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# 15. Triathlon and ultra-endurance events in tropical environments 

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#### Abstract

Physical performance in tropical environments, which combine heat and high humidity, is a challenge that requires specific preparation. The high humidity of a tropical climate alters thermoregulatory capacity by limiting the rate of sweat evaporation. Proper management of wholebody temperature is thus essential to complete an endurance event like a long-distance triathlon or an ultramarathon in such an environment. In triathlon and ultra-endurance races, which can last from 8 to 20 h , performance in tropical settings is closely linked to the capacity to maintain hydration status. Indeed, the rate of withdrawal in these longer events has been associated with water intake, with many finishers showing alterations in electrolyte (e.g. sodium) balance. To counterbalance the impact of a tropical climate and maintain performance, several countermeasures can be adopted, such as using hydration and cooling strategies, and heat acclimation.


1 Influence of heat on performance and health

### 1.1 Specificity of the triathlon

The Ironman and Challenge triathlon series are trademark brands for long-distance triathlons consisting of a $3.8-\mathrm{km}$ swim, $180-\mathrm{km}$ cycling leg, and full marathon ( 42.195 km ). The best
professional triathletes complete the distance in under 7 h and 50 min , whereas age group athletes vary from 9 to 13 h and more, making this one of the longest endurance races. The duration depends on several factors, including terrain (i.e. course route and geography) and environmental conditions. For example, hot and humid climates impact on performance and the rate of withdrawal, as observed in the Kona (Hawaii) Ironman World Championships every October (Giambelluca et al. 2014; Stiefel et al. 2013): top age-groupers were slower at Hawaii than at their qualifier races (Stiefel et al. 2013), and abandon rate can reach $10 \%$, a high proportion considering the fitness level of athletes participating in this particular event, more resistant to heat stress (Cheung and McLellan 1998; Ironman 2018b). Similarly, more than $25 \%$ of the athletes did not reach the finish line at the inaugural Ironman Vichy in 2015, which was held in unusually hot conditions ( $31 \sim 35^{\circ} \mathrm{C}$ ), in contrast to North American races with a minimum 95\% finish rate (Britt 2011).

The following sections detail how thermal stress can specifically impact each of the triathlon legs: swimming, cycling and running.

### 1.1.1 Swimming

Most long distance triathlons allow neoprene wetsuits to be worn for the swim leg as long as water temperature does not exceed $24.5^{\circ} \mathrm{C}$. Between $24.5^{\circ} \mathrm{C}$ and $28.8^{\circ} \mathrm{C}$, athletes who choose to wear a wetsuit are allowed to participate, but are not eligible for age-group awards or for qualifying slots for the Ironman World Championships, and over $28.8^{\circ} \mathrm{C}$ wetsuits are prohibited (Ironman 2018). With its enhanced buoyancy, the neoprene wetsuit reduces ventilation and $\mathrm{O}_{2}$ consumption $\left(\mathrm{V}_{2}\right)$ at a given swimming speed, and therefore metabolic heat production (Trappe et al. 1996). However, wetsuits reduce heat dissipation capacity and can lead to high core body temperatures and dehydration (Kerr et al. 1998; Laursen et al. 2006). Hence, although banning wetsuits in warm water might impair swimming performance, it might also decrease the risk of hyperthermia.

Interestingly, Kerr et al. (Kerr et al. 1998) showed in a simulated Olympic triathlon that core temperature did not change by wearing a wetsuit, thought to limit thermoregulatory mechanisms
through heat-insulating properties of neoprene, as excess heat was still transferred at the periphery, leading to a higher skin temperature. A subsequent field study confirmed that core temperature remained around $38^{\circ} \mathrm{C}$ in well-trained athletes wearing a wetsuit in $20.5^{\circ} \mathrm{C}$ water during a 3.8 km swim (Laursen et al. 2006). This was again confirmed by a case report in which an athlete's core temperature was continuously monitored during an Ironman (Laursen et al. 2009). In $29.5^{\circ} \mathrm{C}$ water, another study showed that the core temperature of moderately trained athletes increased by an average $0.7^{\circ} \mathrm{C}$ and remained under $38^{\circ} \mathrm{C}$ during a non-wetsuit half-Ironman (Figure 1; (Baillot and Hue 2015)). Thus, no study appears to have shown a dangerous elevation in core temperature during the swim leg of long-distance triathlon events. Moreover, while 13 of the 14 deaths in triathlon races from 2006 to 2008 occurred during the swim leg, pre-existing cardiovascular abnormalities seem to have been the major factor, ruling out hyperthermia as a potential cause (Harris et al. 2010).

