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Research article

## Hydration and Thermoregulation during a Half-Ironman Performed in Tropical Climate

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### Abstract

The aim of this study was to compare the core temperature (TC) and markers of hydration status in athletes performing a half Ironman triathlon race in hot and humid conditions ( $27.2 \pm 0.5^\circ\text{C}$ , relative humidity was  $80 \pm 2\%$ ). Before and immediately after the 2012 Guadeloupe half Ironman triathlon, body mass and urine osmolality (mean  $\pm$  SD) were measured in 19 well-trained male triathletes. TC was measured before and after the race, and at each transition during the event, using an ingestible pill telemetry system. Ambient temperature and heart rate (HR) were measured throughout the race. Mean  $\pm$  SD performance time was  $331 \pm 36$  minutes and HR was  $147 \pm 16$  beats $\cdot$ min $^{-1}$ . Wet bulb globe temperature (WBGT) averaged  $25.4 \pm 1.0^\circ\text{C}$  and ocean temperature was  $29.5^\circ\text{C}$ . The average TC at the beginning of the race (TC1) was  $37.1 \pm 0.7^\circ\text{C}$ ; it was  $37.8 \pm 0.9^\circ\text{C}$  after swimming (TC2),  $37.8 \pm 1.0^\circ\text{C}$  after cycling (TC3), and (TC4)  $38.4 \pm 0.7^\circ\text{C}$  after running. Body mass significantly declined during the race by  $3.7 \pm 1.9$  kg ( $4.8 \pm 2.4\%$ ;  $p < 0.05$ ), whereas urine osmolality significantly increased from  $491.6 \pm 300.6$  to  $557.9 \pm 207.9$  mosm $\cdot$ L $^{-1}$  ( $p < 0.05$ ). Changes in body mass were not related to finishing TC or urine osmolality. Ad libitum fluid intake appears applicable to athletes acclimatized to tropical climate, when performing a half Ironman triathlon in a warm and humid environment.

**Key words:** Aerobic exercise, triathlon, hygrometry, hydration.

### Introduction

Cyclic aerobic exercise is negatively affected by a hot environment; this has been demonstrated for running (Maughan, 2010) and cycling, although in cycling, it depends on somewhat on the type of race (Nybo, 2010). Swimming in hot water or a tropical climate has also been shown to stimulate and induce thermoregulatory adaptations and to impair performance (Hue and Galy, 2012).

The effects of various factors on triathlon thermoregulation, dehydration and performance have been widely explored. For example, one study found that wearing a wet suit while swimming in relatively warm water as defined by Kerr ( $25.4 \pm 0.1^\circ\text{C}$ ) induced no heat stress during a subsequent cycling bout (Kerr et al., 1998), and this was confirmed using a one-piece competition speed-suit (Peeling and Landers, 2007). Moreover, no hyperthermia- or dehydration-induced thermoregulatory failure has been demonstrated during long-distance (i.e., Ironman) triathlons (Laursen et al., 2006) (Sharwood et al., 2004). However, the studies in hot and humid conditions/climate were performed in a laboratory in relatively warm water (i.e.,  $25.4 \pm 0.1^\circ\text{C}$ ) for sub-2.5 hours of exer-

cise (Kerr et al., 1998) or for sub-1 hour (i.e.,  $27.9 \pm 0.5^\circ\text{C}$ ) (Peeling and Landers, 2007).

The half Ironman triathlon (i.e., 1.9-km swimming, 90-km cycling and 21.1-km running) has become very popular but little has been studied for endurance events i.e.  $>3$ h in duration, especially in a tropical climate. Thus, our understanding of the influences of a warm and humid environment and fluid intake strategies on aerobic exercise capacity has essentially been studied through experiments conducted on cyclists or runners within the confines of a laboratory. In fact, only one study examined the relationship between warm and humid conditions and Ironman triathlon exercise capacity (Sharwood et al., 2004). These authors reported that the large changes in body weight during the triathlon were not associated with higher rectal temperatures post-race.

