

Triathlon and Ultra-Endurance Events in Tropical Environments

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8

9 Abstract

10 Physical performance in tropical environments, which combine heat and high humidity, is a 11 challenge that requires specific preparation. The high humidity of a tropical climate alters 12 thermoregulatory capacity by limiting the rate of sweat evaporation. Proper management of whole-13 body temperature is thus essential to complete an endurance event like a long-distance triathlon or 14 an ultramarathon in such an environment. In triathlon and ultra-endurance races, which can last 15 from 8 to 20 h, performance in tropical settings is closely linked to the capacity to maintain 16 hydration status. Indeed, the rate of withdrawal in these longer events has been associated with 17 water intake, with many finishers showing alterations in electrolyte (e.g. sodium) balance. To 18 counterbalance the impact of a tropical climate and maintain performance, several countermeasures 19 can be adopted, such as using hydration and cooling strategies, and heat acclimation.

20 1 Influence of heat on performance and health

21 1.1 Specificity of the triathlon

The Ironman and Challenge triathlon series are trademark brands for long-distance triathlons consisting of a 3.8-km swim, 180-km cycling leg, and full marathon (42.195 km). The best 24 professional triathletes complete the distance in under 7 h and 50 min, whereas age group athletes 25 vary from 9 to 13 h and more, making this one of the longest endurance races. The duration depends 26 on several factors, including terrain (i.e. course route and geography) and environmental conditions. 27 For example, hot and humid climates impact on performance and the rate of withdrawal, as 28 observed in the Kona (Hawaii) Ironman World Championships every October (Giambelluca et al. 29 2014; Stiefel et al. 2013): top age-groupers were slower at Hawaii than at their qualifier races 30 (Stiefel et al. 2013), and abandon rate can reach 10%, a high proportion considering the fitness level 31 of athletes participating in this particular event, more resistant to heat stress (Cheung and McLellan 32 1998; Ironman 2018b). Similarly, more than 25% of the athletes did not reach the finish line at the 33 inaugural Ironman Vichy in 2015, which was held in unusually hot conditions (31~35°C), in contrast to North American races with a minimum 95% finish rate (Britt 2011). 34

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

37 1.1.1 Swimming

38 Most long distance triathlons allow neoprene wetsuits to be worn for the swim leg as long as 39 water temperature does not exceed 24.5°C. Between 24.5°C and 28.8°C, athletes who choose to 40 wear a wetsuit are allowed to participate, but are not eligible for age-group awards or for qualifying 41 slots for the Ironman World Championships, and over 28.8°C wetsuits are prohibited (Ironman 2018). With its enhanced buoyancy, the neoprene wetsuit reduces ventilation and O₂ consumption 42 43 $(\dot{V}O_2)$ at a given swimming speed, and therefore metabolic heat production (Trappe et al. 1996). 44 However, wetsuits reduce heat dissipation capacity and can lead to high core body temperatures and 45 dehydration (Kerr et al. 1998; Laursen et al. 2006). Hence, although banning wetsuits in warm 46 water might impair swimming performance, it might also decrease the risk of hyperthermia.

47 Interestingly, Kerr et al. (Kerr et al. 1998) showed in a simulated Olympic triathlon that core
48 temperature did not change by wearing a wetsuit, thought to limit thermoregulatory mechanisms

49 through heat-insulating properties of neoprene, as excess heat was still transferred at the periphery, 50 leading to a higher skin temperature. A subsequent field study confirmed that core temperature 51 remained around 38°C in well-trained athletes wearing a wetsuit in 20.5°C water during a 3.8 km 52 swim (Laursen et al. 2006). This was again confirmed by a case report in which an athlete's core 53 temperature was continuously monitored during an Ironman (Laursen et al. 2009). In 29.5°C water, 54 another study showed that the core temperature of moderately trained athletes increased by an 55 average 0.7°C and remained under 38°C during a non-wetsuit half-Ironman (Figure 1; (Baillot and 56 Hue 2015)). Thus, no study appears to have shown a dangerous elevation in core temperature during 57 the swim leg of long-distance triathlon events. Moreover, while 13 of the 14 deaths in triathlon 58 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). 59