### 1.1.2 Cycling

When cycling, some of the heat produced by the muscles is dissipated via convection. This however, depends on a sufficient temperature gradient between the skin and ambient air. Convection is therefore limited in hot conditions when air temperatures exceeds $35^{\circ} \mathrm{C}$. Heat is also dissipated during cycling via the evaporation of sweat, which depends on the water vapor partial pressure gradient between air and skin. Like convection, this mechanism is reduced in humid environments, making performance in a tropical environment challenging as thermoregulatory efficiency is reduced (Nybo 2010). In a tropical climate ( $31-33^{\circ} \mathrm{C}, 70-75 \% \mathrm{RH}$ ), one-hour of pedalling at a submaximal intensity increases core temperature, heart rate, sweat rate and water loss (Saat et al. 2005a; Saat et al. 2005b; Voltaire et al. 2003). These results can be extrapolated to describe the physiological impact of 4-6-h events, especially if the cycling course includes hills, where the diminished air speed reduces heat dissipation (Nybo 2010). Laboratory-controlled studies showed that increasing ambient temperature impaired cycling capacity when relative humidity was clamped at $70 \%$ (Galloway and Maughan 1997; Maughan et al. 2012). During a 9-day ( $2.5 \mathrm{~h} /$ day)
cycling race held in Guadeloupe $\left(31.1^{\circ} \mathrm{C}, 75.6 \% \mathrm{RH}\right)$, tympanic temperatures measured immediately after the stages never exceeded $2^{\circ} \mathrm{C}$ of resting pre-race values (Hue et al. 2006). In contrast to the variability associated with stage racing in a peloton, triathletes will adopt a much steadier pace during racing in some cases to "save their legs" for the following marathon (Wu et al. 2015). Interestingly, Baillot et al. (Baillot and Hue 2015) showed a negative correlation between body mass and the evolution of core temperature throughout the cycling leg, implying greater heat storage and inertia. A bigger body thus presents a larger surface to preserve heat exchange at high velocity, even in a hot and humid environment (Nielsen 1996).

In summary, the high velocities and individual nature of cycling in the triathlon support heat dissipation by convection on the condition that air temperature is lower than skin temperature. In a thermally challenging environment, sweat evaporation is the main avenue for heat dissipation but it is limited by the high humidity of a tropical environment. Nevertheless, triathletes appear to show adequate thermoregulatory capability to prevent excessive hyperthermia, mainly through intensity management and pacing strategies (Baillot and Hue 2015).

### 1.1.3 Running

Of the three sports in the triathlon, running may carry the greatest risk of hyperthermia for triathletes competing in a tropical climate. Several factors come into play. Firstly, although running is faster than swimming, air possesses neither the heat capacity nor transfer celerity of water, hence limiting the quantity of heat energy transferred from the body. Secondly, unlike in cycling, the lower speed associated with running does not allow for excess heat dissipation via convection (Nielsen 1996). These factors can have a strong negative impact on running performance (Kenefick et al. 2007), particularly the marathon (Ely et al. 2007). This negative impact is amplified (i) by a heavier body mass, which, at a given pace, requires more energy for running propulsion and therefore produces more heat, and (ii) in heavier athletes running in a hot/humid environment
limiting heat exchange by convection and evaporation, who display greater imbalance between heat production and dissipation, even at slower paces (Marino et al. 2000).