Although the negative effects of hot-wet conditions (i.e., the so-called tropical climate) have been demonstrated for almost every cyclic sport (Gonzalez-Alonso et al., 2008), such as swimming (Wade and Veghte, 1977), cycling (Voltaire et al., 2003) and running (Kenefick et al., 2007), no study to our knowledge has explored the thermoregulatory and hydration responses to a relatively long-distance triathlon (i.e., the half Ironman) performed in tropical conditions. We therefore tested the hypothesis that the swimming phase performed in warm temperature under high radiation would induce relative hyperthermia that would not be reversed during the cycling phase and would be aggravated during running.

### Methods

#### Subjects

We contacted Guadeloupean triathlon clubs and recruited 19 tropically-acclimatized male volunteers, all internationally and regionally ranked and regularly competing in triathlons on the island. All competed in the 2012 Guadeloupe half Ironman triathlon in tropical conditions, i.e. with high ambient temperature and high relative humidity ( $27.2 \pm 0.5^\circ\text{C}$ ;  $80 \pm 2\%$ ). The mean ( $\pm$  SD) age, body mass, and height of the subjects were respectively  $39.1 \pm 6.9$  yrs,  $72.6 \pm 7.9$  kg, and  $1.80 \pm 0.07$  m. Each athlete was contacted before the race and was sent a complete explanation of the study and an informed consent form. The day before the race, an interview was scheduled with each race entrant to ensure that each was fully informed of, and understood, the aims and methods of the study. All gave informed written consent to participate in the study. The Ethics Committee of the University of Guadeloupe approved the protocol. The race organizers also

gave permission for the present investigation.

### Half Ironman triathlon race description

The 2012 Guadeloupe half Ironman triathlon starting at 11 am consisted of two 0.95-km laps of swimming followed by 92 km of cycling and 21.1 km of running. The swimming phase consisted of a single 0.95-km double lap, the cycling phase consisted of three flat 30.6-km laps, and the half-marathon run consisted of three flat 7-km laps. Ambient temperature was  $27.2 \pm 0.5^\circ\text{C}$  (range 26.5–28.2°C) and relative humidity was  $80 \pm 2\%$  (78–82%). The cloud cover was minimal and no precipitation was recorded during the race. The ocean temperature was 29.5°C. Performance times for the swim, cycle, and run phases for all triathletes were retrieved from the race timing system.

### Wet Bulb Globe Temperature (WBGT)

The WBGT index was recorded during the event with a QUESTemp<sup>o</sup> 32 Portable Monitor (QUEST Technologies, Oconomowoc, WI, USA). The mean WBGT over the competition duration for the 19 athletes was  $25.2 \pm 0.1^\circ\text{C}$  (range 24.2–27.2), with the first subject finishing with a WBGT of 24.3 and the last with 24.2.

### Recommendations, water intake and hydration

The athletes were permitted to eat and drink fluid ad libitum during the race. The water intake (WI) was the addition of the water ingested from the cycle phase and at refreshment. The subjects were asked to follow their usual diet and to refrain from alcohol and caffeine for 24 hr before the competition. At the end of the race, all athletes wrote down their WI between the start and end of the race. Urine samples were collected just before and immediately after the race and sent to the biochemistry laboratory of the University Hospital. Pre- and post-race urine osmolarity (Uosm) was measured to investigate changes in hydration status. We used a Uosm of  $>800 \text{ mOsm}\cdot\text{L}^{-1}$  to indicate clinical dehydration, a cut-off which has been frequently used (Shirreffs and Maughan, 1998).