60 1.1.2 Cycling

When cycling, some of the heat produced by the muscles is dissipated via convection. This 61 62 however, depends on a sufficient temperature gradient between the skin and ambient air. 63 Convection is therefore limited in hot conditions when air temperatures exceeds 35°C. Heat is also 64 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 65 66 environments, making performance in a tropical environment challenging as thermoregulatory 67 efficiency is reduced (Nybo 2010). In a tropical climate (31-33°C, 70-75% RH), one-hour of 68 pedalling at a submaximal intensity increases core temperature, heart rate, sweat rate and water loss 69 (Saat et al. 2005a; Saat et al. 2005b; Voltaire et al. 2003). These results can be extrapolated to 70 describe the physiological impact of 4–6-h events, especially if the cycling course includes hills, 71 where the diminished air speed reduces heat dissipation (Nybo 2010). Laboratory-controlled studies 72 showed that increasing ambient temperature impaired cycling capacity when relative humidity was 73 clamped at 70% (Galloway and Maughan 1997; Maughan et al. 2012). During a 9-day (2.5 h/day)

cycling race held in Guadeloupe (31.1°C, 75.6% RH), tympanic temperatures measured 74 75 immediately after the stages never exceeded 2°C of resting pre-race values (Hue et al. 2006). In 76 contrast to the variability associated with stage racing in a peloton, triathletes will adopt a much 77 steadier pace during racing in some cases to "save their legs" for the following marathon (Wu et al. 78 2015). Interestingly, Baillot et al. (Baillot and Hue 2015) showed a negative correlation between 79 body mass and the evolution of core temperature throughout the cycling leg, implying greater heat 80 storage and inertia. A bigger body thus presents a larger surface to preserve heat exchange at high 81 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).

88 1.1.3 Running

89 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 90 91 is faster than swimming, air possesses neither the heat capacity nor transfer celerity of water, hence 92 limiting the quantity of heat energy transferred from the body. Secondly, unlike in cycling, the 93 lower speed associated with running does not allow for excess heat dissipation via convection 94 (Nielsen 1996). These factors can have a strong negative impact on running performance (Kenefick 95 et al. 2007), particularly the marathon (Ely et al. 2007). This negative impact is amplified (i) by a 96 heavier body mass, which, at a given pace, requires more energy for running propulsion and 97 therefore produces more heat, and (ii) in heavier athletes running in a hot/humid environment 98 limiting heat exchange by convection and evaporation, who display greater imbalance between heat
99 production and dissipation, even at slower paces (Marino et al. 2000).

100 While the core temperature data of professional triathletes in the Hawaii Ironman or other 101 tropical locations are currently not available, a few studies of moderately to very well trained age 102 group athletes have shown that none of them suffered from heat-related illness and excessive 103 increases in core temperature (Laursen et al. 2006) (Figure 1; (Baillot and Hue 2015; Del Coso et al. 104 2014)). In the report from Laursen et al. (Laursen et al. 2006) 7 out of 10 well trained triathletes 105 performed a high-level sub-10-hour performance at Ironman Western Australia in temperate but 106 humid conditions (23.3°C, 60% RH), and the average core body temperature remained close to 107 38°C. Despite a much hotter and more humid environment in Guadeloupe (27.2°C, 80% RH), the 108 average body temperature of moderately trained athletes during a half-Ironman run was 38.2°C and 109 none of them reached 40°C (Baillot and Hue 2015). These values are not surprising given the 110 relative intensity and absolute workload at which most long-distance triathlon races are performed, 111 which is in contrast to shorter events performed at a higher intensity and thus higher heat production 112 (Siegel et al. 2010; Baillot and Hue 2015). The importance of exercise intensity was confirmed in 113 dryer conditions in a study showing that the fastest athletes exhibited the highest core temperatures 114 (Del Coso et al. 2014).