While the core temperature data of professional triathletes in the Hawaii Ironman or other tropical locations are currently not available, a few studies of moderately to very well trained age group athletes have shown that none of them suffered from heat-related illness and excessive increases in core temperature (Laursen et al. 2006) (Figure 1; (Baillot and Hue 2015; Del Coso et al. 2014)). In the report from Laursen et al. (Laursen et al. 2006) 7 out of 10 well trained triathletes performed a high-level sub-10-hour performance at Ironman Western Australia in temperate but humid conditions ( $23.3^{\circ} \mathrm{C}, 60 \% \mathrm{RH}$ ), and the average core body temperature remained close to $38^{\circ} \mathrm{C}$. Despite a much hotter and more humid environment in Guadeloupe $\left(27.2^{\circ} \mathrm{C}, 80 \% \mathrm{RH}\right)$, the average body temperature of moderately trained athletes during a half-Ironman run was $38.2^{\circ} \mathrm{C}$ and none of them reached $40^{\circ} \mathrm{C}$ (Baillot and Hue 2015). These values are not surprising given the relative intensity and absolute workload at which most long-distance triathlon races are performed, which is in contrast to shorter events performed at a higher intensity and thus higher heat production (Siegel et al. 2010; Baillot and Hue 2015). The importance of exercise intensity was confirmed in dryer conditions in a study showing that the fastest athletes exhibited the highest core temperatures (Del Coso et al. 2014).

### 1.2 Specificity of ultra-endurance events

1.2.1 Ultra-endurance in the heat

Ultramarathons last more than 6 h (Zaryski and Smith 2005). In the past decade, trail running races have become a major ultra-endurance sport. Since the first edition of the Ultra Trail du Mont Blanc ( 160 km and $+10,000 \mathrm{~m}$ of elevation), the number of finishers has grown from 67 in 2003 to 1685 in 2017. This kind of effort involves several physiological and psychological parameters that are modulated by environmental factors. Ultramarathon races are performed with a variety of off-
road terrains, elevation profiles (positive: D+ and negative: D- changes), and distances, all of which greatly complicate the attempt to understand how environmental conditions affect performance. Marathon races have more standardized characteristics, facilitating the comparison of performances in order to study the role played by heat (see chapter 12). Based on the analysis of winners' times in several marathons, (Maughan 2010) et al., 2010 determined that the best running temperature is between $10^{\circ} \mathrm{C}$ to $12^{\circ} \mathrm{C}$ for elite athletes. Beyond this temperature, the analysis of 136 marathons performed between a wet-bulb globe temperature (WBGT) of 5 and $25^{\circ} \mathrm{C}$ showed a decrease in performance with an increase in WBGT (Figure 2; (Ely et al. 2007)). Interestingly, these authors also showed that slower runners, who are exposed to heat for a longer time than faster runners, are more affected by temperature. For ultramarathon distances, the same effect of hot environments on performance was observed in a study that examined running times in the Western States Endurance Run (161 km and 6000 m D+) in 2006 and 2007 (Parise and Hoffman 2011). In these two editions (Figure 3), the authors followed 50 runners who had finished the race in both years to investigate the effect of temperature changes from $7-38^{\circ} \mathrm{C}$ in 2006 to $2-30^{\circ} \mathrm{C}$ in 2007. Independently of their level, the athletes were $8 \%$ slower in the hot condition (2006) than in the cooler environment (2007), and the withdrawal rate was $14 \%$ higher in 2006. In this study, slower runners did not appear to be more impacted by the hot environment, but this observation was probably due to the longer time running at a comfortable temperature (i.e. night).
1.2.2 Hydration requirements during ultra-endurance exercise in the heat

