ORIGINAL ARTICLE

Core temperature and hydration status during an Ironman triathlon

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Background: Numerous laboratory based studies have documented that aggressive hydration strategies (~1–2 litres/h) are required to minimise a rise in core temperature and minimise the deleterious effects of hyperthermia on performance. However, field data on the relations between hydration level, core body temperature, and performance are rare.

Objective: To measure core temperature (T_{core}) in triathletes during a 226 km Ironman triathlon, and to compare T_{core} with markers of hydration status after the event.

Method: Before and immediately after the 2004 Ironman Western Australia event (mean (SD) ambient temperature 23.3 (1.9) ℃ (range 19–26˚C) and 60 (14)% relative humidity (44–87%)) body mass, plasma concentrations of sodium ($[Na^+]$), potassium ($[K^+]$), and chloride ($[Cl^-]$), and urine specific gravity were measured in 10 well trained triathletes. T_{core} was measured intermittently during the event using an ingestible pill telemetry system, and heart rate was measured throughout.

Results: Mean (SD) performance time in the Ironman triathlon was 611 (49) minutes; heart rate was 143 (9) beats/min (83 (6)% of maximum) and T_{core} was 38.1 (0.3) ℃. Body mass significantly declined during the race by 2.3 (1.2) kg (−3.0 (1.5)%; $p<0.05$), whereas urine specific gravity significantly increased (1.011 (0.005) to 1.0170 (0.008) g/ml; $p<0.05$) and plasma $[Na^+]$, $[K^+]$, and $[Cl^-]$ did not change. Changes in body mass were not related to finishing T_{core} ($r = -0.16$), plasma $[Na^+]$ ($r = 0.31$), or urine specific gravity ($r = -0.37$).

Conclusion: In contrast with previous laboratory based studies examining the influence of hypohydration on performance, a body mass loss of up to 3% was found to be tolerated by well trained triathletes during an Ironman competition in warm conditions without any evidence of thermoregulatory failure.

Previous laboratory based research has been interpreted to suggest that, if athletes allow themselves to become dehydrated during exercise, they will experience reduced sweat rates and elevations in core body temperature, and thereby increase their risk of developing a life threatening heat disorder.[1–3] Consequently, the current American College of Sports Medicine (ACSM) position stand,[3] the Nutrition and Athletic Performance joint position stand,[4] and the National Athletic Trainers Association position statement on fluid replacement[5] recommend that athletes replace all fluid losses during exercise in order to increase performance and prevent hypohydration and the development of a heat illness.

The practical usefulness of these guidelines for athletes has been critically challenged of late.[6–10] Recent work examining hydration status and resulting core body temperature in outdoor environments suggests that hypohydration is not associated with increases in core body temperature to levels that would be considered excessive. Sharwood *et al*[11 12] have shown that faster Ironman triathlon performance times were associated with higher levels of hypohydration in 871 triathletes participating in the South African Ironman triathlon. No relation was shown, however, between levels of hypohydration and post-race rectal temperature.[11] This study by Sharwood *et al*[11] challenges these fluid replacement guidelines[3–5] by documenting that (*a*) dehydration does not necessarily lead to detriments in exercise performance and (*b*) subtle dehydration does not cause increases in rectal temperature during an Ironman triathlon conducted in moderate ambient conditions. One limitation of this study, however, was that rectal temperature was measured after athletes finished the race.[11] It is possible therefore that core body temperature may have been elevated during this event (ambient conditions ~20.5℃ and 55% relative humidity) and that the low core body temperatures reported in this study may have simply been the result of a cooler environmental temperature present when the final rectal temperature was measured, in addition to the cessation of the metabolic heat load once the athletes had stopped.[11 12] Thus it is at present not known whether the dehydration that commonly occurs during an Ironman triathlon[13] is associated with rises in core body temperature during the event.

The purpose of this study therefore was to measure core temperature in triathletes during a 226 km Ironman triathlon using an ingestible pill telemetry system[14] and to compare these measures with various indices of hydration status after the event.[15] We hypothesised that the progressive dehydration commonly experienced by triathletes performing the Ironman triathlon would be associated with rises in core body temperature. The alternative hypothesis, however, was that subjects would thermoregulate adequately and that no relation would be found between finishing hydration status and core body temperature.

MATERIALS AND METHODS

Subjects

Ten well trained male Ironman triathletes (mean (SD) age 34.7 (4.8) years, height 181.6 (5.8) cm, mass 77.7 (5.4) kg, sum of seven skinfolds 48.5 (10.5) mm, maximum oxygen uptake 66 (6) ml/kg/min)) from the Perth region, volunteered to participate in this study four to six weeks before the Ironman Western Australia triathlon that took place in Busselton, Western Australia, on 28 November 2004. Inclusion criteria for the study were a cycling maximum oxygen uptake greater than 60 ml/kg/min and having completed a minimum of one previous Ironman distance triathlon in less than 10 hours and 30 minutes. Before

