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HAL Authorization

1 Ultra-endurance events in tropical environments and countermeasures to
2 optimize performances and health

3
4 **Running head:** Aerobic performance in tropical climate

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27

28 **Abstract**

29 Physical performance in a tropical environment, combining high heat and humidity, is a
30 difficult physiological challenge that requires specific preparation. The elevated humidity of a
31 tropical climate impairs the thermoregulatory mechanisms by limiting the rate of sweat evaporation.
32 Hence, a proper management of whole-body temperature is required to complete an ultra-endurance
33 event in such an environment. In these long-duration events, which can last from 8 to 20 h, held in
34 hot and humid settings, performance is tightly linked to the ability in maintaining an optimal
35 hydration status. Indeed, the rate of withdrawal in these longer races was associated with lower
36 water intake, and the majority of finishers exhibited alterations in electrolyte balance (e.g. sodium).
37 Hence, this work reviews the effects on performance of high heat and humidity in two
38 representative ultra-endurance sports, ultramarathons and long-distance triathlons, and several
39 countermeasures to counteract the impact of these harsh environmental stresses and maintain a high
40 level of performance, such as hydration, cooling strategies and heat acclimation.

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44 **Keywords**

45 Performance, tropical climate, heat, humidity, triathlon, ultra-endurance

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49 **Abstract word count:** 163

50 1. Influence of heat on performance and health

51 It is now well established that aerobic performance and health can be deeply impacted by a
52 hot and humid climate [1]. In particular, long-duration races, such ultra-marathons or long-distance
53 triathlons, are highly concerned by these environmental stresses due to a much longer exposure to
54 these conditions compared to most events, from short-distance runs or triathlons to marathons.

55

56 1.1. Ultra-endurance events: ultramarathon

57 1.1.1. Ultra-endurance in the heat

58 Ultramarathon is a running event which lasts more than 6 h and usually presents a high
59 *dénivelé*, from hundreds to thousands meters elevation [2]. In the past decade, trail running races
60 have become a major ultra-endurance sport. Since the first edition of the ‘Ultra Trail du Mont
61 Blanc’ (160 km and +10,000 m of elevation), the number of finishers has grown from 67 in 2003 to
62 1685 in 2017. This specific effort involves several physiological and psychological parameters that
63 are modulated by environmental factors. Ultramarathon races are performed in a variety of off-road
64 terrains, elevation profiles (positive: D+ and negative: D- changes) and distances, all of which may
65 greatly complicate the understanding how environmental conditions affect performance. Marathon
66 races present more standardized characteristics, facilitating the comparison of performances in order
67 to study the role played by heat [3]. The analysis of winners’ times in several marathons, evidenced
68 that the optimal ambient temperature for running performance is between 10°C and 12°C for elite
69 athletes [4]. Above this temperature, data from 136 marathons performed between a wet-bulb globe
70 temperature (WBGT) of 5 and 25°C showed a negative correlation between WBGT and running
71 performance (Figure 2) [5]. Interestingly, the same authors also showed that the performance of
72 slower runners, exposed to heat for a longer time than faster runners, are more affected by higher
73 temperatures. In ultramarathon distances, a similar effect of a hot environment on performance was
74 observed in a study that analysed running times in the Western States Endurance Run (161 km and
75 6000 m D+) [6]. The authors followed 50 runners who completed the race in two consecutive years
76 (2006 and 2007) to investigate the effect of temperature changes, from 7–38°C in 2006 to 2–30°C
77 in 2007 (figure 3). Regardless of their level, athletes were 8% slower during the ‘hot’ year (2006)
78 than during the ‘cooler’ (2007), and the withdrawal rate was 14% higher in 2006. Slower runners
79 did not appear to be more impacted by the hot environment, but this observation was probably due
80 to the longer time running at a comfortable temperature (i.e. during the night).

81

82 1.1.2. Hydration requirements during ultra-endurance exercise in the heat

83 During muscle contraction, only ~25% of the substrate energy is converted to mechanical
84 work, with the other ~75% released as heat. An effective thermoregulation during exercise relies on
85 the balance between the absolute mechanical work generated by the athlete and the heat dissipating
86 process. Ultramarathons, characterized by a low and steady relative exercise intensity over very