During muscle contraction, only $\sim 25 \%$ of the substrate energy is converted to mechanical work, with the other $\sim 75 \%$ released as heat. Effective thermoregulation during exercise depends on the balance between the absolute mechanical work generated by the athlete and the heat loss process (Chapter 2). Ultramarathons, characterized by the maintenance of a low relative exercise intensity over very long periods, do not significantly challenge the heat balance in temperate environments. However, maintaining mechanical load over a longer time may challenge heat balance in athletes,
especially when competing in hot and/or humid environments. Furthermore, environmental heat stress (i.e. temperature) reduces dry heat loss, due to the small (or even negative) temperature gradient between the skin and air, which progressively places sweat evaporation as the only mechanism available for the organism to dissipate endogenous heat (Brotherhood 2008; Taylor 2006). Indeed, at in $30^{\circ} \mathrm{C}$ conditions a dry heat loss of 75 W is observed whereas at $40^{\circ} \mathrm{C}$, it induces a dry heat gain of 75 W , increasing the sweating rate require to maintain body core temperature (Gagnon et al. 2013). Thus, ultramarathons performed in a hot environment require bigger volumes of water intake to compensate for increased water losses. During the Badwater Ultramarathon of 2012 ( 217 km and $4000 \mathrm{~m} \mathrm{D}+$ ), the temperature oscillated from $10.1^{\circ} \mathrm{C}$ at night to $46.6^{\circ} \mathrm{C}$ during the day. The follow-up of 4 runners who completed the race in $36 \pm 3 \mathrm{~h}$ showed a mean water intake of $34 \pm 13 \mathrm{~L}$ (Brown and Connolly 2015). On average, each athlete drank $0.93 \mathrm{~L}^{-1} \mathrm{~h}^{-1}$, whereas on completion of the Biel Ultramarathon in Switzerland ( 100 km and 645 m D+), in a temperate environment varying from 8 to $28^{\circ} \mathrm{C}$, the runners consumed 0.65 L.h $^{-1}$ (Knechtle et al. 2011). When the distances of these two races were linked to elevation changes ( $100 \mathrm{~m} \mathrm{D}+$ corresponds to 1 km of distance), the corrected distance for the Biel Ultramarathon was 106.45 km and 257 km for Badwater. According to these corrected distances, the Badwater runners drank almost twice as much water as the Biel runners ( $0.13 \mathrm{~L} . \mathrm{km}^{-1}$ and $0.069 \mathrm{~L}^{\mathrm{Lm}}{ }^{-1}$, respectively), despite the higher mechanical workload developed during the Biel Ultramarathon due to its shorter distance and lower elevation change ( $6.6 \mathrm{~min} . \mathrm{km}^{-1}$ vs. $8.5 \mathrm{~min} . \mathrm{km}^{-1}$ for Badwater). The characteristics of the 2007 Peninsula Ultra Fun Run (PUFfeR) of South Africa ( 80 km and $1000 \mathrm{~m} \mathrm{D+}$ ) were close to those of the Biel Ultramarathon, but the participants were subjected to lower environmental temperatures $\left(8-20^{\circ} \mathrm{C}\right)$. The runners drank less during this more temperate race than during the Biel Ultramarathon ( $0.028 \mathrm{~L}_{\mathrm{L}} . \mathrm{km}^{-1}$ and $0.069 \mathrm{~L}^{\mathrm{Lm}}{ }^{-1}$, respectively) (Tam et al. 2009). Analysis of the hydration status of 16 ultramarathon runners ( $161 \mathrm{~km}, 7000 \mathrm{~m} \mathrm{D}+$ ) in a hot environment $\left(4.8-37.8^{\circ} \mathrm{C}\right)$ showed that finishers $(\mathrm{n}=6)$ had drunk significantly more water at the $48^{\text {th }}$ kilometer than non-finishers $(\mathrm{n}=10)$ (Stuempfle et al. 2011). However, the authors were unable to determine
whether beverage intake was directly linked to finishing capacity or if it was due to other factors, such as the experience or endurance capacity of the runners. A second study performed during a $160-\mathrm{km}$ foot race (positive elevation not known) in temperatures that peaked at $38^{\circ} \mathrm{C}$ followed only those runners who had completed at least one previous ultramarathon among the top 50\% (Glace et al. 2002). The authors showed that, despite the homogenous level and experience of these runners, non-finishers also drank significantly less than finishers ( $-35 \%, \mathrm{p}<0.01$ ). All these data confirmed the relationship between event temperature and water intake that is crucial to health and performance. A study during the Gwada Run of 2011, a 6-day multi-stage race for a total of 142 km under tropical conditions ( $30 \pm 2.4^{\circ} \mathrm{C}$ and $82 \pm 4 \% \mathrm{RH}$ ) showed a sweat loss of $0.19 \mathrm{~L} \cdot \mathrm{~km}^{-1}$ (Hue et al. 2014). Yet water intake ( $1.5 \pm 0.3 \mathrm{~L}$ per stage) was probably distorted by the shortness of the stages (from 16 to 21 km ), which enabled athletes to tolerate transient dehydration during the races ($4.2 \pm 0.9 \mathrm{~L}$ per stage).

