Thermoregulation, Hydration and Performance over 6 Days of Trail Running in the Tropics
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Thermoregulation, Hydration and Performance over 6 Days of Trail Running in the Tropics

Abstract

The purpose of this study was to investigate thermal response, hydration and performance over a 6-day, 142-km trail running race in tropical conditions. 9 participants competed in the 2011 Gwadarun (30 °C ± 2.4 °C and 82 ± 4 % RH). Data were collected on days 1, 4 and 6. Gastrointestinal temperature (Tgi) and heart rate (HR) were measured using portable telemetry units, whereas blood samples were collected for hematocrit, osmolarity, plasma concentrations, alkaline reserves and creatine phosphokinase. The performances expressed in speed were correlated with both total body water and body mass loss per hour (TBWL.h⁻¹ and ∆BM.h⁻¹), HR and changes in Tgi per hour (∆Tgi.h⁻¹): the more water and mass the participants lost, the higher the HR and the greater the Tgi change, and the better the performance. The ∆Tgi.h⁻¹ was significantly correlated with ∆BM.h⁻¹, and the participants who lost the most mass had the greatest increases in Tgi. None of the blood parameters demonstrated significant changes. The present study showed that well-trained acclimated runners performing a 6-day trail race in a tropical environment and drinking ad libitum did not demonstrate heat-related illness or severe dehydration. Moreover, high performance was associated with increases in Tgi, TBW and BM losses per hour.

Introduction

Running, particularly long-distance running, is negatively affected by hot environments [17, 19]. For example, marathon performance was shown to progressively slow as the wet bulb globe temperature (WBGT) index increased from 5 to 25 °C [7]. This phenomenon is even more marked during running in a hot/wet climate (i.e., tropical climate [12]), which limits the evaporative processes [12, 18, 38]. Although the exact causes are not well known, explanations related to hyperthermia and/or dehydration have been proposed. During exercise, a large volume of sweat loss can gradually reduce blood and stroke volumes if not replaced, which tends to limit muscle blood flow [8]. If heat storage cannot be limited (because of the failure of evaporation processes), core temperature may limit exercise [9], or the brain may provoke a voluntary cessation of effort – or a reduction in its intensity – to maintain thermal homeostasis [23]. As pointed out by Maughan et al. [17], most of the data on the thermoregulatory response to exercise come from laboratory studies, with fewer studies having focused on real-life situations. As the relationship between exercise and heat stress is currently a hot topic [34], the study of exercise performed in valid ecological conditions is particularly important to determine how the physiological response is affected [6]. Recently, the advent of ingestible sensors and data loggers has allowed sports scientists to measure core temperature during running competition in warm and humid conditions [2, 14]. While these studies demonstrated high core temperature elevation without medical consequences and no detectable effects of the ingested fluid volume on any of the variables related to central temperature (Tc) or performance, a relationship between running speed and Tc increase was observed, with the best runners finishing with the highest Tc, as previously reported [25]. However, these results were obtained for relatively short-distance runs (i.e., 21 km), in which runners can afford to take physiological risks in order to succeed [2, 14], and in high-level marathon runners [28, 37]. For longer distances such as ultra-trail or multi-day trail runs, the relation-
ship between $T_C$, hydration status and performance seems to be less clear [32]. The aim of the present study was to investigate the thermal response, hydration behaviour and performance during a 6-day, 142-km trail race performed under tropical conditions.

Material and Methods

Participants

9 regionally- to internationally-ranked participants (8 males and 1 female; ▶ Table 1) competed in the 2011 Guadaran (a 6-day trail race covering the 6 islands of Guadeloupe, French West Indies: day 1: 27 km; day 2: 27 km; day 3: 15 km; day 4: 15 km; day 5: 25 km and day 6: 33 km, for a total of 142 km under tropical conditions: 30 ± 2.4 °C and 82 ± 4 % RH). All participants gave written informed consent, and the protocol was approved by the ethics committee of the university and was conducted according to the Declaration of Helsinki. In addition, this study was performed in accordance with the ethical standard of the IJSM [11]. Participant characteristics are presented in ▶ Table 1.