### Temperature measurement and heart rate (HR)

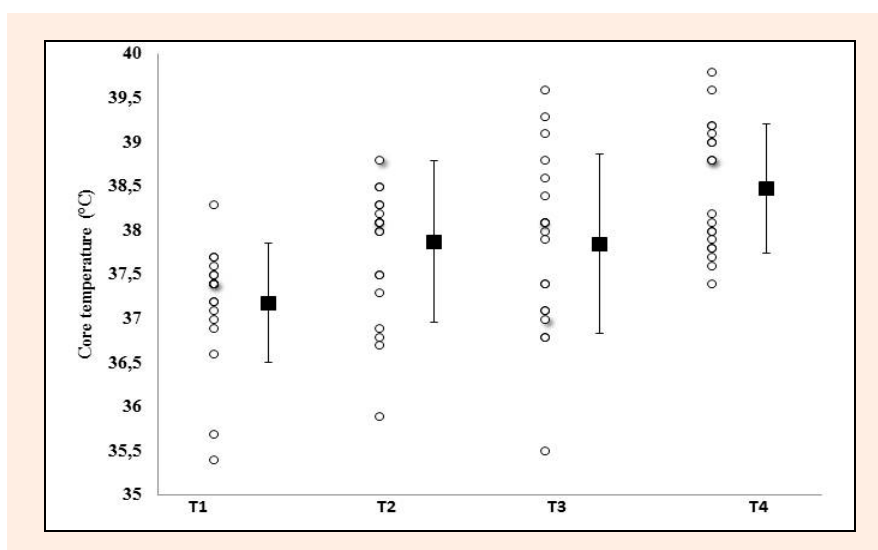
Core temperature (TC) measurements were obtained throughout the race using the a CorTemp<sup>TM</sup> 2000 ambulatory remote sensing system (HQ Inc., Palmetto, FL, USA) and pills that were given at least 6 hr before the race began, in line with previously reported guidelines (Byrne and Lim, 2007) (a telemetric check was performed to ensure that the temperature sensor was inside each volunteer and transmitting a signal). TC was measured just before the race (TC1), immediately after the swim phase in the transition tent while subjects were changing into their cycling attire (TC2), in the cycle-to-run transition tent while subjects were changing into their running attire (TC3), and immediately at the end of the half-marathon run (TC4). HR was recorded throughout the triathlon at 5-s increments using a chest band and wrist-watch HR monitor (PolarVantage, Polar Electro Oy, Kempele, Finland).

### Anthropometric measurements

Body height was determined before the race using a stadiometer (Tanita HR001, Tanita Europe B.V., Amsterdam, the Netherlands) to the nearest 0.01 m. Body mass (BM) was measured within 10 minutes of the athletes finishing the race to the nearest 0.1 kg using the same calibrated scale (Seca 881, Seca Vogel & Halke GmbH & Co, Hamburg, Germany) as before the race with subjects wearing only their running shorts or swimsuit bottoms.

### Statistical analysis

All statistical computations were performed using Systat 12. The assumption of normality based on skewness and kurtosis tests was confirmed and parametric tests were performed. TC, delta TC, performance, HR, and urine osmolarity were analyzed with a two-way ANOVA with repeated measures. Pairwise contrasts were used when necessary to determine where significant differences had occurred. Stepwise single and multiple forward linear regressions were used to determine the relations between the variables related to TC, performance and hydration status. Data are displayed as mean  $\pm$  SD, and statistical significance was set at  $p < 0.05$ .



**Figure 3.** Individual and mean values ( $\pm$  SD) of core temperature at each stage of the race. T1: just before the race; T2: after the swim phase; T3: after the cycle phase; T4: at the end of the run phase

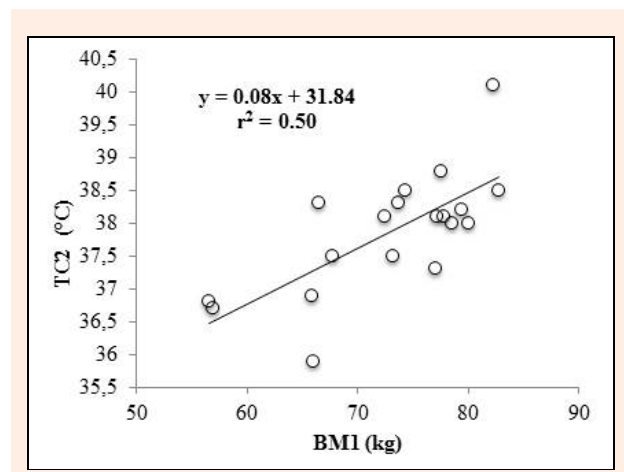
**Table 1.** WBGT, weight and urine osmolarity of the athletes. Data are means ( $\pm$ SD).