## 2 Countermeasures to optimize performance and health

### 2.1 Hydration

Limiting dehydration during triathlons and ultramarathons in hot environments seems to be essential to maintain the exercise workload over many hours. The role of hydration in a tropical climate (see chapter 6) is critical since it has been shown that hyperthermia and dehydration are worse than hyperthermia alone (Sawka et al. 2001; Sawka and Noakes 2007). Despite contradictory observations on influencing thermoregulation and core temperature (Latzka et al. 1997; Ross et al. 2012), it seems that hyperhydration can delay the development of dehydration (Latzka and Sawka 2000; Latzka et al. 1997; Sawka et al. 1984). However, hyperhydration does not seem to lead to better performances during a laboratory-based 46 km cycling time trial by elite cyclists (Ross et al. 2012) or a 60 min run in endurance trained runners (Scheadler 2009). As hyperhydration results in
non-negligible added body weight, it may not be an advantage for running performance, which is greatly affected by extra weight (Teunissen et al. 2007). In addition, it does not enhance thermoregulation in a hot and humid climate and augments the risk of hyponatremia (Noakes et al. 2005).

In the triathlon, although hydration depends very much on the availability of adequate means set up by the race organization, the descriptive papers to date report that no triathlete has suffered from dehydration symptoms in hot and humid events, despite occasional significant water loses (Baillot and Hue 2015; Del Coso et al. 2014; Laursen et al. 2006; Speedy et al. 2001). This suggests that the hydration strategies employed by the athletes meet the body's water requirements (Kenefick 2018).

Maintaining optimal hydration is more complicated than it would seem in the ultramarathon. Indeed, analysis of the hydration status of ultramarathon runners in 2 different races showed that finishers had drunk significantly more water than non-finishers, even if the runners' experience was taking into account (Glace et al. 2002; Stuempfle et al. 2011). In contrast, slower runners became over-hydrated because they feared dehydration, which may lead to hyponatremia (Hew-Butler et al. 2008; Noakes 2007). Hyponatremia however, is not only due to over-hydration, but may be the consequence of insufficient sodium intake during the race (Glace et al. 2002; Stuempfle et al. 2011). In a hot environment, hyponatremia affected $30-50 \%$ of ultramarathon finishers, reflecting the inadequate or incorrect hydration strategies of many runners (Glace et al. 2002; Hoffman et al. 2012; Lebus et al. 2010). Thus, better sodium intake during ultramarathons could contribute to better performances by stimulating thirst, increasing voluntary fluid intake, enhancing intestinal glucose and water absorption, optimizing extracellular and intracellular fluid balance, and potentially mitigating the occurrence of clinically significant episodes of hyponatremia (Maughan 1991; Shirreffs and Sawka 2011; Speedy et al. 1999; Vrijens and Rehrer 1999).

### 2.2 Hydration policy and implementation

In a triathlon field study, oral salt supplementation improved half-Ironman performance through faster cycling ( $\mathrm{p}<0.05$ ) and showed a similar trend in the running leg ( $\mathrm{p}=0.06$ ), with reduced sweat rate and limited electrolyte deficit (Del Coso et al. 2016). The consensus recommendation is thus to ingest 0.5 to $0.7 \mathrm{~g} \cdot \mathrm{~L}^{-1} . \mathrm{h}^{-1}$ for long endurance races (Von Duvillard et al. 2004) and up to $1.5 \mathrm{~g} \cdot \mathrm{~L}^{-1} \cdot \mathrm{~h}^{-1}$ for athletes prone to develop muscle cramping (Bergeron 2003). However, adding salt to the consumed water is not sufficient to avoid hyponatremia if athletes overdrink during a race ( $73 \%$ of severe symptomatic hyponatremia found after an Ironman (Speedy et al. 1999)).
(Hoffman and Stuempfle 2014) observed no advantage to sodium-enriched beverages during a $161-\mathrm{km}$ ultramarathon performed by all levels of athletes in heat $\left(38^{\circ} \mathrm{C}\right)$. This result may have been due to a variation in sodium intake from solid food and/or to the tolerance of faster runners to hypohydration and hyperthermia (Baillot et al. 2014; Hue et al. 2014).