Exercise intervention

For the sake of the athletes' comfort, only trail days 1, 4 and 6 were studied. The sessions were performed in the early morning (starting at 7 am). Gastrointestinal temperature ($T_g$) was measured before and after each trail session with a CorTemp™ 2000 ambulatory remote sensing system (HQ Inc., Palmetto, FL, USA), using pills that were given at least 3 h before each session. Heart rate (HR) was monitored continuously using a portable teleme

Blood analysis

The day before T1 and immediately at the end of T6, blood samples were collected in tubes containing ethylenediaminetetraacetic acid (i.e., EDTA tubes). Hematocrit (Hct) was measured with a micro-method following blood microcentrifugation (16000 g, 10 min, 25 °C) (XE 2100, Sysmex, Kobe, Japan). The plasma concentrations in alkaline reserves (AR), proteins (Prot), sodium [Na⁺], potassium [K⁺], and creatine phosphokinase (CPK) were also measured at each sample time with a bench analyzer (Integra 800 Roche, Meylan, France). The plasma osmolality was measured using an osmometer (Löser, Fisher Scientific, Illkirch, France).

Statistical analysis

Each variable was tested for normality using the Skewness and Kurtosis tests, with acceptable Z values not exceeding +1 or −1. Once the assumption of normality was confirmed, parametric tests were performed. The following variables: performance (Perf), $T_g$, variation in $T_g$ ($\Delta T_g$), water intake (WI), difference in body mass ($\Delta BM$), total body water loss (TBWL) and HR, were analysed with a one-way analysis of variance (ANOVA) with repeated measures (trail day). Pairwise correlations were used to analyse the effect of variables on performance, water intake and $T_g$. Data are displayed as mean ± SD, and statistical significance was set at $p < 0.05$. All statistics were computed using Systat 12® software.

Results

Changes in trail performance

The mean performance for the 6-day trail race (Perf$_{6d}$) in terms of rank or % of first place was not different among trail sessions (▶ Table 2). However, both the speed ($p < 0.0001$) and the mean speed ($\text{m.s}^{-1}$; $p < 0.02$; ▶ Table 2) were significantly affected by the trail day. Although $T_g$ and $\Delta T_g$ did not change over the trail days, the $T_g$ expressed in time unit (°C.h$^{-1}$) demonstrated significant change ($p < 0.05$) across trail days (▶ Table 2). Weight loss ($p < 0.0001$), WI ($p < 0.02$) and TBWL ($p < 0.0001$) were significantly affected by the trail day when expressed in absolute values. Although WI expressed in time unit (h$^{-1}$) and weight loss expressed in time unit (kg.h$^{-1}$) were not affected by trail day, both TBWL ($p < 0.0001$) and $\Delta T_g$ ($p < 0.0001$) expressed in time units were affected by the day. HR$_{\text{mean}}$ was likewise affected by the trail day ($p < 0.005$).

Global performance

The Perf$_{6d}$ was significantly correlated with the cumulative performance on the 3 trail days studied ($R^2 = 0.98$; $p < 0.001$). When simple linear regressions were carried out, the performances expressed in speed on trail days 6 and 3 (Perf$_{6d}$) were similarly correlated with: TBWL.h$^{-1}$ ($R^2 = 0.61$; $p < 0.02$ and $R^2 = 0.61$; $p < 0.02$); $\Delta BM$.h$^{-1}$ ($R^2 = 0.50$; $p < 0.04$ and $R^2 = 0.48$; $p < 0.04$), HR$_{\text{mean}}$ ($R^2 = 0.50$; $p < 0.04$ and $R^2 = 0.50$; $p < 0.04$) and $\Delta T_g$ (h$^{-1}$) ($R^2 = 0.73$; $p < 0.003$ and $R^2 = 0.73$; $p < 0.003$) (▶ Fig. 1). When stepwise multiple linear regression was applied, both Perf$_{6d}$ and Perf$_{6d}$ were significantly correlated with HR$_{\text{mean}}$ and TBWL.h$^{-1}$; Perf$_{6d}$ (m.s$^{-1}$) = 0.233HR$_{\text{mean}}$ − 0.762TBWL.h$^{-1}$ − 2.2; ($R^2 = 0.86$.

Table 1 Anthropometric data for the 9 subjects.

