Partial Heat Acclimation in Cricketers Using a 4-Day High Intensity Cycling Protocol

Carl J. Petersen, Marc R. Portus, David B. Pyne, Brian T. Dawson, Matthew N. Cramer, and Aaron D. Kellett

Cricketers are often required to play in hot/humid environments with little time for heat adaptation. **Purpose:** We examined the effect of a short 4-d hot/humid acclimation program on classical physiological indicators of heat acclimation. **Methods:** Male club cricketers were randomly assigned into heat acclimation (ACC, n = 6) or control (CON, n = 6) groups, and 30 min treadmill trials (10 km/h, approx. 30 ± 1.0°C, approx. 65 ± 6% RH) were conducted at baseline and postacclimation. The ACC group completed four high intensity (30–45 min) acclimation sessions on consecutive days at approx. 30°C and approx. 60% RH using a cycle ergometer. The CON group completed matched cycle training in moderate conditions (approx. 20°C, approx. 60% RH). Physiological measures during each treadmill trial included heart rate; core and skin temperatures; sweat Na⁺, K⁺ and Cl⁻ electrolyte concentrations; and sweat rate. **Results:** After the 4-d intervention, the ACC group had a moderate decrease of –11 (3 to –24 beats/min; mean and 90% CI) in the 30 min heart rate, and moderate to large reductions in electrolyte concentrations: Na⁺ –18% (–4 to –31%), K⁺ –15% (0 to –27%), Cl⁻ –22% (–9 to –33%). Both ACC and CON groups had only trivial changes in core and skin temperatures and sweat rate. After the intervention, both groups perceived they were more comfortable exercising in the heat. The 4-d heat intervention had no detrimental effect on performance. **Conclusions:** Four 30–45 min high intensity cycle sessions in hot/humid conditions elicited partial heat acclimation. For full heat acclimation a more intensive and extensive (and modality-specific) acclimation intervention is needed for cricket players.

**Keywords:** core temperature, skin temperature, sweat rate, heart rate

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Cricket is a field sport involving intermittent higher velocity running with walking and jogging frequently played in hot and humid environments for extended durations (approx. 6 h/d), over successive (up to five) days. Cricketers’ physical performance and motor skills (ie, bowling velocity, line and length) can be compromised in the heat.1,2 Factors contributing to impaired thermoregulatory function are likely to include adverse environmental conditions (high ambient temperature and relative humidity), cricketers operating at a high intensity (eg, during fast bowling, or sprinting when fielding and batting) and wearing a large amount of protective equipment (batsmen and wicketkeeper) and/or sunscreen which limits evaporative cooling.3,4 Presumably, episodes of impaired thermoregulatory function are more prevalent in the early part of tours before cricketers are fully heat acclimatized to the local environmental conditions.

It is well established that improved thermal tolerance and endurance capacity occur after repeated exposures (either artificially via heat acclimation; or naturally via heat acclimatization) to a thermally challenging environment.5 Physiological adaptations associated with heat acclimatization include: a reduced exercising heart rate, a lower core temperature (rectal, tympanic, esophageal), increased sweat rate, a reduced concentration of sweat minerals (sodium, chloride), and an earlier onset of sweating.6–8 These adaptations enhance fluid balance and distribution and thermoregulatory control; furthermore these adaptations should limit decrements in physical performance while simultaneously improving player comfort levels.

Elite cricketers usually have little time to adapt to local environmental conditions before a tour and often are not fully heat acclimatized before the first few games. An international tour typically comprises several games over several weeks. Traditional heat acclimation leading to improved thermal tolerance and enhanced endurance performance commonly takes up to 10–14 d of repeated heat exposure to achieve 95% of its maximal response (while performing low intensity activity, 50–60% VO2max).9 Soldiers wearing normal combat clothing had twofold greater acclimation after 12 compared with 6 d, when acclimating (40°C, relative humidity 30%) by treadmill walking (50% VO2max speed) for 60 min daily.10 Importantly for athletes, fitter subjects respond more rapidly to traditional heat acclimation protocols.11 Nevertheless, a traditional laboratory based heat acclimation protocol involving 7–14 d is often impractical for most elite cricketers.