87 long periods, do not significantly challenge the heat balance in temperate environments. However,
88 maintaining mechanical load over a longer time may challenge heat balance in athletes, especially
89 when competing in hot and/or humid environments. Furthermore, environmental heat stress (i.e.
90 temperature) reduces dry heat loss, due to the small (or even negative) temperature gradient
91 between the skin and air, which progressively puts sweat evaporation as the only mechanism
92 available for the organism to dissipate endogenous heat [7,8]. Indeed, in 30°C conditions, a dry heat
93 loss of 75 W is observed whereas it induces a dry heat gain of 75 W at 40°C, increasing the
94 sweating rate required to maintain body core temperature [9]. Thus, ultramarathons performed in a
95 hot environment require greater water intake to compensate increased water losses. During the
96 Badwater Ultramarathon of 2012 (217 km and 4000 m D+), the temperature oscillated from 10.1°C
97 at night to 46.6°C during the day. The follow-up of 4 runners who completed the race in 36±3 h
98 showed a mean water intake of 34±13 [10]. On average, each athlete drank 0.93 L.h⁻¹, whereas on
99 completion of the Biel Ultramarathon in Switzerland (100 km and 645 m D+), in a temperate
100 environment varying from 8 to 28°C, the runners consumed 0.65 L.h⁻¹ [11]. When the distances of
101 these two races were linked to elevation changes (100 m D+ is equivalent to 1 km distance), the
102 adjusted distance for the Biel Ultramarathon was 106.45 km and 257 km for Badwater. Hence, the
103 Badwater runners drank almost twice as much water as the Biel runners (0.13 L.km⁻¹ and 0.069
104 L.km⁻¹, respectively), despite a higher mechanical workload developed during the Biel
105 Ultramarathon due to its shorter distance and lower elevation change (6.6 min.km⁻¹ vs. 8.5 min.km⁻¹
106 for Badwater). The characteristics of the 2007 Peninsula Ultra Fun Run (PUFfeR) of South Africa
107 (80 km and 1000 m D+) were close to those of the Biel Ultramarathon, but the participants were
108 subjected to lower environmental temperatures (8–20°C). The runners drank less during this more
109 temperate race than during the Biel Ultramarathon (0.028 L.km⁻¹ and 0.069 L.km⁻¹, respectively)
110 [12]. The analysis of the hydration status of 16 ultramarathon runners (161 km, 7000 m D+) in a hot
111 environment (4.8–37.8°C) showed that finishers (n=6) had drunk significantly more water at the
112 48th km than non-finishers (n=10) (Stuempfle et al. 2011). However, the authors were unable to
113 determine whether beverage intake was directly linked to finishing capacity or if it was due to other
114 factors, such as runners' experience or endurance capacity. A second study was focused on a 160-
115 km foot race (positive elevation not known) with temperatures that peaked at 38°C, and followed
116 only runners who had completed at least one previous ultramarathon among the top 50% [13]. The
117 authors showed that, despite their homogenous level and experience, non-finishers also drank
118 significantly less than finishers (-35%, p<0.01). These data confirm the tight relationship between
119 event temperature and water intake, and that hydration strategies remain essential for health and
120 performance. Another study showed an average 0.19 L.km⁻¹ sweat loss in runners during the 2011
121 Gwada Run, multi-stage race (6 days, 142 km) held in tropical conditions (30 ± 2.4°C and 82 ± 4%
122 RH) [14]. Yet water intake (1.5±0.3 L per stage) was probably distorted by the shortness of the

123 stages (from 16 to 21 km), which enabled athletes to tolerate transient dehydration during the races
124 (- 4.2±0.9 L per stage).

125

126 1.2. Triathlon

127 Ironman and Challenge triathlon series are trademark brands for long-distance triathlons
128 consisting of a 3.8-km swim, a 180-km cycling leg and a closing full marathon (42.195 km). The
129 best professional triathletes complete the distance under 7 h and 50 min, whereas time of age group
130 athletes may vary from 9 to 13 h and more, making this race one of the longest endurance races.
131 The duration depends on several factors, including terrain (e.g. course route, technicality, elevation)
132 and environmental conditions. For the latter, hot and humid climate impacts the performance and
133 the rate of withdrawal, as observed in the Kona (Hawaii) Ironman World Championships, held
134 every October [15,16]: top age-groupers were slower in Hawaii than in their qualifier races [16],
135 and abandon rate can reach 10%, a high proportion considering the higher fitness level of athletes
136 participating in this particular event, more resistant to heat stress [17,18]. Similarly, more than 25%
137 of the athletes did not reach the finish line at the inaugural Ironman Vichy in 2015, which was held
138 in unusually hot conditions (31~35°C), in contrast to North American races which present a
139 minimum 95% finish rate (Britt 2011).