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (Yrs)</th>
<th>Weight (kg)</th>
<th>Height (m)</th>
<th>BFM (%)</th>
<th>BSA (m$^2$)</th>
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<tbody>
<tr>
<td>1</td>
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<td>66.5</td>
<td>170</td>
<td>8</td>
<td>1.78</td>
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<tr>
<td>2</td>
<td>44</td>
<td>77.7</td>
<td>193</td>
<td>15</td>
<td>2.08</td>
</tr>
<tr>
<td>3</td>
<td>49</td>
<td>61.2</td>
<td>180</td>
<td>11.2</td>
<td>1.78</td>
</tr>
<tr>
<td>4</td>
<td>49</td>
<td>66</td>
<td>170</td>
<td>13.7</td>
<td>1.76</td>
</tr>
<tr>
<td>5</td>
<td>64</td>
<td>73.2</td>
<td>180</td>
<td>15.6</td>
<td>1.92</td>
</tr>
<tr>
<td>6</td>
<td>43</td>
<td>65.4</td>
<td>172</td>
<td>10</td>
<td>1.77</td>
</tr>
<tr>
<td>7</td>
<td>52</td>
<td>68.3</td>
<td>183</td>
<td>14.6</td>
<td>1.88</td>
</tr>
<tr>
<td>8</td>
<td>35</td>
<td>71.8</td>
<td>183</td>
<td>12.2</td>
<td>1.93</td>
</tr>
<tr>
<td>9</td>
<td>47</td>
<td>55.5</td>
<td>161.5</td>
<td>15</td>
<td>1.57</td>
</tr>
<tr>
<td>Mean</td>
<td>46.6</td>
<td>67.3</td>
<td>176.9</td>
<td>12.8</td>
<td>1.83</td>
</tr>
<tr>
<td>SD</td>
<td>8.7</td>
<td>6.6</td>
<td>9.4</td>
<td>2.6</td>
<td>0.14</td>
</tr>
</tbody>
</table>
Table 2  Performance, core temperature (TC), change in TC (delta TC), body mass (BM) and body mass loss (BML), water intake (WI) and total body water loss (TBW) and heart rate (HR) during the 3 analysed trials and the final performance. a, b, c: significantly different from T1, T4 and T6, respectively.

<table>
<thead>
<tr>
<th></th>
<th>T1</th>
<th>T4</th>
<th>T6</th>
<th>Perf6d</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td>s</td>
<td>10 534 ± 2399bc</td>
<td>6123 ± 1497ac</td>
<td>15 413 ± 4617ab</td>
<td>67096 ± 17649</td>
</tr>
<tr>
<td>rank</td>
<td>13.9 ± 9.3</td>
<td>13.6 ± 10.8</td>
<td>14.8 ± 10.5</td>
<td>14.1 ± 10.7</td>
<td></td>
</tr>
<tr>
<td>%</td>
<td>143.5 ± 32.7</td>
<td>139.3 ± 34.0</td>
<td>152.7 ± 45.75</td>
<td>142.6 ± 37.5</td>
<td></td>
</tr>
<tr>
<td>m.s⁻¹</td>
<td>2.7 ± 0.6</td>
<td>2.6 ± 0.6</td>
<td>2.3 ± 0.7a</td>
<td>2.25 ± 0.58</td>
<td></td>
</tr>
<tr>
<td>T °C</td>
<td>38.3 ± 1.2</td>
<td>38.7 ± 0.7</td>
<td>38.6 ± 0.9</td>
<td>38.5 ± 0.2</td>
<td></td>
</tr>
<tr>
<td>delta T °C</td>
<td>1.3 ± 0.6</td>
<td>1.8 ± 0.6</td>
<td>1.8 ± 0.6</td>
<td>1.6 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>Delta BM kg.h⁻¹</td>
<td>0.4 ± 0.3</td>
<td>1.1 ± 0.5ac</td>
<td>0.5 ± 0.3</td>
<td>0.7 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>kg.h⁻¹</td>
<td>-3.4 ± 1.0</td>
<td>-1.6 ± 0.4a</td>
<td>-2.8 ± 1.4a</td>
<td>-2.6 ± 0.7</td>
<td></td>
</tr>
<tr>
<td>BML %</td>
<td>5.1 ± 1.4%</td>
<td>2.4 ± 0.7%</td>
<td>4.0 ± 1.5%</td>
<td>3.8 ± 0.8%</td>
<td></td>
</tr>
<tr>
<td>WI L</td>
<td>1.6 ± 0.9</td>
<td>1.1 ± 0.7</td>
<td>1.8 ± 0.6b</td>
<td>1.5 ± 0.3</td>
<td></td>
</tr>
<tr>
<td>Lh⁻¹</td>
<td>0.5 ± 0.3</td>
<td>0.6 ± 0.3</td>
<td>0.5 ± 0.2</td>
<td>0.5 ± 0.1</td>
<td></td>
</tr>
<tr>
<td>TBW Lh⁻¹</td>
<td>-5.0 ± 1.1</td>
<td>-2.9 ± 3.2ab</td>
<td>-4.6 ± 1.3</td>
<td>-4.2 ± 0.9</td>
<td></td>
</tr>
<tr>
<td>Lh⁻¹</td>
<td>-1.8 ± 0.6</td>
<td>-1.6 ± 0.4</td>
<td>1.1 ± 0.5ab</td>
<td>-1.7 ± 0.9</td>
<td></td>
</tr>
<tr>
<td>HR bpm</td>
<td>148 ± 13</td>
<td>147 ± 12</td>
<td>137 ± 10ab</td>
<td>144 ± 5</td>
<td></td>
</tr>
</tbody>
</table>