Recently, a protocol of four high intensity (30–45 min) intermittent exercise sessions (interspersed with recovery days) was used to successfully heat acclimate female hockey players.12 The athletes’ distance run improved 33% during the Loughborough Intermittent Shuttle Test when performed in hot conditions (31°C). These athletes also displayed a lower resting core temperature and reported improved sensations of thermal comfort. We sought to evaluate whether a similar protocol of short duration / high intensity exercise could be used to acclimate cricket players during a short (4 or 5 d) pretour training camp: these camps are commonly used by national teams preparing for competitive games. It is known that with traditional lower intensity acclimation protocols, daily heat exposure is a more effective acclimation strategy compared with intermittent (with recovery days) heat exposure.13 We modified the high intensity approach used recently in hockey12 by eliminating the recovery days to create daily heat exposures. This approach could offer promise as an effective and convenient acclimation protocol for cricketers, given their time constraints.
Complicating any heat acclimation protocol is the need of cricket conditioning coaches to limit the running volume of players, particularly fast bowlers. This need stems from research demonstrating that 27% of injuries occurred during practice and training, and most injuries were sustained early in the season when the least cricket is played, with fast bowlers the most susceptible to injury. Fast bowlers missed approximately 16% of potential playing time through injury, where for other positions it was less than 5%. Nearly half of the injuries (49%) were lower limb and when classified by the mechanism of injury, overuse accounted for 17% of all injuries. Microtrauma or overuse injury, results from repeated, abnormal stress (especially on hard surfaces) applied to a tissue by continuous training or training with too little recovery time. Therefore, to limit the volume of running training and potential for overuse injury, it was agreed to utilize cycling exercise for the daily heat exposure in this study. Nevertheless, running testing was performed, as a more cricket-specific exercise modality.

As elite cricketers regularly play in hot and humid conditions, the aim of this study was to quantify the thermoregulatory responses of cricketers to a short 4-d heat acclimation protocol using high intensity cycle exercise. A secondary aim was to assess whether this protocol had any effect on cricket specific repeated running performance. We expect that in comparison with matched training; a short-term heat acclimation protocol will infer superior physiological adaptations and will not be detrimental to cricket specific repeated running performance. For cricketers touring hot and humid countries, the inclusion of an effective heat acclimation program will improve physical preparation and also has the potential to indirectly improve match performance.

Methods

Experimental Approach to the Problem

Utilizing a randomized controlled experimental design, participants completed four high intensity cycling exercise sessions in either hot / humid conditions (approx. 30°C, approx. 61% relative humidity [RH]) or in normal ambient conditions (approx. 20°C, approx. 63% RH). Treadmill running (10 km·h⁻¹ for 30 min) in a heat tent (30°C and 65% RH) was conducted at baseline and postintervention to quantify the magnitude of changes in a number of heat acclimation variables. To assess the effect of the acclimation protocol on cricket performance, 15 min after each 30 min treadmill run, a cricket-specific repeated running test was conducted in normal ambient conditions. A schematic of the study design is provided in Figure 1.

Subjects

Senior club level male cricketers (n = 12) volunteered for the study. The cricketers were divided into two groups: an acclimation (ACC, n = 6) and a control (CON, n = 6) group. Age, height, body mass, sum of seven skinfolds and estimated body surface area of the ACC and CON groups were 25.3 ± 4.4, 22.2 ± 3.8 y; 1.83 ± 0.07, 1.82 ± 0.08 m; 81.2 ± 7.3, 85.0 ± 11.0 kg; 71 ± 23, 87 ± 35 mm; 2.03 ±
0.13, 2.07 ± 0.17 m², respectively (mean ± SD). All participants provided written informed consent. The study was approved by the Ethics Committee of the Australian Institute of Sport.