140 During long-distance triathlon, heat stress specifically impacts each successive leg:
141 swimming, cycling and running.

142

143 1.2.1. Swimming

144 Most long distance triathlons allow neoprene wetsuits to be worn for the swim leg as long as
145 water temperature does not exceed 24.5°C. Between 24.5°C and 28.8°C, athletes who choose to
146 wear a wetsuit are allowed to participate, but are not eligible for age-group awards or for qualifying
147 slots for the Ironman World Championships; over 28.8°C wetsuits are prohibited (Ironman 2018).
148 Enhancing swimmer's buoyancy, the neoprene wetsuit reduces ventilation and O₂ consumption
149 ($\dot{V}O_2$) at a given swimming speed, and therefore decreases metabolic heat production [19].
150 However, wetsuits also reduce heat dissipation capacity and may lead to a higher core body
151 temperatures and subsequent dehydration [20,21]. Hence, although proscribing wetsuits in warm
152 water may impair swimming performance, it also might decrease the existing risk of hyperthermia
153 [22].

154 However, interestingly, Kerr et al. showed in a simulated Olympic triathlon that core
155 temperature was not modified by wearing a wetsuit, thought to limit thermoregulatory mechanisms
156 through heat-insulating properties of neoprene [20], as excess heat was still transferred to the
157 periphery, leading to a higher skin temperature. Some field studies confirmed that core temperature
158 remained around 38°C in well-trained athletes wearing a wetsuit in 20.5°C water during a 3.8 km
159 swim [21], and in triathletes completing a long-distance Ironman, whose core temperature was

160 continuously monitored [23] . In 29.5°C water, another study showed that the core temperature in
161 moderately trained athletes increased by an average 0.7°C but remained under 38°C during a non-
162 wetsuit half-Ironman (Figure 1). Thus, to this day, no study evidenced a critical elevation of core
163 temperature during the swim leg of long-distance triathlon events. Moreover, while 13 of the 14
164 documented deaths in triathlon races from 2006 to 2008 occurred during the swim leg, pre-existing
165 cardiovascular abnormalities seem to have been the major factor, ruling out hyperthermia as a
166 potential cause [24].

167 1.2.2. Cycling

168 During cycling, some of the heat produced by the muscles is dissipated via air convection
169 around the body. This, however, depends on a sufficient temperature gradient between the skin and
170 ambient air. Convection mechanisms are therefore limited in hot conditions when air temperature
171 exceeds 35°C. Heat is also dissipated during cycling via sweat evaporation, itself depending on the
172 pressure gradient of water vapor between air and skin surface. Like convection, this mechanism is
173 reduced in a humid environment, making performance more challenging as thermoregulatory
174 efficiency is dramatically reduced [25]. In a tropical climate (31-33°C, 70-75% RH), one-hour of
175 pedalling at a submaximal intensity increases core temperature, heart rate, sweat rate and water loss
176 [26–28]. These results can be extrapolated to describe the physiological impact of 4–6-h events,
177 especially if the cycling course includes hills, where the diminished air speed reduces heat
178 dissipation by convection [25]. Laboratory-controlled studies showed that increasing ambient
179 temperature impaired cycling capacity when relative humidity was clamped at 70% [29,30]. During
180 a 9-day (2.5 h/day) cycling race held in Guadeloupe (31.1°C, 75.6% RH), tympanic temperatures
181 measured immediately after the stages never exceeded a 2°C rise compared to resting pre-race
182 values [31]. In contrast to the intrinsic variability associated with stage racing in a peloton,
183 triathletes usually adopt a much steadier pace during non-drafting racing to “save the legs” for the
184 following marathon [32]. Interestingly, Baillot et al showed a negative correlation between body
185 mass and the evolution of core temperature throughout the cycling leg, illustrating greater heat
186 storage and inertia in larger athletes [33]. Thus, a larger body presents a larger surface which allow
187 to preserve heat exchange at high velocity, even in a hot and humid environment [34].

188 In summary, the higher velocity and the intrinsic non-drafting nature of cycling in triathlon
189 promotes heat dissipation by convection only if air temperature is lower than skin's. In a thermally
190 challenging environment, sweat evaporation remains the main process for heat dissipation but is
191 limited by the high humidity of a tropical environment. Nevertheless, triathletes appear to show
192 adequate thermoregulatory capability to prevent excessive hyperthermia, mainly through intensity
193 management and pacing strategies [33].