	T1	T2	T3	T4
WBGT ( $^{\circ}$ C)	27.2 (.0)	27.1 (.0)	25.1 (.1)	24.2 (.0)
Weight (kg)	72.6 (7.9)			69.0 (7.3)*
Urine osmolarity ( $\text{mosm}\cdot\text{L}^{-1}$ )	492 (301)			558 (208)

WBGT: Wet Bulb Globe Temperature. \*Significantly different from start value ( $p < 0.05$ ).

## Results

Performance times for the swim, cycle, and run phases were  $47 \pm 5$ ,  $175 \pm 13$ , and  $109 \pm 18$  minutes respectively, for a total time of  $331 \pm 36$  minutes. This indicates a relatively elite completion time, with ten of the 19 subjects finishing in under 5 hours. HR throughout the event averaged  $147 \pm 16$  beats $\cdot\text{min}^{-1}$ , and TC averaged  $37.1 \pm 0.7^{\circ}\text{C}$  just before the beginning of the race,  $37.8 \pm 0.9^{\circ}\text{C}$  after swimming (TC2),  $37.8 \pm 1.0^{\circ}\text{C}$  after cycling (TC3), and  $38.4 \pm 0.7^{\circ}\text{C}$  after running (TC4). The relative change of TC between the different phases was a rise of  $0.7^{\circ}\text{C}$  for the swim phase, no change for the cycle phase and a rise of  $0.6^{\circ}\text{C}$  for the run phase (Figure 1). Table 1 shows the measures of WBGT and hydration status, including BM and urine osmolarity. BM significantly decreased during the event by  $3.7 \pm 1.9$  kg ( $5.0 \pm 2.4\%$ ;  $p < 0.05$ ), with BM at the beginning of the race (BM1) greater than at the end (BM2) ( $p < 0.00$ ;  $69.3 \pm 7.0$  kg vs.  $73.0 \pm 7.55$ ). Two subjects produced a urine sample with a urine osmolarity  $> 800$  mOsm $\cdot\text{L}^{-1}$  prior to the start of the race. The mean WI was  $3.5 \pm 1.0$  L and total body water loss (TBWL) was  $7.2 \pm 2.1$  L.

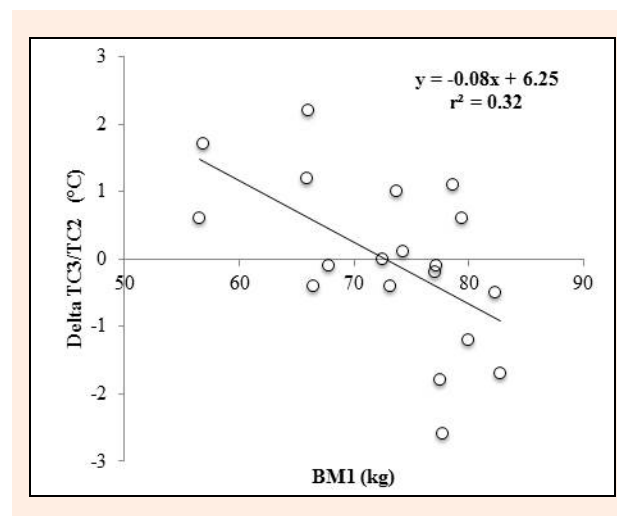


**Figure 1.** Correlation between BM1 and TC2,  $p < 0.05$ . BM1: Body Mass measured before the race; TC2: Core temperature after the swim phase

Changes in BM were not related to TC4 ( $r^2 = 0.004$ ) or urine specific gravity ( $r^2 = 0.04$ ). Total finishing time was not significantly related to changes in BM ( $r^2 = 0.001$ ), TC4 ( $r^2 = 0.02$ ), or urine osmolarity ( $r^2 = 0.04$ ). HR was not significantly related to core temperature ( $r^2 = 0.43$ ;  $n = 7$ ) during the event. After the swim phase, TC2 was correlated with BM1:  $y = 0.08x + 31.84$  ( $r^2 = 0.50$ ;  $n = 19$ ), (Figure 2,  $p = 0.001$ ). Heavier swim finishers had higher TC and delta TC3/TC2 was correlated with BM1:  $y = -0.08x + 6.25$  ( $r^2 = 0.32$ ;  $n = 19$ ), (Figure 3,  $p = 0.01$ ), indicating that the heavier triathletes decreased their heat load more during the cycling phase.