### 2.3 Cooling

Cooling strategies such as cold drink ingestion or cold-water immersion to reduce the thermal load may enhance performance in the heat (see chapter 7). This effect has been manifested in cyclists (Figure 4; (Burdon et al. 2013; Riera et al. 2016; Tran Trong et al. 2015) and runners as a longer time to exhaustion (Siegel et al. 2010; Siegel et al. 2012; Yeo et al. 2012). Wearing cooling garments prior to or during exercise has proven to be performance-effective in hot and humid climates (Arngrimsson et al. 2004; Hasegawa et al. 2005; Luomala et al. 2012), but they are difficult, impractical and potentially not allowed to be used during official long-distance events.

Other studies have focused on cooling strategies, but the exercise duration has been relatively short compared with ultra-endurance events. Nonetheless, they show interesting results that may be
extrapolated for long to ultra-long events. Spraying or pouring water over the face and/or body can improve performance in tropical conditions. For example, pouring cold water over the skin will reduce skin temperature before dripping off the body, and transiently improve thermal comfort. Cooling the head in this manner resulted in a $51 \%$ increase in cycling time to exhaustion at $75 \%$ $\mathrm{VO}_{2 \max }$ (Ansley et al. 2008), with similar effects recently observed in running (Stevens et al. 2017b). Neck cooling during a $90-$ min running trial in a hot environment ( $30.4^{\circ} \mathrm{C}$ and $53 \% \mathrm{RH}$ ) increased the distance covered by $7.4 \%$ with no change in rectal temperature (Tyler and Sunderland 2011). A similar effect was found with menthol ingestion, as it activates cold dermal sensors (Stevens and Best 2017). Mixed into a cold beverage, menthol did not lower core body temperature but had a positive effect on thermal sensation and running/cycling performances over various distances in tropical climate (Stevens et al. 2016; Tran Trong et al. 2015). Indeed, Stevens et al. 2016 showed that a menthol mouth rinse every kilometre ( 25 mL at a concentration of $0.01 \%$ ) during a running time trial in the heat significantly improved $5-\mathrm{km}$ performance time by $3 \%$. A cumulative effect of menthol and ice slurry or cold water was observed on performances during a $20-\mathrm{km}$ cycling trial in hot environment $\left(30.7 \pm 0.8^{\circ} \mathrm{C}\right.$ and $\left.78 \pm 0.03 \% \mathrm{RH}\right)$ (Tran Trong et al. 2015). Ultimately, menthol mouth rinsing and ingesting influence thermal perception and thermal comfort, which in turn might contribute to enhance performance in hot climates (Stevens et al. 2017a; Stevens et al. 2016).

### 2.4 Cooling policy and implementation

According to the literature, pre-cooling by ice or cold water has been successfully studied during short duration exercise ( $<60 \mathrm{~min}$ ) that is too brief to be a key factor of performance during ultra-endurance trials (Siegel et al. 2012; Stevens et al. 2017b). Conversely, per-cooling by cold water or ice slurry ingestion during exercise seems to be a very interesting intervention to improve performances in a hot environment and possibly increase fluid intake, particularly for well-trained
athletes (see chapter 7). Indeed, most high-performing runners show the biggest increase in internal temperature, probably due to higher thermogenesis consecutive to higher workloads (Baillot et al. 2014; Hue et al. 2014). Faster trail runners ( 27 km ; Baillot et al. 2014) and multi-stages trail runners (127 km on 6 days; Hue et al. 2014) also present greater post-race dehydration, which could be reduced by cold water due to its effect on voluntarily increasing water absorption during exercise. The higher temperatures and greater dehydration observed in faster trail runners also seem to indicate that performance in heat is associated with a better tolerance to hyperthermia in elite athletes (McKeag and Moeller 2007).

### 2.5 Heat acclimation

Heat acclimation (HA) before a race is an efficient way to increase performance in a hot environment (Armstrong and Maresh 1991; Nielsen 1994) (see chapter 8 for further details). The physiological adaptations of HA lead to better cardiovascular function (output, stroke volume, heart rate) and a decreased core temperature at rest and during exercise, in part due to an enhanced sweat rate and expanded plasma volume (Armstrong and Maresh 1991). HA is also known to reduce sodium loss by sweating (Kirby and Convertino 1986). However, HA does not fully restore long to ultra-long endurance performance to the level reached by athletes in temperate conditions (Voltaire et al. 2002).