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1.2.3. Running

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Of the three sports in the triathlon, running may carry the greatest risk of hyperthermia for triathletes competing in a tropical climate. Several factors and stressors come into play. Firstly, although running is faster than swimming, air possesses neither the heat capacity nor the transfer celerity of water, hence limiting the quantity of heat energy dissipated from the body. Secondly, unlike in cycling, the lower speed of running does not allow excess heat dissipation via air convection around the body [34]. These factors may have a strong negative impact on running performance [35], particularly in a marathon [5]. Furthermore, this negative impact is amplified under two additional factors: (i) a heavier body mass, at a given pace, requires more energy for running locomotion and therefore produces a larger quantity of metabolic-related heat; and (ii) heat exchange by convection and evaporation is limited in heavier athletes running in a hot/humid environment, who display a greater imbalance between heat production and dissipation, even at slower paces [36].

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While the core temperature data of professional triathletes in the Hawaii Ironman or other hot/humid locations are not available, a few studies in moderately to very well trained age group athletes pointed out that they did not suffer from heat-related illness and excessive increases in core temperature [21] (Figure 1). Laursen et al showed, in 7 out of 10 well trained triathletes racing a high-level sub-10-hour performance at Ironman Western Australia in temperate but humid conditions (23.3°C, 60% RH), that the average core body temperature remained close to 38°C [21]. Despite a much hotter and more humid environment in Guadeloupe (27.2°C, 80% RH), the average body temperature of moderately trained athletes during a half-Ironman run was 38.2°C and none of them reached 40°C [33]. These values are coherent with the relatively lower intensity and absolute workload at which most long-distance triathlon races are performed, in contrast with shorter events at a higher intensity and thus inducing a higher heat production [33,37]. The key role of exercise intensity on core temperature was confirmed in dryer conditions in a study showing that the fastest athletes exhibited the highest core temperatures [38].

223

2. Countermeasures to optimize performance and health

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2.1. Hydration

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Limiting dehydration during triathlons and ultramarathons in hot environments seems to be essential in order to maintain a mechanical workload over 6~7 hours. The key role of hydration strategy in a tropical climate is critical since it has been shown that combined hyperthermia and dehydration are worse than hyperthermia alone [39,40]. Despite contradictory observations on thermoregulatory mechanisms and core temperature [41,42], it seems that hyperhydration can delay the development of dehydration [41,43,44]. However, hyperhydration did not lead to enhanced

232 performances during a laboratory-controlled 46 km cycling time trial by elite cyclists [42] or a 60
233 min run by trained runners [45]. As hyperhydration results in non-negligible added body weight, it
234 may not be an advantage for running performance, greatly impacted by extra weight [46]. In
235 addition, it does not enhance thermoregulation in a hot and humid climate and augments the risk of
236 hyponatremia [47].

237 In triathlon, although hydration depends very much on beverage availability provided by race
238 organization, descriptive papers report that no triathlete has suffered from dehydration symptoms in
239 hot and humid events, despite occasional significant water losses [21,33,38,48]. This suggests that
240 hydration strategies used by athletes meet the body's water requirements [49].

241 Maintaining an optimal hydration level is more complicated in ultramarathon. Indeed,
242 analysis of the hydration status of ultramarathon runners in two different races showed that finishers
243 drank significantly more water than non-finishers, even if the runners' experience was taken into
244 account [13,50]. In contrast, slower runners became over-hydrated because they feared dehydration,
245 potentially leading to hyponatremia [51,52]. Hyponatremia however, is not only due to over-
246 hydration, but may be the consequence of insufficient sodium intake during the race [13,50]. In a
247 hot environment, hyponatremia affected 30–50% of ultramarathon finishers, reflecting the
248 inadequate or incorrect hydration strategies of numerous runners [13,53,54]. Thus, additional
249 sodium intake during ultramarathons could contribute to faster performances by stimulating thirst,
250 increasing voluntary fluid intake, enhancing intestinal glucose and water absorption, optimizing
251 extracellular and intracellular fluid balance, and potentially mitigating the occurrence of clinically
252 significant episodes of hyponatremia [55–58].

253

254 2.2. Heat acclimation

255 Heat acclimation (HA) before a race is an efficient way to limit the decrease of performance
256 in a hot environment [59,60], with physiological adaptations ranging from the fifth day [61] to a
257 two-week span [61,62]. These adaptations of HA lead to better cardiovascular function (output,
258 stroke volume, heart rate) and a decreased core temperature at rest and during exercise, partly due to
259 an enhanced sweat rate and an expanded plasma volume [59]. HA is also known to reduce sodium
260 loss by sweating [63]. However, HA does not fully restore long to ultra-long endurance
261 performance to the level reached by athletes in temperate conditions [62].