**Procedures**

**Treadmill Testing.** All subjects performed two 30 min treadmill runs at 10 km·h⁻¹ in a hot and humid heat tent. Dry bulb temperatures and relative humidity (RH) for baseline and posttests averaged 30.1 ± 1.0°C, 64 ± 5%, and 29.8 ± 0.6°C, 64 ± 6%, respectively (mean ± SD). Temperature and humidity was monitored with an environmental monitor (Kestral 3000, Nielsen-Kellerman, Chester, PA, USA) hung 1 m from the ceiling of the tent. Subjects completed baseline and posttrials at the same time of day to control for circadian influences. Subjects were instructed to repeat their previous 24 h diet before each heat test. Four hours before each heat trial, subjects ingested a radiotelemetry pill (CorTemp, HQ Inc, Palmetto, FL, USA) to measure core temperature ($T_c$).

On reporting to the laboratory, subjects provided a urine sample to assess their hydration status via urine specific gravity (USG) this was measured with a handheld refractometer (PAL-10S, Atago, Japan). Body mass (minimal clothing) and drink bottle mass were then recorded and the CorTemp data logger (HT150001, HQ Inc, Palmetto, FL, USA) used to check data transmission of the ingested radio-telemetry pill. The subjects’ left and right forearms were cleaned with an alcohol swab, washed with distilled water and dried. Sweat patches (Tegaderm plus pad 6 × 10 cm transparent film dressing; 3M, Minnesota, USA) were carefully applied horizontally across the upper anterior forearm (participant in the anatomical plane).

Every 5 min during each trial (and 2 min afterward), heart rate (Polar, Kempele, Finland), sternal skin temperature ($T_{sk}$) (Zephyr, Bioharness version 2.2.0.10, Auckland, New Zealand), and $T_c$ were recorded. Ratings of thermal sensation (using a 13-point scale from “unbearably cold” to “unbearably hot”) and thermal comfort
Heat Acclimation of Cricketers

Two minutes after the 30-min treadmill run, subjects provided a blood sample taken from an earlobe for determination of lactate concentration using an automated analyzer (Lactate Pro, Japan). Sweat rates were estimated from pre- and postexercise body mass measurements after adjusting for fluid intake. Finally, the two sweat patches were carefully removed with tweezers and placed into prelabeled tubes. Sweat samples were analyzed using the ion selective electrode method (Hitachi 911, Roche Diagnostics, Switzerland) to determine the concentration of the electrolytes sodium (Na\(^+\)), potassium (K\(^+\)) and chloride (Cl\(^-\)).

**Repeat Run of Three Trials.** Fifteen minutes after each treadmill trial, the subjects completed a cricket-specific repeat run of three trials. These trials involved six repeats of the run of three (3 × 17.68 m), starting each repeat on 30 s. Electronic dual beam light-gate timing (Speedlight, Swift performance equipment, NSW, Australia) was employed to measure each run of three repetitions. The total performance time of all six repeats from the run of three trials as well as the time difference between the fastest and slowest repetitions were recorded. A blood lactate sample (Lactate Pro, Japan) was obtained 3 min after the last repetition. These trials were conducted on an outdoor asphalt surface, with pre- and posttrials conducted at approx. 24°C and 48% RH.

**Acclimation Sessions.** Between baseline and posttesting all subjects completed four consecutive days of intervention (cycling) training using a spin bike (Infiniti, SB250). For group ACC, this intervention involved exercising (heat acclimation) in a heat tent at 30.1 ± 0.8°C and 61 ± 6% RH, while the CON group performed matched training in ambient conditions of 19.9 ± 0.9°C and 63 ± 10% RH (mean difference 10.3 ± 0.4°C, 2 ± 4% RH; mean ± 90% confidence limits). The cycling training involved multiple exercise sets, with each set consisting of eight repeated 20 s maximal efforts interspersed with a 10 s rest. There was a 4 min recovery (low intensity cycling) between each set. In the first and fourth training sessions, four sets (total time 30 min) were performed, whereas six sets (total time 45 min) were performed in the second and third training sessions. Water was drunk ad libitum during all training and testing sessions.