115

116 1.2 Specificity of ultra-endurance events

117 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 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 off123 road terrains, elevation profiles (positive: D+ and negative: D- changes), and distances, all of which 124 greatly complicate the attempt to understand how environmental conditions affect performance. 125 Marathon races have more standardized characteristics, facilitating the comparison of performances 126 in order to study the role played by heat (see chapter 12). Based on the analysis of winners' times in 127 several marathons, (Maughan 2010) et al., 2010 determined that the best running temperature is 128 between 10°C to 12°C for elite athletes. Beyond this temperature, the analysis of 136 marathons 129 performed between a wet-bulb globe temperature (WBGT) of 5 and 25°C showed a decrease in 130 performance with an increase in WBGT (Figure 2; (Ely et al. 2007)). Interestingly, these authors 131 also showed that slower runners, who are exposed to heat for a longer time than faster runners, are 132 more affected by temperature. For ultramarathon distances, the same effect of hot environments on 133 performance was observed in a study that examined running times in the Western States Endurance 134 Run (161 km and 6000 m D+) in 2006 and 2007 (Parise and Hoffman 2011). In these two editions 135 (Figure 3), the authors followed 50 runners who had finished the race in both years to investigate 136 the effect of temperature changes from 7–38°C in 2006 to 2–30°C in 2007. Independently of their 137 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 138 139 appear to be more impacted by the hot environment, but this observation was probably due to the 140 longer time running at a comfortable temperature (i.e. night).

141 1.2.2 Hydration requirements during ultra-endurance exercise in the heat

During muscle contraction, only ~25% of the substrate energy is converted to mechanical work, with the other ~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, 148 especially when competing in hot and/or humid environments. Furthermore, environmental heat 149 stress (i.e. temperature) reduces dry heat loss, due to the small (or even negative) temperature 150 gradient between the skin and air, which progressively places sweat evaporation as the only 151 mechanism available for the organism to dissipate endogenous heat (Brotherhood 2008; Taylor 152 2006). Indeed, at in 30°C conditions a dry heat loss of 75 W is observed whereas at 40°C, it induces 153 a dry heat gain of 75 W, increasing the sweating rate require to maintain body core temperature 154 (Gagnon et al. 2013). Thus, ultramarathons performed in a hot environment require bigger volumes 155 of water intake to compensate for increased water losses. During the Badwater Ultramarathon of 2012 (217 km and 4000 m D+), the temperature oscillated from 10.1°C at night to 46.6°C during 156 the day. The follow-up of 4 runners who completed the race in 36 ± 3 h showed a mean water intake 157 of 34±13 L (Brown and Connolly 2015). On average, each athlete drank 0.93 L.h⁻¹, whereas on 158 completion of the Biel Ultramarathon in Switzerland (100 km and 645 m D+), in a temperate 159 environment varying from 8 to 28°C, the runners consumed 0.65 L.h⁻¹ (Knechtle et al. 2011). When 160 the distances of these two races were linked to elevation changes (100 m D+ corresponds to 1 km of 161 distance), the corrected distance for the Biel Ultramarathon was 106.45 km and 257 km for 162 163 Badwater. According to these corrected distances, the Badwater runners drank almost twice as much water as the Biel runners (0.13 L.km⁻¹ and 0.069 L.km⁻¹, respectively), despite the higher 164 165 mechanical workload developed during the Biel Ultramarathon due to its shorter distance and lower elevation change (6.6 min.km⁻¹ vs. 8.5 min.km⁻¹ for Badwater). The characteristics of the 2007 166 Peninsula Ultra Fun Run (PUFfeR) of South Africa (80 km and 1000 m D+) were close to those of 167 168 the Biel Ultramarathon, but the participants were subjected to lower environmental temperatures 169 (8-20°C). The runners drank less during this more temperate race than during the Biel Ultramarathon (0.028 L.km⁻¹ and 0.069 L.km⁻¹, respectively) (Tam et al. 2009). Analysis of the 170 171 hydration status of 16 ultramarathon runners (161 km, 7000 m D+) in a hot environment (4.8–37.8°C) showed that finishers (n=6) had drunk significantly more water at the 48th kilometer 172 than non-finishers (n=10) (Stuempfle et al. 2011). However, the authors were unable to determine 173

174 whether beverage intake was directly linked to finishing capacity or if it was due to other factors, 175 such as the experience or endurance capacity of the runners. A second study performed during a 176 160-km foot race (positive elevation not known) in temperatures that peaked at 38°C followed only 177 those runners who had completed at least one previous ultramarathon among the top 50% (Glace et 178 al. 2002). The authors showed that, despite the homogenous level and experience of these runners, 179 non-finishers also drank significantly less than finishers (-35%, p<0.01). All these data confirmed 180 the relationship between event temperature and water intake that is crucial to health and 181 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±2.4°C and 82±4% RH) showed a sweat loss of 0.19 L.km⁻¹ (Hue et al. 182 2014). Yet water intake (1.5±0.3 L per stage) was probably distorted by the shortness of the stages 183 184 (from 16 to 21 km), which enabled athletes to tolerate transient dehydration during the races (-185 4.2±0.9 L per stage).

