature calculated\(^7\). After the subjects had been sitting for 20 min a butterfly cannula was inserted in a superficial forearm vein. The needle was kept patent by a saline drip set at an infusion rate of 0.3 ml min\(^{-1}\) so as to deliver a volume approximately equal to the blood volume removed. Subjects then moved to the cycle ergometer and rested in the seated position for 15 min before starting exercise.

Heart rate, skin temperature, rectal temperature, room temperature and relative humidity were recorded every 5 min, beginning 5 min before exercise. Expired air samples (Douglas bag) for the determination of \( \dot{V}O_{2} \) and the respiratory exchange ratio (R) were taken at 14–16, 29–31, 44–46 and 58–60 min where subjects completed 1 h of exercise. In the two trials where the subjects failed to ride for 60 min, stopping due to fatigue after approximately 56 min, the last gas sample was collected within the 3 min before the termination of exercise. Samples were analysed for oxygen by a paramagnetic analyser and carbon dioxide by an infrared analyser, and volume was measured by a dry gas meter. The gas analysers were calibrated using dry gases whose concentration had been verified by the Haldane method.

Blood samples (5 ml) were taken while seated 15 min before and immediately before exercise; further samples were collected at 15, 30 and 45 min of exercise and a final sample was obtained at the end of exercise. Part (2.5 ml) was immediately mixed with anticoagulant (potassium ethylenediamine tetra-acetic acid, 1.5 mg ml\(^{-1}\)) for determination of haemoglobin and haematocrit. The remainder was allowed to clot, and was centrifuged before the serum was removed. Haematocrit was estimated in triplicate by the microhaematocrit method and corrected for 3% trapped plasma. All other blood parameters were determined in duplicate. Haemoglobin was estimated by the cyanmethaemoglobin method. Percent change in plasma volume was calculated using the measured haemoglobin and haematocrit values as described by Dill and Costill\(^8\). Serum sodium and potassium concentrations were determined by flame photometry. Serum chloride concentration was determined using a coulometric chloride meter. Osmolality was estimated using freezing point depression.

After the exercise bouts in the heat the subjects moved to a cool environment (approximately 20\( ^{\circ}\)C). When they had recovered, subjects showered and towel dried, and nude body weight was recorded. Sweat loss was calculated as the difference between pre- and post-exercise body weight corrected for respiratory and metabolic weight loss\(^9\).

All statistical comparisons, except that for sweat loss, were made using repeated measures analysis of variance. Post hoc comparisons were made, where appropriate using Tukey’s A test according to the method described by Cicchetti\(^10\). The comparison of mean sweat loss between trials was made using a one-way analysis of variance, with post hoc analysis by Tukey’s A test. Statistical significance was accepted when \( P < 0.05 \).

Results

Despite strong encouragement, two subjects failed to complete the prescribed 1 h of cycling during the first trial in the heat. They rode for 56 min 11 s and 56 min 29 s, although both of these subjects completed the 60-min exercise period on the trial in moderate conditions. Both also completed the second and third trials in the heat at the same exercise intensity. For data analysis, the final time point has been referred to as end-exercise and the above data included with the 60-min values for the other subjects.

Rectal temperature, heart rate and skin temperature were not significantly different at any time point among the three exercise trials in the heat (Figures 1–3). During all trials in the heat mean skin temperature was significantly different (\( P < 0.05 \)) from that during the trial in moderate conditions. Due to technical problems rectal temperature was not obtained for one subject during the trial in moderate conditions. As we were specifically interested in the possible acclimation response to the trials in the heat and not in the difference between the response to exercise in the heat and exercise in moderate conditions which has been described previously\(^11\), no comparisons were made between the trial in moderate conditions and the trials in the heat for rectal temperature. This allowed the maintenance of a subject number of five for this variable. Heart rate during all trials in the heat was significantly higher (\( P \)
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Figure 1. Rectal temperature as a function of time during the three trials in the heat. Values are means(s.e. of the outermost means) at each time point. □ TH1, △ TH2, ○ TH3.

Figure 2. Heart rate as a function of time during the four trials. Values are means(s.e. of the outermost means) at each time point. *TH1 and TH2 significantly different from TA (P < 0.05). ● TA, □ TH1, △ TH2, ○ TH3

(P = 0.08), some indication of greater loss of plasma volume during the last trial in the heat (Figure 4). The serum potassium concentration at the end of exercise was significantly greater (P < 0.05) than the trial in moderate conditions for all trials in the heat, but the three trials in the heat were not different from each other (Figure 5).

Discussion

Heat acclimation has been shown to result in lower heart rate, lower rectal and skin temperature and an increase in sweat rate for a given exercise task in the heat\(^1\). Also, some\(^13\,18\) but not all\(^19\,20\) investigators have reported a lower \(\text{VO}_2\) at a given workload after acclimation. A comparison of the heat acclimation methodology used in these studies does not reveal any systematic differences in experimental conditions which can account for these divergent findings. There appears to be no consistent difference in environmental temperature or humidity; exercise type, frequency or duration; exposure time, frequency or number; state of training or \(\text{VO}_2\)\(_{\text{max}}\). Differences between studies in these variables cannot, therefore, explain why some investigators see a decrease in \(\text{VO}_2\) at a given workload after heat acclimation and others do not.