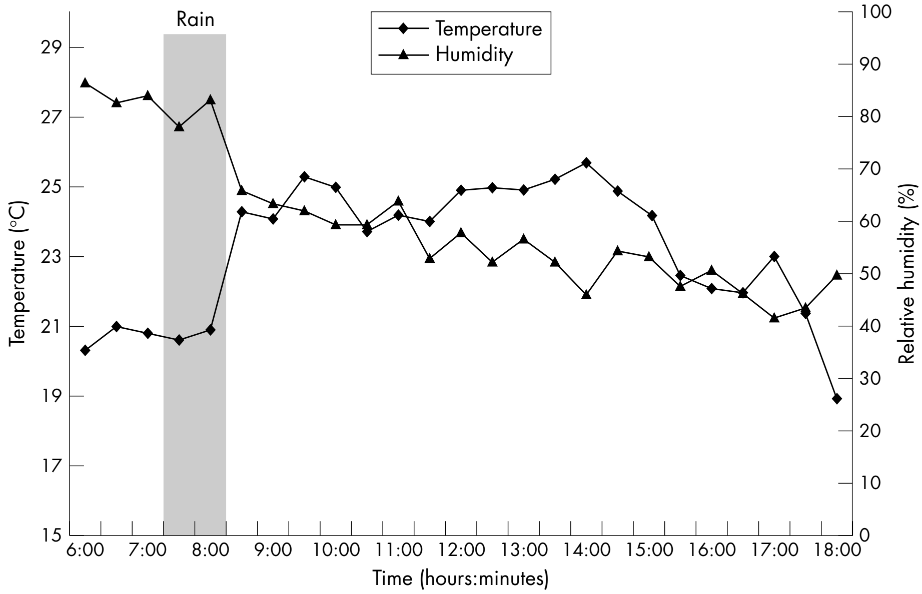

Figure 1 Ambient conditions recorded during the 2004 Ironman Western Australia event.

testing, all risks and benefits of the study were explained, and written informed consent was obtained in accordance with the human research ethics committees of the University of Western Australia and Edith Cowan University.

Preliminary testing

Two days before the 2004 Ironman Western Australia event (at midday), subjects reported two hours after eating a meal for assessment of body mass, height, body composition, and concentrations of plasma sodium ($[Na^+]$), potassium ($[K^+]$), and chloride ($[Cl^-]$). Blood samples were taken after the subject had lain supine for 10 minutes. Body mass was measured to the nearest 0.1 kg with subjects standing on a calibrated scale (Avery Berkel, Taichung City, Taiwan; 0–150 kg; $\pm$0.02 kg) wearing only their cycling shorts. Height was measured using a portable stadiometer as outlined by Norton and Marfell-Jones.[16] Skinfold measurements were completed by a level 2 International Society for the Advancement of Kinanthropometry (ISAK) accredited anthropometrist across seven sites (triceps, subscapular, biceps, supraspinale, abdominal, mid thigh, and calf) as described by Norton and Marfell-Jones[16] using calibrated Harpenden skinfold callipers (British Indicators, St Albans, Hertfordshire, UK). Blood samples were taken from a single prick of the subject's fingertip (Unistik 2 Extra; Owen Mumford Ltd, Oxford, UK), which had been cleaned with an alcohol swab, and collected in a 125 µl electrolyte balanced heparinised capillary tube (Clinitubes; Reflotron, Copenhagen, Denmark) and analysed using a 6+ i-STAT cartridge inserted into an i-STAT blood gas analyser (i-STAT Corporation, East Windsor, New Jersey, USA) for $[Na^+]$, $[K^+]$, and $[Cl^-]$. At this point in time, subjects were provided with a core temperature pill (CorTemp; HQInc, Palmetto, Florida, USA[14]), a urine cup, and a heart rate monitor (S810i; Polar Electro Oy, Kempele, Finland). Subjects were then asked to complete three tasks immediately on waking on race morning: (*a*) collect a mid-stream urine sample; (*b*) swallow the core temperature pill; (*c*) report to the laboratory to provide a blood sample, a core temperature measurement, a body mass measurement, and to deliver their urine sample. Urine specific gravity was determined using a calibrated urinary refractometer (Atago hand refractometer, model UNC-NE; Atago, Tokyo, Japan).[15]

Although it is generally recommended that subjects swallow the CorTemp pill the night before testing to ensure that the pill passes the pyloric sphincter,[14] previous experience with the CorTemp pill telemetry system showed that ~20% of well trained athletes pass the pill in a bowel movement the morning after (unpublished observations). To avoid this occurring, subjects ingested the CorTemp pill on waking on race morning about three hours before the race start. Eight of the ten subjects completed the measurements between two hours and 30 minutes before the race start. Two subjects did not report for measurements before the race. These subjects placed their urine sample in a standard refrigerator, and urine specific gravity was measured in these samples when the subjects presented for their assessment 12 hours after the race.