262 If early arrival at the race location is not possible, HA in an environmental chamber remains
263 an alternative strategy that may help preserve ultramarathon performance. Costa et al examined the
264 effects of six 2-h sessions of running at 60% of VO_{2max} on a motorized treadmill in an
265 environmental heat chamber at 30°C or 35°C [64]. From the third session onward, mean heart rate
266 was lower at 30°C, whereas mean heart rate and thermal comfort were lower at 35°C. The authors
267 concluded that two bouts of running at 60% of VO_{2max} in a 30°C air temperature conditions were

268 sufficient to induce heat acclimation in ultra-runners, which may enhance their performance in such
269 environments.

270

271 2.3. Hydration policy and implementation

272 In a triathlon field study, oral salt supplementation improved half-Ironman performance
273 through faster cycling ($p < 0.05$) and showed a similar trend in the running leg ($p = 0.06$), with
274 reduced sweat rate and limited electrolyte deficit [65]. Thus, the consensus recommendation is to
275 ingest 0.5 to 0.7 g.L⁻¹.h⁻¹ for long endurance races [66] and up to 1.5 g.L⁻¹.h⁻¹ for athletes prone to
276 develop muscle cramping [67]. However, adding salt to the consumed water is not sufficient to
277 avoid hyponatremia if athletes overhydrate during a race, as 73% of severe symptomatic
278 hyponatremia found after an Ironman [57].

279 Hoffman et al observed no advantage to sodium-enriched beverages during a 161-km
280 ultramarathon performed by all levels of athletes in heat (38°C) [68]. This result may have been due
281 to a variation in sodium intake from solid food and/or to a better tolerance of faster runners to
282 hypohydration and hyperthermia [14,69].

283

284 2.4. Cooling

285 Cooling strategies such as cold drink ingestion or cold-water immersion in order to reduce the
286 thermal stress may enhance performance in the heat. This effect has been observed in cyclists
287 (Figure 4) [70–72] and runners, illustrated by a longer time to exhaustion [37,73,74]. Wearing
288 cooling garments prior to or during exercise has proven to be performance-effective in hot and
289 humid climate [75–77], but remain difficult and impractical to use, and are often banned in official
290 long-distance events.

291 Other studies have focused on more direct cooling strategies, but the exercise durations were
292 shorter than ultra-endurance events. Nonetheless, they show interesting results that may be
293 extrapolated for long and ultra-long events. Spraying or pouring water over the face and/or body
294 can improve performance in tropical conditions. For example, pouring cold water over the skin will
295 reduce skin temperature by absorbing the peripherally-transferred heat, before dripping off the
296 body, and transiently improve thermal comfort. Cooling the head in this manner resulted in a 51%
297 increase in cycling time to exhaustion at 75% VO_{2max} [78], with similar effects recently observed in
298 running [79]. Neck cooling during a 90-min running trial in a hot environment (30.4°C and 53%
299 RH) increased the distance covered by 7.4% with no change in rectal temperature [80]. A similar
300 effect was found with menthol ingestion, as it activates cold dermal sensors [81]. Mixed into a cold
301 beverage, menthol did not lower core body temperature but had a positive effect on thermal
302 sensation and running/cycling performances over various distances in tropical climate [72,82].
303 Indeed, Stevens et al showed that a menthol mouth rinse every kilometre (25 mL at a concentration
304 of 0.01%) during a running time trial in the heat improved 5-km performance time by 3% [82]. A

305 cumulative effect of menthol and ice slurry or cold water was observed on performances during a
306 20-km cycling trial in hot environment ($30.7\pm 0.8^{\circ}\text{C}$ and $78\pm 0.03\%$ RH) [72]. Ultimately, menthol
307 mouth rinsing and ingesting influence thermal perception and thermal comfort, which in turn might
308 contribute to enhance performance in hot climates [82,83].

309

310 2.5. Cooling policy and implementation

311 According to the existing literature, pre-cooling by ice or cold water has been successfully
312 studied during short duration exercise (<60 min), yet too brief to be a key factor of performance
313 during ultra-endurance trials [73,79]. Conversely, precooling by cold water or ice slurry ingestion
314 during exercise seems to be a very interesting intervention to improve performances in a hot
315 environment and possibly increase fluid intake, particularly for well-trained athletes. Indeed, most
316 high-level runners exhibit the greatest increase of internal temperature, probably due to higher
317 thermogenesis consecutive to higher workloads. Faster trail runners (27 km) [69] and multi-stages
318 trail runners (127 km on 6 days) [14] also present a greater post-race dehydration, which could be
319 reduced by cold water due to its effect on voluntarily increasing water absorption during exercise.
320 The higher temperature and greater dehydration observed in faster trail runners also seem to
321 indicate that performance in heat is associated with a better tolerance to hyperthermia in elite
322 athletes [84].