These changes have been seen after as few as 3–4 days’ exposure to heat\(^5\), but none of these changes was observed in the present study. This indicates that one exercise session in the heat per week does not

![Response to weekly exercise in the heat: A. Barnett and R. J. Maughan](http://bjsm.bmj.com/)

<table>
<thead>
<tr>
<th>Trial</th>
<th>TA</th>
<th>TH1</th>
<th>TH2</th>
<th>TH3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean sweat loss (kg)</td>
<td>0.82(0.26)</td>
<td>1.25(0.42)</td>
<td>1.38(0.33)</td>
<td>1.31(0.23)</td>
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Table 3. Mean(s.d.) values for % VO₂ max, respiratory exchange ratio (R) and rate of carbohydrate usage

<table>
<thead>
<tr>
<th>Variable</th>
<th>Trial</th>
<th>Time (min)</th>
<th></th>
<th></th>
<th></th>
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<tr>
<td></td>
<td></td>
<td>15</td>
<td>30</td>
<td>45</td>
<td>End-exercise</td>
</tr>
<tr>
<td>% VO₂ max</td>
<td>TA</td>
<td>53.8(2.9)</td>
<td>55.4(1.6)</td>
<td>56.6(2.4)</td>
<td>57.2(2.2)</td>
</tr>
<tr>
<td></td>
<td>TH1</td>
<td>54.1(3.0)</td>
<td>55.9(2.4)</td>
<td>56.9(2.4)</td>
<td>56.9(4.6)</td>
</tr>
<tr>
<td></td>
<td>TH2</td>
<td>52.7(2.9)</td>
<td>53.5(5.1)</td>
<td>55.7(2.8)</td>
<td>56.2(3.1)</td>
</tr>
<tr>
<td></td>
<td>TH3</td>
<td>53.2(6.1)</td>
<td>55.1(5.9)</td>
<td>56.0(5.7)</td>
<td>56.6(5.6)</td>
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<tr>
<td>R</td>
<td>TA</td>
<td>0.81(0.02)</td>
<td>0.82(0.04)</td>
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<tr>
<td></td>
<td>TH1</td>
<td>0.85(0.05)</td>
<td>0.82(0.04)</td>
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<tr>
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<td>TH2</td>
<td>0.83(0.04)</td>
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<tr>
<td></td>
<td>TH3</td>
<td>0.87(0.04)</td>
<td>0.85(0.03)</td>
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</tr>
<tr>
<td>Rate of carbohydrate use (g min⁻¹)</td>
<td>TA</td>
<td>1.14(0.35)</td>
<td>1.15(0.47)</td>
<td>1.17(0.47)</td>
<td>1.17(0.41)</td>
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<tr>
<td></td>
<td>TH1</td>
<td>1.51(0.60)</td>
<td>1.30(0.53)</td>
<td>1.40(0.73)</td>
<td>1.35(0.76)</td>
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<tr>
<td></td>
<td>TH2</td>
<td>1.29(0.53)</td>
<td>1.07(0.45)</td>
<td>1.18(0.60)</td>
<td>1.15(0.63)</td>
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<tr>
<td></td>
<td>TH3</td>
<td>1.67(0.55)</td>
<td>1.59(0.60)</td>
<td>1.69(0.62)</td>
<td>1.57(0.67)</td>
</tr>
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</table>

result in the adaptive responses associated with heat acclimation. A corollary of this observation is that separating exercise bouts in the heat by 1 week is a valid method of comparing the effect of different treatments on physically active, unacclimatized individuals.

The fact that two subjects could not complete the 1-h task during their first trial in the heat, but could complete the subsequent trials, implies some degree of adaptation in these individuals. This adaptation is not due to heat acclimation as indicated by the classical changes mentioned above. It may be the result of task familiarity or some other factor. When using this or similar experimental protocol it would seem appropriate for unacclimatized subjects to perform one familiarization trial in the heat.

Most heat acclimation protocols reported in the literature use daily exposures to exercise in the heat. To our knowledge, the maximum time between exercise/heat exposure sessions that will produce a heat acclimation effect in unacclimatized males living in a cool environment has not been determined. Bean and Eichna²⁵ reported that exercise heat exposure at intervals of 3 days resulted in heat acclimation after three or four exposures as indicated by decreased heart rate and rectal temperature during acclimation sessions. It would appear that the maximum interval between exposures for effective heat acclimation is between 3 and 7 days.