## Discussion

This is the first study of the core temperatures at each transition of a half Ironman triathlon in hot and humid conditions and the amount of fluid ingestion. We demonstrated that (1) performance was not negatively dependent on the level of dehydration, (2) athletes were able to self-rehydrate adequately, and (3) core temperature was dependent on both activity and anthropometry.



**Figure 3.** Correlation between BM1 and delta TC3/TC2,  $p < 0.05$ . BM1: Body Mass measured before the race; delta TC3/TC2: The delta of core temperature between the cycle phase and the swim phase

### Body mass loss, hydration and heart rate

Previous laboratory findings have been interpreted to suggest that athletes experience a rise in core body temperature when they become dehydrated during exercise, which increases their risk of developing heat illness (Sawka and Coyle, 1999). However, recent work examining hydration status and the resulting core body temperature in outdoor environments suggests that hypohydration is not associated with increases in core temperature to levels that would be considered excessive. Del Coso et al. (2014) showed a change in body mass of  $-3.8 \pm 1.6\%$  in a half-Ironman, and Lee et al. (2010) reported a body mass change of  $-3.7 \pm 0.9\%$  in a 21-km road running. Moreover, the estimated loss in elite runners based on calculated sweat rates and rates of fluid ingestion was  $8.8 \pm 2.1\%$  during major city marathons (Beis et al., 2012). Sharwood et al. (2004) showed that higher levels of hypohydration were associated with faster performance times at the South African Ironman triathlon in warm conditions. These authors therefore challenged the ACSM guidelines by suggesting that (1) dehydration does not necessarily impair exercise performance and (2) the rectal temperature during an Ironman triathlon conducted in moderate ambient conditions is not increased by slight dehydration. However, these results were obtained during events per-

formed in temperate or warm and dry conditions. In a tropical climate, aerobic performance was found to be negatively affected by the environment (Voltaire et al., 2003) because the humidity is high and sweating is much less effective in releasing body heat due to inefficient evaporation. In this climate, sweating does not allow heat loss and will increasingly dehydrate athletes performing aerobic exercise (Maughan et al., 2012), thereby impairing endurance performance (Cheuvront et al., 2010).

Recent investigations performed in ecological conditions have shown that body mass loss is not directly related to decreased aerobic performance (Beis et al., 2012). In the present study, the change in body mass was not correlated with race time even though body mass changed by  $-3.7 \pm 1.9$  kg ( $5.0 \pm 2.4\%$ ) after the race. Similar body mass losses in warm and humid environment have been reported for a 27-km trail running race, where Baillot et al. (2014) showed a decrease of  $3.9 \pm 1.1\%$ . Interestingly, the half Ironman triathlon athletes did not maintain their body mass within the currently recommended range of 2%-3% but, although urine osmolarity was significantly increased after the race compared with immediately before (Table 1), this did not indicate that the subjects were hypohydrated (Shirreffs and Maughan 1998). In other words, dehydration did not impact performance in this study. This finding agrees with the ecologically-valid study by Noakes (2007), who suggested that maintaining fluid balance is not essential to the maintenance of physiological function, and it challenges previous laboratory-based research as discussed by Sawka and Noakes (2007). In environmental conditions, Beis et al. (2012) demonstrated that the most successful marathon runners drank fluid ad libitum (according to the dictates of thirst) for less than approximately 60 s at an extrapolated fluid ingestion rate of  $0.55 \pm 0.34$  L·hr<sup>-1</sup>, suggesting that the best runners were those who spent less time drinking and who also ingested the lowest fluid volumes. Moreover, Sharwood et al. (2004) speculated that if the runner is not thirsty, a level of “dehydration” even up to -11% BM might not impair exercise performance. In line with this speculation, we recently demonstrated in a 2-2.5-hr trail race that the fastest trail runners had the smallest fluid intake in warm and humid conditions (Baillot et al., 2014). In the present study, three subjects opted not to wear a heart rate monitor, and nine heart rate monitors malfunctioned for various reasons, leaving seven complete sets of heart rate data. The mean heart rate recorded during the race was  $147 \pm 16$  beats·min<sup>-1</sup>. Based on the changes in core temperature:  $37.1 \pm 0.7^\circ\text{C}$ ,  $37.8 \pm 0.9^\circ\text{C}$ ,  $37.8 \pm 1.0^\circ\text{C}$  and  $38.4 \pm 0.7^\circ\text{C}$  (TC1  $\pm$  SD, TC2  $\pm$  SD, TC3  $\pm$  SD and TC4  $\pm$  SD), the running phase appears to have had the most deleterious effect with an elevation of  $0.6^\circ\text{C}$  during the run phase. It can be hypothesized that athletes perform the half Ironman triathlon at moderate exercise intensity (Laursen et al., 2006). If the metabolic rate does not explain the delta TC4/TC1, the rise in core temperature might lie in the nature of the activity itself. The swim-bike and bike-run transitions have physiological impact, with potential changes in the various physiological parameters and the energy cost of running (Hue et al., 1998).