**Statistical Analyses**

Descriptive data are presented as mean (±SD) and displayed in Table 1. The effectiveness of the heat acclimation for each group was assessed by quantifying the within-individual change scores from baseline to post. In addition, between-group comparisons using the unequal-variances version of the unpaired t-statistic were made on the change scores to assess the effectiveness of the heat acclimation in comparison with the matched training conducted in ambient conditions. Inferential statistics and standardized scores were generated to assess the magnitude of difference between baseline and post. Briefly the criteria for assessing effect sizes (ES) were: <0.2 trivial, 0.2–0.6 small, 0.6–1.2 moderate, 1.2–2.0 large, and >2.0 very large.
Table 1  Changes resulting from 4 d of heat acclimation (ACC) or matched training (CON) in cricketers

<table>
<thead>
<tr>
<th></th>
<th>ACC</th>
<th>CON</th>
<th>Change</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Baseline</td>
<td>After</td>
<td>Change</td>
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<tr>
<td><strong>Treadmill Test</strong></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Prehydration Status—USG</td>
<td>1.014±0.010</td>
<td>1.013±0.008</td>
<td>-0.001±0.009</td>
</tr>
<tr>
<td>30 min Fluid (Water) Intake (mL)</td>
<td>112±139</td>
<td>127±145</td>
<td>15±150</td>
</tr>
<tr>
<td><strong>Physiological Responses</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweat Conc., Sodium (μmol·L⁻¹)</td>
<td>78±12</td>
<td>63±10‡</td>
<td>-14±12</td>
</tr>
<tr>
<td>Sweat Conc., Potassium (μmol·L⁻¹)</td>
<td>6.4±0.9</td>
<td>5.4±0.8‡</td>
<td>-0.9±0.9b</td>
</tr>
<tr>
<td>Sweat Conc., Chloride (μmol·L⁻¹)</td>
<td>51.3±9.3</td>
<td>39.8±4.4†</td>
<td>11.5±7.9a</td>
</tr>
<tr>
<td>Sweat Rate (L·h⁻¹)</td>
<td>1.3±0.3</td>
<td>1.2±0.2</td>
<td>-0.1±0.3</td>
</tr>
<tr>
<td>Post 2 min Blood Lactate (mmol·L⁻¹)</td>
<td>3.4±1.5</td>
<td>2.8±1.4</td>
<td>-0.6±1.5a</td>
</tr>
<tr>
<td><strong>Athlete Perception</strong></td>
<td></td>
<td></td>
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<tr>
<td>Thermal Sensation (Scale 1–13)</td>
<td>10.5±0.6</td>
<td>9.2±1.0†</td>
<td>-1.3±0.8</td>
</tr>
<tr>
<td>30 min Change in Thermal Sensation</td>
<td>3.5±0.6</td>
<td>2.7±0.8‡</td>
<td>-0.8±0.7b</td>
</tr>
<tr>
<td>Thermal Comfort (Scale 1–5)</td>
<td>3.1±0.7</td>
<td>2.3±0.5‡</td>
<td>-0.8±0.6</td>
</tr>
<tr>
<td>30 min Change in Thermal Comfort</td>
<td>2.1±0.7</td>
<td>1.3±0.5‡</td>
<td>-0.8±0.6</td>
</tr>
<tr>
<td><strong>Repeat Run of Three Test</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Time (s)</td>
<td>67.87±3.28</td>
<td>67.62±2.81</td>
<td>-0.26±3.22</td>
</tr>
<tr>
<td>Difference Fastest to Slowest Rep (s⁻¹)</td>
<td>1.52±0.53</td>
<td>1.24±0.44</td>
<td>-0.29±0.51</td>
</tr>
<tr>
<td>Post Lactate (mmol·L⁻¹)</td>
<td>13.6±2.3</td>
<td>13.5±1.9</td>
<td>-0.2±2.2</td>
</tr>
</tbody>
</table>

Note. +Small, ‡moderate, and †large magnitudes of difference between baseline and posttesting within group, and a small and b medium magnitudes of difference in the between-group changes scores.
Results

Intervention Training Sessions

During the four cycling training sessions the heart rate (postset) and blood lactate (postsession) measures were 174 ± 6 beats·min⁻¹ and 10.5 ± 2.8 mmol·L⁻¹ for the ACC group, and 170 ± 12 beats·min⁻¹ and 11.3 ± 3.2 mmol·L⁻¹ for the CON group. The interventions were comparable in terms of blood lactate (ie, no substantial difference) but a small difference existed in heart rate (lower in CON, ES = 0.48 ± 0.21).