Fluid intake and sweat loss

The water intake on the trails amounted to very little (i.e., around 0.5L.h⁻¹), especially considering the tropical climate and the sweat loss rate (i.e., from 1.1 to 1.8L.h⁻¹). However, this intake agrees with the American College of Sports Medicine [32] recommendations to drink 0.4 to 0.8L.h⁻¹, depending on the runner’s anthropometry and the intensity and distance of the event, and contradicts former guidelines that suggested drinking as much as possible to prevent dehydration [33]. Studies conducted in similar environments report similar data on water intake in mass-participation road races: Byrne et al. [2] noted a mean 0.37L.h⁻¹ during a 21-km road race performed in 26.5°C WBGT; and Lee et al. [14] noted a mean 0.25L.h⁻¹ during the same race 4 years later in conditions of 26.4°C and 81% RH. Moreover, elite marathon runners showed similar intake (i.e., a mean 0.42L.h⁻¹ extrapolated by Beis et al. [1] for the 2008 Beijing Olympic marathon.

The sweat loss rate of 1.1–1.8L.h⁻¹ was in the range of previous reports from studies performed in a tropical environment – that is, 1.47L.h⁻¹ for Byrne et al. [2] and 1.45L.h⁻¹ for Lee et al. [14] – and, added to the water intake, induced a body mass loss of 2.4–5.1%. This is considered to be beyond the normal TBWL fluctuation [3], and has been demonstrated to negatively affect endurance performance [4, 21]. However, a decrease in performance due to dehydration has been shown in participants already dehydrated before the exercise [4, 5, 21]. In the present study, the participants began the trail sessions euhydrated (as reflected by the osmolarity before the sessions). However, since we did not collect urine or blood samples over the entire 6 days of the race, we cannot determine whether some of the participants were dehydrated for at least one of the trail races, with correspondingly decreased performances.

Discussion

The most important findings of our study were that (1) performance was related to an increase in Tgi, a loss in both TBWL.h⁻¹ and BM.h⁻¹, and greater HR; (2) the increase in Tgi was related to a decrease in BM; and (3) no heat stress was evidenced in any of the recruited participants.
Such results have been noted during running and long-duration exercises, with the fastest finishers in endurance events often being the most dehydrated [33], and elite endurance athletes not appearing to drink very much during exercise [1, 22, 37]. Although all highly trained, the participants of the present study were clearly of mixed level, with some being internationally ranked. Therefore, the relationship between the losses in both TBWL and BM and performance would have to be seen as “the best and the best-trained runners losing the most TBWL and BM” and not “the more TBWL and BM runners lose, the faster they are”, even though, as noted by Noakes [24], weight loss during the race is a good thing, as weight increases the running cost.

**Intestinal temperature and performance**

The maximal average gastrointestinal temperature (38.3–38.7°C) was lower than that noted by both Lee et al. [14] and Byrne et al. [3] (i.e., 39.8°C and 39.9°C, respectively) during a 21-km road run in tropical environment using ingestible telemetry sensors, and far from the rectal temperatures (40.0–42.0°C) reported for heatstroke [29]. It was also lower than the critical internal temperature (assumed to be 39.7°C during laboratory experiments) and higher during competitive situations [16, 20, 30, 34]; and lower than the core temperature usually described as being the critical temperature during self-paced exercise [34]. We therefore hypothesize that, despite a great loss in water, the participants were not at their core temperature “limit” during the trail runs. Moreover, we found a positive correlation between delta Tgi and performance, with the participants showing the greatest increases in Tgi being the fastest. This finding is also likely related to the positive correlation between HR and performance in our study. 2 explanations can be suggested: (1) the participants of the present study were acclimated to living and training in a tropical climate and had made the appropriate adaptations, one of which being a

![Figure 1](image1.png)  
**Fig. 1** Correlations between performance and delta temperature (delta T°C), total body water loss (TBWL), delta body mass (delta BM) and heart rate.