323

324 .

325 3. Conclusion

326 The maintenance of performance in long endurance events such triathlon and ultramarathon
327 held in a hot environment is a considerable challenge which requires meticulous preparation and
328 management before and during the race. To limit performance decrements induced by these harsh
329 environmental conditions, several countermeasures have been proposed, such as cold-water or ice
330 slurry ingestion, external precooling (before exercise) and precooling (during) and/or menthol use.
331 However, the limited duration of exercise performed in these studies does not allow a direct
332 application to an ultra-endurance or ultra-triathlon context. Thus, further studies will be needed to
333 validate these approaches in ultra-endurance events.

334 Currently, one of the most relevant strategies to employ for performing in the heat is to
335 consume adequate fluids: maintaining water availability along different race courses is thus crucial
336 due to the detrimental effects of dehydration on fluid balance and the subsequent heat loss via
337 sweating. Individual sweat rates are highly dependent on athlete's morphology, the intensity level of
338 exercise and the environmental temperature and humidity. Sweat losses are accompanied by
339 electrolyte losses, mostly sodium, potentially contributing to hyponatremia if not compensated:
340 exogenous intake of sodium-enriched beverages is the most effective strategy to reduce this risk. In
341 addition to the traditional compounds found in most sport drinks (e.g. glucose, magnesium,)

342 ultramarathon beverages should contain about 0.7–1.2 g.L⁻¹ of salt when performing in the heat.
343 However, sodium-enriched beverages remain insufficient if athletes overdrink by fear of
344 dehydration during the race, placing management of water intake as a key determinant of
345 performance.

346 Heat acclimation remains a relevant strategy that may enhance ultra-endurance performance
347 in hot environments: most of the acclimation benefits occur in the first 14 days of exposure, and a
348 short-term protocol of 5 days will already induce significant early adaptations.

349

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354 **Captions**

355 **Figure 1.**

356 Individual and mean values (\pm SD) of core temperature at each stage of the Guadeloupe half-Ironman held in
357 tropical climate. T1: just before the race; T2: after the swim phase; T3: after the cycle phase; T4: at the end
358 of the run phase. Temperatures were obtained from telemetric intestinal temperature devices ingested at least
359 6 hours before the race. Modified from [33].

360

361 **Figure 2.**

362 Nomogram representing the impact of WBGT on the relation between marathon finishing times according to
363 quartiles and relative performance decrement in comparison with WBGT at 5°C. Modified from [5].

364

365 **Figure 3.**

366 Proportion of runners abandoning the Western States Endurance Run (161 km; 6000m D+) race at each
367 checkpoint along the course (A), and relationship between finish times for the 2006 (7-38°C) and 2007 (2-
368 30°C) edition (B). Modified from [6].

369

370 **Figure 4.**

371 Trial times for 5 successive blocks (4 km cycling + 1.5 km running,) with the ingestion of Neutral water
372 (orange), Cold water (blue) and Ice-slurry (green). Mean \pm SD.

373 ^a Neutral water vs. Ice-Slurry/Menthol ($P < 0.05$).

374 ^b Cold vs. Ice-Slurry/Menthol ($P < 0.05$).

375 β and \dagger denote that block performance was affected by Time Period (β : $P < 0.007$) and the Time Period x
376 Drink Temperature interaction (\dagger : $P < 0.004$), respectively.