### Swimming

The heaviest swimmers were those who finished with the highest core temperatures, similar to the finding of Marino et al. (2004) that the relative rates of heat production were highest for those runners with the greatest muscle mass. The core temperatures of these runners rose more because they produced more heat through aerobic exercise in a warm and humid environment. We showed that core temperature increased by  $0.7^\circ\text{C}$  during the swim phase in  $29.5^\circ\text{C}$  water. Since it is evident that the outcome of a half-Ironman triathlon race can be determined by the swim time (Laursen et al., 2006), we would expect this rise in core temperature as a reflection of increased swim speed. It has been amply demonstrated that a higher-positioned swim exit plays an important role in determining a triathlete's success (Vleck et al., 2006). Thus, our results are concordant with the results in the literature showing a mean  $0.9^\circ\text{C}$  increase in core temperature in long-distance swimmers in warm water (Hue et al., 2013). We recorded a  $40.1^\circ\text{C}$  core temperature in only one subject after the swimming phase, which was above the physiological limit of  $40^\circ\text{C}$  regularly denied by Ely et al. (2009) and promoted by Nielsen (1997). This core temperature nevertheless declined to  $39.6^\circ\text{C}$  after cycling. It should also be noted that this  $40.1^\circ\text{C}$  core temperature was recorded in the subject who also had the highest body mass. Therefore, this outcome of our study highlights the observation that the heaviest athletes had the highest core temperature after swimming. Interestingly, Laursen et al. (2006) recorded a similar  $40.5^\circ\text{C}$  core temperature in the fastest swimmer of an Ironman triathlon and suggested that dehydration had no impact on this rise in temperature since it was recorded at the beginning of the race when body water levels were at their maximum. They highlighted the correlation between the rise in core temperature and swimming performance, suggesting that the high temperature was related to the metabolic rate during swimming, i.e., the exercise intensity, and not to dehydration. The high core temperature in our study was likely due to the metabolic rate in warm water. Thus, swimming in warm water ( $29.5^\circ\text{C}$ ) is a complex situation where the evacuation of the heat load can be difficult due to high radiation and the high water temperature. In this sense, the environmental temperature may pose a challenge for endurance swimmers (Hue et al., 2007); for example, swimming in high water temperature increases heart rate, skin circulation and esophageal temperature to the same extent as running in a hot environment (Hue and Galy, 2012; Holmer and Bergh, 1974). This provides evidence of the limited capacity for heat dissipation when swimming at a high metabolic rate in warm water.

### Cycling

Another important finding of our study concerned the heat load after the cycling phase with regard to body mass. We found that delta TC3/TC2 was negatively correlated with BM1, suggesting that a higher body mass allowed more time to accumulate the heat load. What seemed to be a handicap in swimming, however, might have been an advantage in cycling. We showed that core temperature did not increase during the cycle phase. Moreover, since