186

187 2 Countermeasures to optimize performance and health

188 2.1 Hydration

189 Limiting dehydration during triathlons and ultramarathons in hot environments seems to be 190 essential to maintain the exercise workload over many hours. The role of hydration in a tropical 191 climate (see chapter 6) is critical since it has been shown that hyperthermia and dehydration are 192 worse than hyperthermia alone (Sawka et al. 2001; Sawka and Noakes 2007). Despite contradictory 193 observations on influencing thermoregulation and core temperature (Latzka et al. 1997; Ross et al. 194 2012), it seems that hyperhydration can delay the development of dehydration (Latzka and Sawka 195 2000; Latzka et al. 1997; Sawka et al. 1984). However, hyperhydration does not seem to lead to 196 better performances during a laboratory-based 46 km cycling time trial by elite cyclists (Ross et al. 197 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 207 2018).

208 Maintaining optimal hydration is more complicated than it would seem in the ultramarathon. 209 Indeed, analysis of the hydration status of ultramarathon runners in 2 different races showed that 210 finishers had drunk significantly more water than non-finishers, even if the runners' experience was 211 taking into account (Glace et al. 2002; Stuempfle et al. 2011). In contrast, slower runners became 212 over-hydrated because they feared dehydration, which may lead to hyponatremia (Hew-Butler et al. 213 2008; Noakes 2007). Hyponatremia however, is not only due to over-hydration, but may be the 214 consequence of insufficient sodium intake during the race (Glace et al. 2002; Stuempfle et al. 2011). 215 In a hot environment, hyponatremia affected 30-50% of ultramarathon finishers, reflecting the 216 inadequate or incorrect hydration strategies of many runners (Glace et al. 2002; Hoffman et al. 217 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 218 219 glucose and water absorption, optimizing extracellular and intracellular fluid balance, and 220 potentially mitigating the occurrence of clinically significant episodes of hyponatremia (Maughan 221 1991; Shirreffs and Sawka 2011; Speedy et al. 1999; Vrijens and Rehrer 1999).

223 2.2 Hydration policy and implementation

In a triathlon field study, oral salt supplementation improved half-Ironman performance 224 225 through faster cycling (p<0.05) and showed a similar trend in the running leg (p=0.06), with reduced sweat rate and limited electrolyte deficit (Del Coso et al. 2016). The consensus 226 recommendation is thus to ingest 0.5 to 0.7 g.L⁻¹.h⁻¹ for long endurance races (Von Duvillard et al. 227 2004) and up to 1.5 g.L⁻¹.h⁻¹ for athletes prone to develop muscle cramping (Bergeron 2003). 228 However, adding salt to the consumed water is not sufficient to avoid hyponatremia if athletes over-229 230 drink during a race (73% of severe symptomatic hyponatremia found after an Ironman (Speedy et 231 al. 1999)).

(Hoffman and Stuempfle 2014) observed no advantage to sodium-enriched beverages during a
161-km ultramarathon performed by all levels of athletes in heat (38°C). 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).

236

237 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.

245 Other studies have focused on cooling strategies, but the exercise duration has been relatively 246 short compared with ultra-endurance events. Nonetheless, they show interesting results that may be 247 extrapolated for long to ultra-long events. Spraying or pouring water over the face and/or body can 248 improve performance in tropical conditions. For example, pouring cold water over the skin will 249 reduce skin temperature before dripping off the body, and transiently improve thermal comfort. 250 Cooling the head in this manner resulted in a 51% increase in cycling time to exhaustion at 75% 251 VO_{2max} (Ansley et al. 2008), with similar effects recently observed in running (Stevens et al. 252 2017b). Neck cooling during a 90-min running trial in a hot environment (30.4°C and 53% RH) 253 increased the distance covered by 7.4% with no change in rectal temperature (Tyler and Sunderland 254 2011). A similar effect was found with menthol ingestion, as it activates cold dermal sensors 255 (Stevens and Best 2017). Mixed into a cold beverage, menthol did not lower core body temperature 256 but had a positive effect on thermal sensation and running/cycling performances over various 257 distances in tropical climate (Stevens et al. 2016; Tran Trong et al. 2015). Indeed, Stevens et al. 258 2016 showed that a menthol mouth rinse every kilometre (25 mL at a concentration of 0.01%) 259 during a running time trial in the heat significantly improved 5-km performance time by 3%. A cumulative effect of menthol and ice slurry or cold water was observed on performances during a 260 261 20-km cycling trial in hot environment (30.7±0.8°C and 78±0.03% RH) (Tran Trong et al. 2015). Ultimately, menthol mouth rinsing and ingesting influence thermal perception and thermal comfort, 262 263 which in turn might contribute to enhance performance in hot climates (Stevens et al. 2017a; 264 Stevens et al. 2016).