If early arrival at the race location is not possible, HA in an environmental chamber is a strategy that may help preserve ultramarathon performance. (Costa et al. 2014) examined the effects of six 2-h sessions of running at $60 \%$ of $\mathrm{VO}_{2 \max }$ on a motorized treadmill in an environmental heat chamber at $30^{\circ} \mathrm{C}$ or $35^{\circ} \mathrm{C}$. From the third session onward, mean heart rate was lower at $30^{\circ} \mathrm{C}$, whereas mean heart rate and thermal comfort were lower at $35^{\circ} \mathrm{C}$. The authors concluded that two bouts of running at $60 \%$ of $\mathrm{VO}_{2 \max }$ in a $30^{\circ} \mathrm{C}$ air temperature conditions were sufficient to induce heat acclimation in ultra-runners, which may enhance their performance in such environments.

## 3 Conclusions

The maintenance of triathlon or ultramarathon performance in a hot environment is a considerable challenge which requires meticulous preparation and management during the race. To limit the performance decrements induced by these harsh environmental conditions, several countermeasures have been proposed, such as cold-water or ice slurry ingestion, external pre- and per- cooling and/or menthol use. However, the limited duration of exercise performed in these studies does not allow for direct application of the results to an ultra-endurance or ultra-triathlon context. Thus, further studies are required to validate these approaches in long to triathlon and ultraendurance events.

Currently, one of the most relevant strategies to employ when performing in the heat is to consume adequate fluids. Maintaining water availability along different race courses is thus crucial due to the detrimental effects dehydration has on fluid balance and consequently heat loss via sweating. Individual sweat rates are highly dependent on the athlete's morphology, the intensity of exercise and the environment temperature and humidity. Sweat losses are accompanied by electrolyte losses, particularly sodium, which may contribute to hyponatremia if not compensated. To limit this risk, exogenous intake by enriched sodium beverages is the most effective strategy. In addition to the traditional compounds found in most sport drinks (e.g. glucose, magnesium, , it seems that ultramarathon beverages should contain about $0.7-1.2 \mathrm{~g} \cdot \mathrm{~L}^{-1}$ of salt when conducted in the heat. However, sodium-enriched beverages are insufficient if athletes overdrink by fear of dehydration during the race, placing management of water intake as a key determinant of performance.

Heat acclimation is also a relevant strategy that may enhance ultra-endurance and triathlon performance in hot environments. Most of the acclimation benefits occur in the first 14 days of exposure, but a short-term protocol of 5 days will induce significant early adaptations.

Figures


Figure 1. Individual and mean values $( \pm \mathrm{SD})$ of core temperature at each stage of the Guadeloupe halfIronman held in tropical climate. T1: just before the race; T2: after the swim phase; T3: after the cycle phase; T4: at the end of the run phase (Baillot and Hue 2015). Temperatures were obtained from telemetric intestinal temperature devices ingested at least 6 hours before the race.


Figure 2. Nomogram representing the impact of WBGT on the relation between marathon finishing times according to quartiles and relative performance decrement in comparison with WBGT at $5^{\circ} \mathrm{C}$ (Ely et al. 2007).


Figure 3. Proportion of runners abandoning the Western States Endurance Run ( $161 \mathrm{~km} ; 6000 \mathrm{~m}$ D+) race at each checkpoint along the course (A), and relationship between finish times for the $2006\left(7-38^{\circ} \mathrm{C}\right)$ and 2007 $\left(2-30^{\circ} \mathrm{C}\right)$ edition (B). (Parise and Hoffman 2011).


Figure 4. Trial times for 5 successive blocks ( 4 km cycling +1.5 km running) with the ingestion of Neutral water (orange), Cold water (blue) and Ice-slurry (green).
${ }^{\text {a }}$ Significantly different from Neutral water Cycling and Running Performance Using IceSlurry/Menthol ( $\mathrm{P}<0.05$ ).
${ }^{\mathrm{b}}$ Significantly different from Cold ( $\mathrm{P}<0.05$ ). Mean values and SD are shown.
$\beta, \dagger$ denote that block performance was affected by Time Period $(\mathrm{P}<0.007)$ and the Time Period x Drink Temperature interaction ( $\mathrm{P}<0.004$ ), respectively (Tran Trong et al. 2015).

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