The rate of loss of heat acclimation/acclimatization on the return to a cool environment or after discontinuation of the acclimation procedure has, however, been investigated. The present study examined the possibility of an acclimation effect from exposure to heat/exercise sessions separated by 1 week and it is pertinent to review those studies briefly in that light. A number of studies has shown loss of heat acclimation in periods of less than 7 days after the cessation of heat acclimation sessions.

Wyndham and Jacobs²⁶ found that adaptation to work in the heat, as measured by mouth temperature midway through a workshift in a mine, was significantly reduced after 6 days in cool conditions. Adam et al.¹⁹ reported that the better heat tolerance of heat acclimated subjects was mostly lost after 6 days without heat exposure, but not totally lost even after 34 days. Williams et al.²⁷ found that after 1 week in a cool environment the effect of acclimatization on heart rate and sweat rate was largely lost, as was 25% of the effect on rectal temperature. However, other investigators have found the effects of acclimation are retained over 8 days after the cessation of acclimation sessions. Stein et al.¹⁴ found that, with the exception of decreased sweat rate, little loss of acclimation occurred after 14 days in a cool environment with 5 h

Figure 4. Percentage change in plasma volume from time 0 during all four trials. Values are means(s.e. of the outermost means) at each time point. ● TA, □ TH1, △ TH2, ○ TH3

Figure 5. Serum potassium concentration as a function of time during all four trials. Values are means(s.e. of the outermost means) at each time point. *Significantly different from TA (P < 0.05). ● TA, □ TH1, △ TH2, ○ TH3

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of cold exposure per day. Lind and Bass found no loss of acclimation, as measured by rectal temperature, and only a small increase in heart rate during re-exposure to heat/exercise, either 3, 5 or 8 days after heat acclimation. Pandolf et al. found no significant loss in heart acclimation, as assessed by changes in heart rate and rectal temperature, 3, 6, 12 or 18 days after subjects completed 9 days of heat acclimation. The contrasting findings on the rate of loss of heat acclimation may be related to the environmental conditions during acclimation. Two of the studies reporting a substantial loss of acclimation after 6 days to 1 week in cool conditions had hot, humid, environmental acclimation conditions (35.6°C, 75% rh\(^{19}\) and 33.8°C, 90% rh\(^{27}\)). The third study\(^{26}\) did not report dry bulb temperature. The investigators reporting little or no loss of acclimation after 8 or more days used conditions of high ambient temperature and low humidity, ranging from 41.7°C, 49% rh to 49°C, 20% rh\(^{14,28,29}\). This suggests that the acclimation resulting from exposure to an extreme hot, dry environment is more sustainable on return to a cool environment than is the acclimation response to a hot, moderately humid environment. This supports the findings of the current investigation where subjects did not show any acclimation effect when exposed to a hot, moderately humid environment at weekly intervals.

The loss of plasma volume during the final trial in the heat, although not statistically different, appears quite markedly greater than in the other trials (Figure 4). Harrison et al.\(^{30}\) reported greater haemoconcentration after acclimation when subjects cycled in the heat at 75 W. Harrison\(^{31}\) suggested that this greater haemoconcentration is related to the expanded plasma volume resulting from heat acclimation; hypervolaemia may act to lessen the physiological responses that act to conserve blood volume. Absolute plasma volume was not measured in the current investigation, but in view of the absences of differences in cardiovascular and thermoregulatory responses between the first and last trials in the heat, it is suggested that no expansion of plasma volume occurred between trials.

Serum potassium concentrations were higher at the end of exercise in the heat compared with exercise in moderate conditions. The results of Fortney and Senay\(^{32}\) indicate a similar, but not significant, trend which was not discussed by the authors. The rise in serum potassium concentration seen during exercise is mainly due to haemoconcentration and to the release of potassium from the contracting muscle. In the present study there was no significant difference between the trials in the extent to which plasma volume contracted during exercise (Figure 4), suggesting that greater muscle efflux may be responsible for the higher end-exercise serum potassium concentration seen during the trials in the heat. The absence of any difference in the rate of carbohydrate utilization during exercise, however, suggests that the higher serum potassium concentrations during exercise in the heat cannot be explained by any increase in the rate of breakdown of glycogen in muscle or in the liver. Similarly, lack of any difference in \(\dot{V}O_2\) \(R\) or rate of carbohydrate utilization makes it unlikely that a decrease in the adenosine 5'-triphosphat (ATP) concentration at the ATP-dependent potassium channels or the sarcolemmal sodium–potassium pump\(^{33}\) is responsible for an increased loss of potassium from the active muscles. Also, this local ATP depletion probably only occurs during high intensity exercise. Therefore, there is no apparent support for a greater efflux of potassium from the muscle during the trials in the heat. Dehydration\(^{34}\) or higher skin and core temperatures\(^{35}\) have also been shown to result in an increased serum potassium, but again the mechanism is unclear.

In conclusion, this study found that heat acclimation of subjects from temperate climates does not occur if exercise bouts in the heat are separated by 1-week intervals.

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**References**

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