265

266 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 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 272 athletes (see chapter 7). Indeed, most high-performing runners show the biggest increase in internal 273 temperature, probably due to higher thermogenesis consecutive to higher workloads (Baillot et al. 274 2014; Hue et al. 2014). Faster trail runners (27 km; Baillot et al. 2014) and multi-stages trail runners 275 (127 km on 6 days; Hue et al. 2014) also present greater post-race dehydration, which could be 276 reduced by cold water due to its effect on voluntarily increasing water absorption during exercise. 277 The higher temperatures and greater dehydration observed in faster trail runners also seem to 278 indicate that performance in heat is associated with a better tolerance to hyperthermia in elite 279 athletes (McKeag and Moeller 2007).

280

281 2.5 Heat acclimation

282 Heat acclimation (HA) before a race is an efficient way to increase performance in a hot 283 environment (Armstrong and Maresh 1991; Nielsen 1994) (see chapter 8 for further details). The 284 physiological adaptations of HA lead to better cardiovascular function (output, stroke volume, heart 285 rate) and a decreased core temperature at rest and during exercise, in part due to an enhanced sweat 286 rate and expanded plasma volume (Armstrong and Maresh 1991). HA is also known to reduce 287 sodium loss by sweating (Kirby and Convertino 1986). However, HA does not fully restore long to 288 ultra-long endurance performance to the level reached by athletes in temperate conditions (Voltaire 289 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 VO_{2max} on a motorized treadmill in an environmental heat chamber at 30°C or 35°C. From the third session onward, mean heart rate was lower at 30°C, whereas mean heart rate and thermal comfort were lower at 35°C. The authors concluded that two bouts of running at 60% of VO_{2max} in a 30°C air temperature conditions were sufficient to induce heat acclimation in ultra-runners, which may enhance their performance in such environments.

298

299 3 Conclusions

300 The maintenance of triathlon or ultramarathon performance in a hot environment is a 301 considerable challenge which requires meticulous preparation and management during the race. To 302 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 303 304 per- cooling and/or menthol use. However, the limited duration of exercise performed in these 305 studies does not allow for direct application of the results to an ultra-endurance or ultra-triathlon 306 context. Thus, further studies are required to validate these approaches in long to triathlon and ultra-307 endurance events.

308 Currently, one of the most relevant strategies to employ when performing in the heat is to 309 consume adequate fluids. Maintaining water availability along different race courses is thus crucial 310 due to the detrimental effects dehydration has on fluid balance and consequently heat loss via 311 sweating. Individual sweat rates are highly dependent on the athlete's morphology, the intensity of 312 exercise and the environment temperature and humidity. Sweat losses are accompanied by 313 electrolyte losses, particularly sodium, which may contribute to hyponatremia if not compensated. 314 To limit this risk, exogenous intake by enriched sodium beverages is the most effective strategy. In 315 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 g.L⁻¹ of salt when conducted in 316 317 the heat. However, sodium-enriched beverages are insufficient if athletes overdrink by fear of 318 dehydration during the race, placing management of water intake as a key determinant of performance. 319

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.



Figure 1. Individual and mean values (\pm SD) of core temperature at each stage of the Guadeloupe half-Ironman 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.

324



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°C (Ely et al.
2007).





Figure 3. Proportion of runners abandoning the Western States Endurance Run (161 km; 6000m D+) race at
each checkpoint along the course (A), and relationship between finish times for the 2006 (7-38°C) and 2007
(2-30°C) 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).

^a Significantly different from Neutral water Cycling and Running Performance Using Ice-Slurry/Menthol (P<0.05).

^b Significantly different from Cold (P<0.05). Mean values and SD are shown.

 β , denote that block performance was affected by Time Period (P<0.007) and the Time Period x Drink Temperature interaction (P<0.004), respectively (Tran Trong et al. 2015).

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