377 Modified from [72].

378

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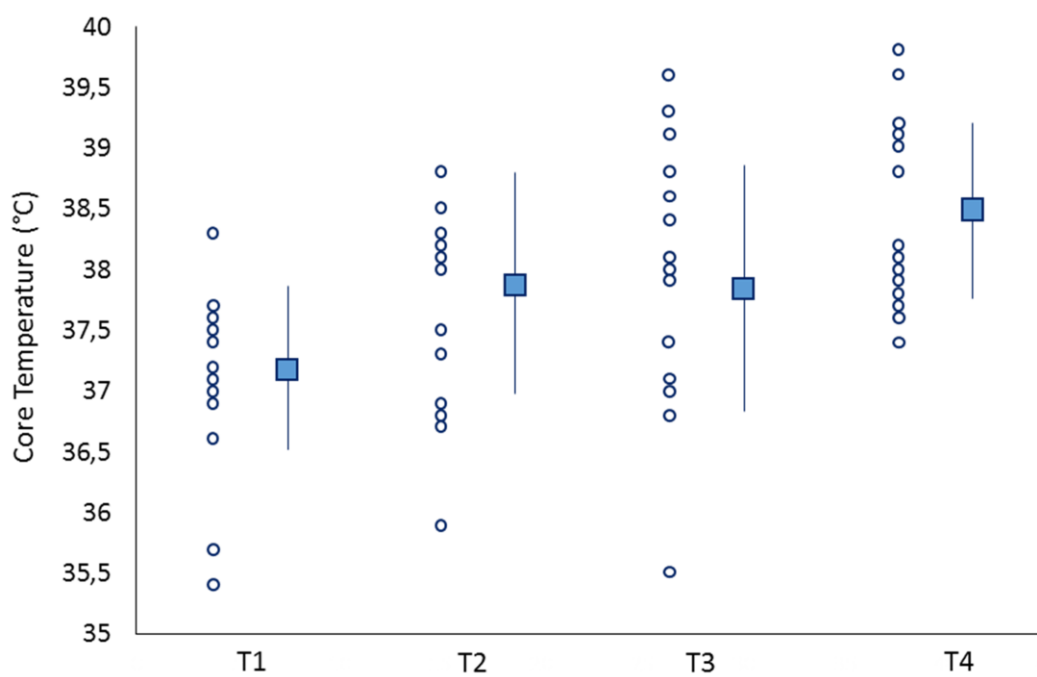


Fig. 1

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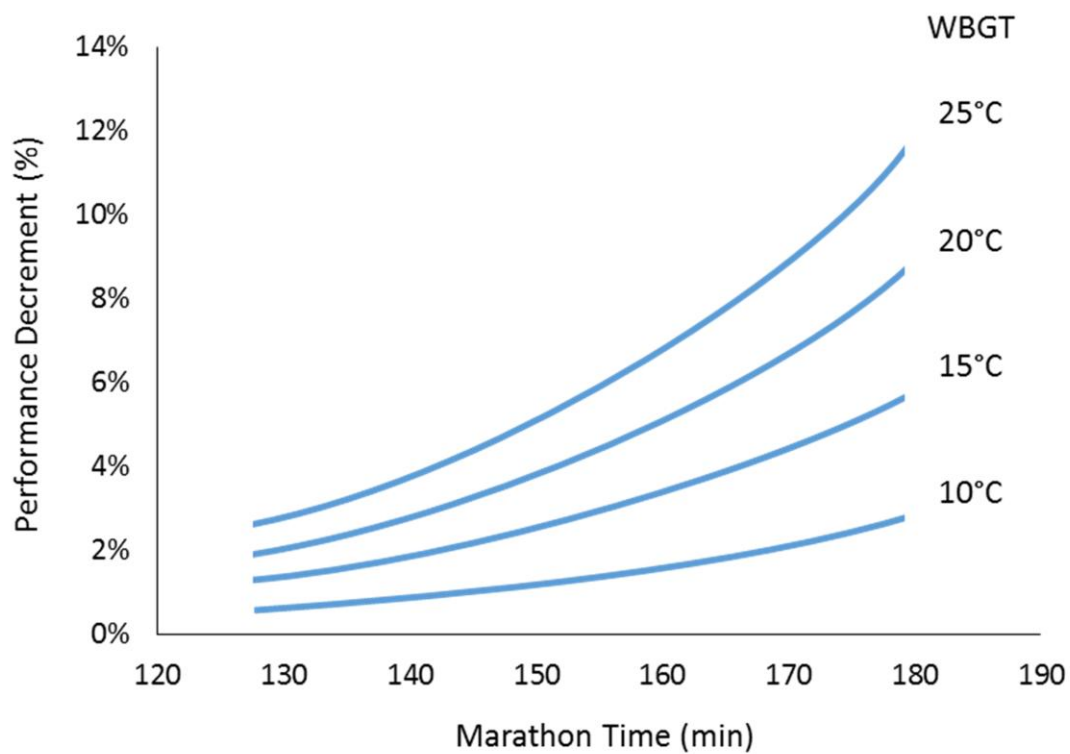