![Figure 2](image2.png)  
**Fig. 2** Correlation between delta body mass (delta BM) and delta temperature (delta T°C) and mean gastrointestinal temperature (Tgi, mean) and water intake.

**Table 3**  

<table>
<thead>
<tr>
<th></th>
<th>Before</th>
<th>After</th>
</tr>
</thead>
<tbody>
<tr>
<td>alkaline reserves</td>
<td>mmol.L⁻¹</td>
<td>27.3 ± 2.5</td>
</tr>
<tr>
<td>proteins</td>
<td>g.L⁻¹</td>
<td>67.2 ± 2.7</td>
</tr>
<tr>
<td>Na⁺</td>
<td>mmol.L⁻¹</td>
<td>139.7 ± 1.6</td>
</tr>
<tr>
<td>K⁺</td>
<td>mmol.L⁻¹</td>
<td>4.4 ± 0.3</td>
</tr>
<tr>
<td>CPK</td>
<td>UI.L⁻¹</td>
<td>184.9 ± 137.7</td>
</tr>
<tr>
<td>osmolarity</td>
<td>mOsm.L⁻¹</td>
<td>299.6 ± 7.2</td>
</tr>
</tbody>
</table>

* p < 0.05, significantly different from before
lower core temperature during exercise [31], and (2) because these participants lived and trained in a tropical climate, they were aware of the stress induced by the climate [12] and thus applied “anticipatory regulation” [15, 35]. This refers to the association observed between the rate of heat storage early in an exercise and the subsequent regulation of exercise intensity [36]; in this case, the participants of the present study may have regulated their intensity in order to limit the heat storage. This is reinforced by the lowest HRmean noted in our studies along trails (i.e., 137–148 bpm) and those noted by Lee et al. (172 ± 7 bpm, [14]) or Byrne et al. (180 ± 7 bpm, [2]). We could also hypothesize that the best runners, being more trained, were able to run at higher intensity, supporting a higher Tgi.

Drinking ad libitum

One of the aims of this study was to investigate the effect of a multiple-day race in tropical climate on the hydration status of self-hydrating participants. As noted by Lee et al. [14], a limited number of studies have accurately assessed fluid balance during mass-participation endurance races. The participants of the present study were free to drink as much water as they wanted, with the only limit being the maximum 4 L carried in their backpacks. The mean volume of 0.5 L h⁻¹ ingested for a sweat loss of 1.1–1.8 L h⁻¹ clearly demonstrated the voluntary dehydration mostly observed in the best runners [27]. Despite this mathematically determined dehydration status, we observed no significant change or abnormal values in osmolarity, Na⁺ or K⁺. The only significant change was in CPK, which was increased at the end of the 6 days compared to the beginning, in relation to the muscle damage induced by the 6 consecutive days of trail running. It thus seems clear that these participants, despite great TBW loss (a mean 4.2 L) associated with a mean 1.5 L of TI inducing a 2.6 kg loss (a mean 4% of body mass loss), did not present severe dehydration or heat-related illness while drinking ad libitum. Similar results have been described in the literature in both high-level marathoners [37] and standard runners [14]. Altogether, these findings reinforce the idea that ad libitum hydration is sufficient for endurance exercise in a hot environment [14, 24, 37]. These results indicate that the participants of the present study were able to perform long-duration trail running over several days without presenting any heatstroke, perhaps because they were acclimated to the tropical climate [10, 12] and also because, as often proclaimed by Noakes [24], humans are adapted to perform in a hot environment.

To sum up, the present study demonstrated that, over the course of a trail race lasting several days in a tropical environment, well-trained acclimated runners who drank water ad libitum demonstrated no heat illness or severe dehydration. Moreover, high performance was associated with higher increases in Tgi and greater TBW and BM losses per hour. Further studies are needed to investigate longer events and the strategies used to perform in such a climate, especially in non-acclimated runners.

What does this paper add?

This paper on the physiological adaptations during a multi-day trail race demonstrates that self-hydrated and acclimated runners do not suffer from dehydration or hyperthermia during multiple days of trail running in a tropical environment. It also shows that performance at the end of a multiple-day race is correlated with increased intestinal temperature and losses in both total body water and body mass in these runners, thereby providing evidence that these factors do not contribute to performance decreases in acclimated runners during multi-day trail races. Finally, because the participants in most sports should be advised to self-hydrate, even in tropical climate, adapted backpacks need to be developed to promote and facilitate self-hydration.

Conflict of interest: The authors have no conflict of interest to declare.

References