Pretest Hydration

There were only trivial within-group changes in USG measurements for baseline and posttests respectively. However, there was a moderate (ES = 0.63 ± 0.70) between group difference in hydration change scores, with the CON group becoming more dehydrated (Table 1).

Treadmill Tests

Figure 2 shows the exercising heart rate, core and skin temperatures during the treadmill tests. From baseline to posttesting there was a moderate decrease (11 beats·min⁻¹, ES = −0.83 ± 1.01) of the 30 min heart rate for the ACC group. In addition, from baseline to posttest, both the ACC and CON groups had a moderate decrease (19 beats·min⁻¹, ES = −1.18 ± 0.86; 11 beats·min⁻¹, ES = −0.85 ± 0.99) in the recovery heart rate 2 min posttrial, but the magnitude of change in ACC was not greater than in CON. Between-group changes in posttrial exercising heart rates were trivial. For Tc and Tsk temperatures, all changes between baseline and posttest were trivial in both groups. Furthermore, the magnitude of the between group changes in both Tc and Tsk were unclear.

The ACC group exhibited substantial reductions in sweat Na⁺, K⁺ and Cl⁻ electrolyte concentrations, and substantial improvements in all measures of thermal sensation and comfort, after 4 d of heat training. In comparison, the CON group had only substantial improvements in measures of thermal sensation and comfort. The ACC group had small (ES: 0.33 ± 0.51) and moderately (ES: 0.88 ± 0.82) greater reductions in chloride and potassium respectively, (but not sodium) in comparison with CON. Table 1 shows the physiological responses and participant’s perceptions from baseline and posttest trials.

Repeat Run of Three Trials

There were only trivial changes in all performance (total time, difference between the fastest and slowest repetition) and blood lactate measures of the repeat run of three trials for both ACC and CON groups (Table 1).
Figure 2 — CON (left column) and ACC (right column) group responses to 4 d of high intensity acclimation. Note. Mean (±SD) (a) heart rate, (b) core temperature ($T_c$), and (c) skin (sternal) temperature ($T_{sk}$) values recorded in the 30 min treadmill runs (approx. 30°C, 64% RH) for the CON (left column) and ACC group (right column). Within group, +small, ‡moderate, and †large magnitudes of difference between baseline and posttest. There were no differences between groups.
Discussion

The main finding of this study was that 4 d of heat acclimation via high intensity cycle exercise was sufficient to elicit partial thermoregulatory adaptations in club cricketers without harming sport-specific repeat sprint exercise performance. The 4-d heat acclimation protocol elicited substantial decreases in sweat electrolyte concentration and 30 min exercising heart rate, while a control group showed only trivial changes in these variables. Both groups had improved perceptions of thermal sensation and comfort while exercising in the heat. However, there were no substantial changes in other physiological variables (increased sweat rate, decreased core temperature) indicative of full heat acclimation. A longer duration or more exercise-specific acclimation protocol may be required to obtain a greater acclimation response in these subjects.