Fig. 2

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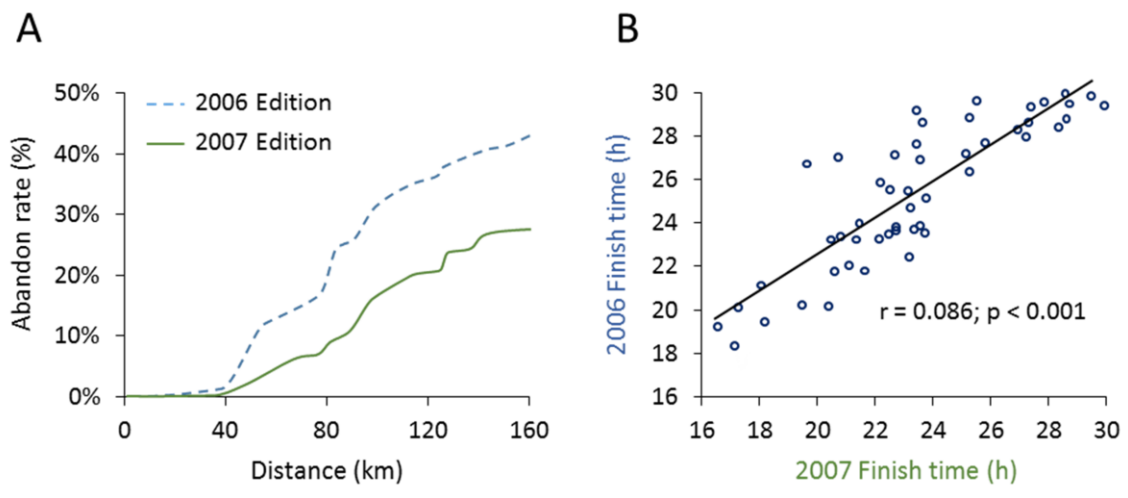


Fig. 3

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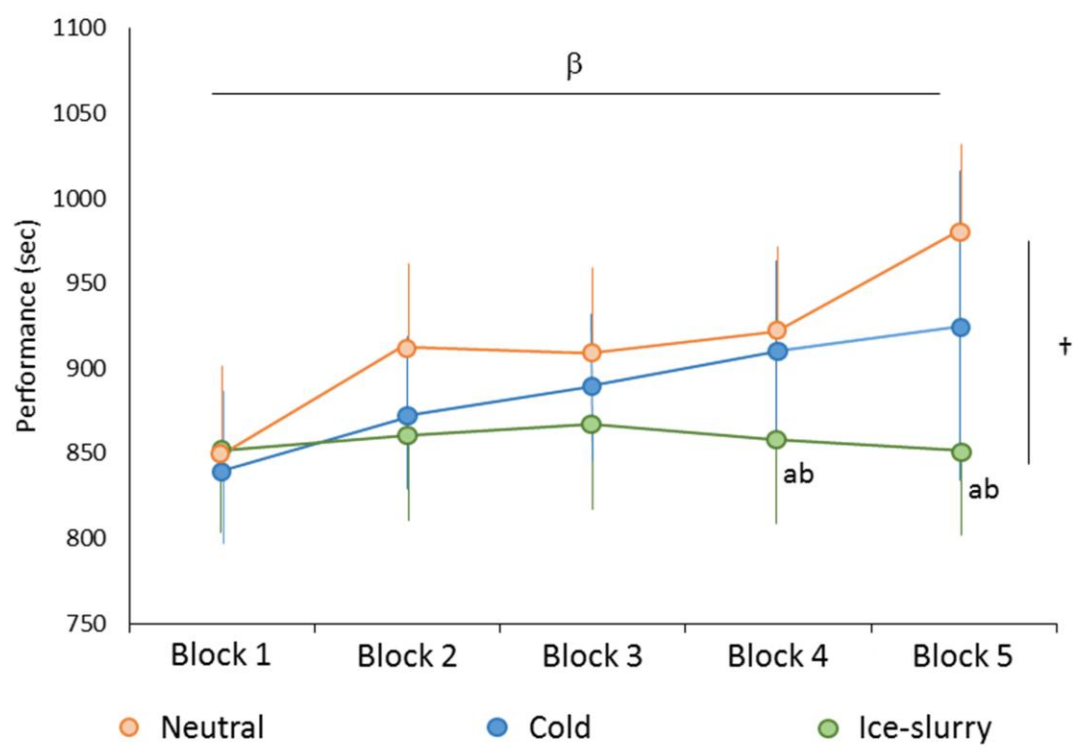


Fig. 4

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