cycling is an endurance activity during which heat is evacuated by convection, high metabolic production can be dissipated, even in a warm and humid environment (Saunders et al., 2005). It can be hypothesized that the heaviest athletes present the greatest surface for heat exchange. As suggested by Marino et al. (2004), the surface/mass ratio is an advantage for bigger athletes, who produce a high metabolic rate and are also able to better dissipate the consequent heat production. Thus, as long as cyclists are able to maintain a high forward velocity, the capacity for evaporative loss is not affected even in a hot and humid environment (Nielsen, 1996), unless the humidity is extreme, as noted by Hue et al. (2006) in professional cyclists competing in the Tour de Guadeloupe. In our study, the cycling phase was held on relatively flat terrain, facilitating the maintenance of high cycling speed over the race, and thus the maintenance of thermal balance. Moreover, the rule that prohibits drafting in the triathlon makes it easier for cyclists to have the entire body surface exposed to airflow, and this also improves the efficiency of convection, thereby explaining why TC3 did not change in comparison with TC2, the value after the swim.

### Running

As high body mass loss is usually associated with hyperthermia (Baillot et al., 2014), we expected high core temperatures, especially after the running phase. The average core temperature increased from  $37.8 \pm 1.0^\circ\text{C}$  after cycling to  $38.4 \pm 0.7^\circ\text{C}$  after running. This  $1.3 \pm 0.0^\circ\text{C}$  increase from the beginning to the end of the race was similar to the core temperature increase of  $1.3 \pm 0.7^\circ\text{C}$  in the study of Del Coso et al. (2014), where athletes reached  $38.8 \pm 0.7^\circ\text{C}$  after a half-Ironman triathlon race in hot and dry conditions. In a tropical climate, thermoregulation limits endurance performance (Shapiro et al., 1980). This is especially so for running during the half Ironman distance, as the running speed is slow and convection is not an effective way to lower metabolic heat production. Because of the high humidity, sweating does not allow heat loss and will increasingly dehydrate athletes performing aerobic exercise (Kenefick et al., 2007). Schlader et al. (2011) hypothesized that the brain might be able to evaluate the allowed rate of heat storage to determine the running pace throughout a race in uncompensable environmental conditions. This potential mechanism would prevent the onset of fatigue by limiting the rate of heat storage. In line with this, a progressive slowing of marathon speed was demonstrated as the WBGT increased from 5 to 25, with a greater negative effect on performance among the slower population of runners (Ely et al., 2007). Although a high percentage of humidity has been demonstrated to be deleterious to aerobic performance, we did not observe a critically high final core temperature with a rise of  $0.6^\circ\text{C}$  during the run phase. We hypothesize that in order to achieve the match between heat gain and heat dissipation in these conditions, the triathletes reduced their metabolic heat production in the run phase, thus the intensity of their workout (Voltaire et al., 2003).

Three limitations of the present study were that (1) food and supplements consumption was not assessed

during the event and (2) the athletes evaluated their own fluid consumption just after the race (3) when looking at TC in the different sections of the race, it is difficult to compare TC1 to TC4 for example. In fact, due to the variation of transit time, it is difficult to know the exact position of the capsule in the gastrointestinal tract (oesophagus/rectum). This problem is something to be aware of and acknowledged as a limitation to the equipment. Thus, although core temperature was measured intermittently throughout the event, we could not ascertain the hydration status of the triathletes at the various core temperature data collection points. In addition, the small number of valid HR data points in this study limited the evaluation of exercise intensity. Nevertheless, we are certain that core temperature was not near hyperthermic levels after the half Ironman triathlon despite the 4.8% reduction in body mass.

### Conclusion

The athletes with the greatest pre-race body mass also showed the highest TC2 and the greatest negative delta TC3/TC2. Performance was not negatively dependent on the level of dehydration and the athletes were able to self-rehydrate adequately. Fluid intake had no impact on the variables related to TC. We recorded a final core temperature average of  $38.8 \pm 0.7^\circ\text{C}$  after the event in these trained triathletes. This temperature was activity-dependent, and the athletes showed no evidence of heat illness in a warm and humid environment.

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### Key points

- Ad libitum fluid intake appears applicable to athletes acclimatized to tropical climate when performing a half Ironman triathlon in a warm and humid environment.
- The final core temperature average was  $38.8 \pm 0.7^\circ\text{C}$  after the event in these triathletes and the athletes showed no evidence of heat illness while competing in a warm and humid environment.
- Core temperature was dependent on both activity and anthropometry.

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