A key issue is the degree of full acclimation that can be achieved by athletes/cricket players in a short time frame of a few days. From traditional heat acclimation research (involving daily 50–70 min of running or cycling at 50–60% \( \text{VO}_2\max \)) it is known that (1) the process of adaptation to exercise in the heat begins within a few days; (2) full adaptation takes 7–14 d for most individuals, and (3) different systems of the human body adapt at varying rates to successive days of heat exposure.\(^{19}\) Decreased heart rate and plasma volume expansion takes 3–6 d to occur,\(^{19,20}\) decreases in sweat \( \text{Na}^+ \) and \( \text{Cl}^- \) concentrations take 5–10 d, and increased sweat rate, sensitivity and increased skin vasodilation take 7–14 d for 95% of the adaptation to occur.\(^{21}\) The sudomotor modifications potentially represent the most potent adaptive response.\(^{5}\) Plasma volume expansion resulting from increased plasma protein and sodium chloride retention ranged from 3 to 27% and was accompanied by a 15–25% decrease in heart rate during the first 5 d of heat acclimation.\(^{21}\) In the present study the ACC group showed a moderate 6% reduction in 30 min heart rate after 4 d of acclimation, indicating there was still scope for further or additional improvement. After complete acclimation, sodium concentrations in sweat are reduced by approximately 50% for any specific sweat rate.\(^{22}\) We observed sweat sodium concentrations were reduced by 18% in the ACC group, indicating there was scope to further reduce sweat electrolyte concentration. The adaptations of increased sweat rate and sweat sensitivity, and a reduced core temperature threshold for sweating onset, combine to produce up to a twofold increase in sweat rate (increasing from 1.5 to 3.0 L⋅h\(^{-1}\)).\(^{4}\) In this study, there was no increase in sweat rate in the ACC group. The 4-d high intensity heat acclimation protocol used here appears to be too short to make substantial changes to the sweat rate.

Cricketers are involved in a running sport, yet cricket conditioning coaches and physiotherapists are often cautious with regard to the running volume that cricketers undertake. The heat adaptation used here involved a nonspecific exercise (4 d of cycling), while the cricketers were tested in a running protocol (specific to cricket). Greater adaptations might have occurred here with a running acclimation protocol. However, undertaking a running-based acclimation protocol could expose cricketers to a higher injury risk if they are not accustomed to the volume of running required. It is well accepted that overuse injuries are often a result of a rapid increase in training volume or excessive training volume on hard training surfaces.\(^{15}\)

The cricketers involved in this study were of a lesser standard (club cricketers) and presumably a lower fitness level than elite (international) cricketers. For example, during the same 30 min treadmill test a group of 14 trained elite cricketers
in our laboratory had a moderately lower peak heart rate (167 ± 10 vs 176 ± 11 beats·min⁻¹) compared with the cricketers in the present study (C.J. Petersen, Australian Institute of Sport, unpublished data). One indicator of improving fitness is that the heart rate during the immediate postexercise recovery period decreases faster (returning toward resting level). Both groups improved their 2 min recovery heart rate after the 30 min run by 19 and 11 beats·min⁻¹ (ACC and CON groups, respectively). Therefore, we tentatively interpret these findings as that at least half of this moderate 19 beats·min⁻¹ improvement in the ACC group could be indicative of an increase in fitness (the cricketers were in their preseason preparation) whereas the remainder of the improvement is likely from improved heat adaptation. While this protocol did not improve cricket-specific repeated high intensity running, it also did not compromise this performance. Therefore, a more aggressive approach (greater number or duration of heat adaptation sessions) could be trialed with club cricketers; however, it may be more effective to use a more modality-specific (running) intervention if the players can tolerate the increased volume of running.

Future work with cricketers undertaking high intensity acclimation should investigate the time course of the plateau effect of the various acclimation/acclimatization changes using a longer experimental protocol. A recent recommendation indicated the heat acclimation of individuals in the general population using a short-term protocol (traditional approach, 90 min per day for 5 d, controlled hyperthermia, and limited to a peak core temperature of 38.5°C) should not be completed more than 1 wk before their relocation to a heat stressful environment. One additional heat exposure should be used for each 5 d away from significant heat exposure.23 There is a need for similar recommendations for athletes especially when undergoing high intensity exercise heat acclimation protocols before major competition.

**Practical Implications**

With senior club cricketers, 4 d of high intensity cycling exercise in the heat was sufficient to produce moderate to large decreases in sweat electrolyte concentrations, and moderate improvements in exercising heart rate, thermal sensation and comfort. However, improvements in thermal sensation and comfort can also be gained using the same protocol in ambient conditions. Substantial changes in other key heat acclimation indicators such as core temperature and sweat rate require more than four sessions in the heat.

While it could be argued that physiological adaptations are fast tracked using this 4-d heat acclimation protocol, adaptations will still be occurring upon arriving in the targeted hot and humid environment. Therefore, we recommend a more intensive and/or extensive (and exercise-specific) acclimation protocol be employed to elicit full heat acclimation in cricketers.

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