Event testing

The 2004 Ironman Western Australia event consisted of a 3.8 km swim, followed by a 180 km cycle, and completed with a 42.2 km marathon run. The swim course consisted of a single 3.8 km lap, the cycle phase consisted of three flat (elevation change ~10 m) 60 km laps, and the marathon run also consisted of three flat (elevation change ~5 m) 14 km laps. As a result of this multiple lap course, core temperature measurements were obtained using the CorTemp Ambulatory Data Recorder (product number HT150001) at even time increments throughout the race. Core temperature was measured immediately after the swim phase in the transition tent while subjects were changing into their cycling attire, at the 80 and 140 km sections of the cycle phase (where competitors slowed to complete a 180° turnaround), in the bike to run transition tent while subjects were changing into their running attire, at 14, 28, and 42 km of the marathon run phase, and at ~30 minutes and 12 (2) hours after the race. As one subject forgot to swallow his CorTemp pill, core temperature measurements were available intermittently in nine of the 10 subjects throughout the event. Core temperature readings below 36℃ and above 43℃ were considered to be equipment errors and were excluded from analysis. This left valid core temperature readings in five subjects after the swim phase, four subjects at 80 km of the bike phase, five subjects at 140 km of the bike phase, nine subjects in the bike to run transition, eight subjects at 14 km of the run phase, seven subjects at 28 km of the run phase, nine subjects at the finish, five subjects 30 minutes after the race, and four subjects 12 hours after the race. This equated to 55 of a possible 72 valid data points (76%) during the event. Reasons for the difficulties encountered with the telemetry readings during the event include possible external radio wave interference and human error in measurement encountered while running beside the bicycles. Indeed, each CorTemp pill is individually calibrated by the manufacturer, and they claim less than 0.05% pill fallout.

Blood samples were taken within five minutes of the athletes finishing the race, with the subject lying supine in the medical tent. Body mass was measured within 10 minutes of the athletes finishing the race to the nearest 0.1 kg using the same calibrated scale as before the race with subjects wearing only their running shorts or swimsuit bottoms. Heart rate was recorded throughout the triathlon at 5 second increments using S810i Polar heart rate monitors. One subject opted not to wear a heart rate monitor, and three heart rate monitors malfunctioned for various reasons, leaving six complete sets of heart rate data. Ambient temperature and relative humidity were recorded every 30 minutes during the event using a portable digital weather tracker (Kestrel 4000; Nielsen-Kellerman, McKellar, ACT, Australia). Performance times for the swim, cycle, and run phase for all triathletes were retrieved from the race timing system posted online after the event (http://www.ironman-wa.com). Athletes were permitted to eat and drink ad libitum during the race, and no guidance was provided to subjects as to what quantities or types of fluids and fuels should be consumed. The post-race samples were taken at midday on the day after the event using the same protocols as the pre-race measurements.

Statistical analysis

Changes in measured variables over time were assessed using either Student's *t* test or one way analysis of variance for repeated measures, with multiple comparisons made using Tukey's post hoc tests. Pearson's product moment was used to establish relations between variables. Statistical analysis was completed with SPSS 10.0 for Windows, and the α level was set at 0.05. Results are expressed as mean (SD).

RESULTS

Ambient conditions during the event were 23.3 (1.9)℃ (range 19–26) and 60 (14)% relative humidity (44–87%) (fig 1); ocean temperature was 19.5℃. Performance times for the swim, cycle, and run phases were 58 (5), 314 (10), and 239 (37) minutes respectively, equating to a total time of 611 (49) minutes. This represents a relatively elite completion time, with seven of the 10 subjects finishing in less than 10 hours. Heart rate throughout the event averaged 143 (9) beats/min (83 (6)% of maximum), and the core temperature averaged 38.1 (0.3)℃ (fig 2).

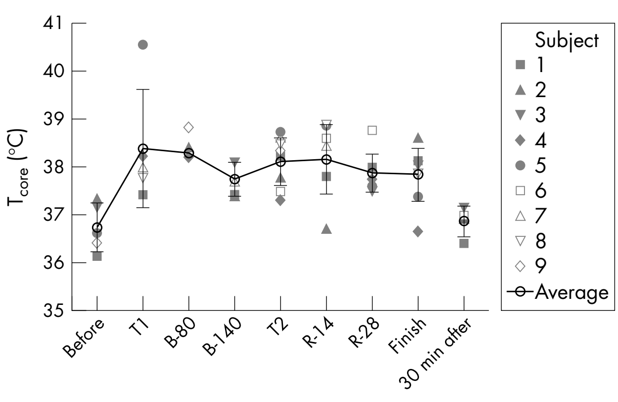

Figure 2 Core temperature (T_{core}) measured during the Ironman Western Australia triathlon. T1, Swim to bike transition; B-80, B-140, 80 and 140 km of cycle phase; T2, bike to run transition; R-14, R-28, 14 and 28 km of run phase.

Table 1 shows measures of hydration status including body mass, plasma [Na^+], [K^+] and [Cl^-], as well as urine specific gravity. Body mass significantly increased from that measured in the two day preliminary testing period to the value immediately before the race (0.8 kg, $p<0.05$), and then significantly decreased during the event by 2.3 (1.2) kg (−3.0 (1.5)%). It had returned to the two day preliminary testing levels within 12 hours of recovery (table 1). Plasma [Na^+] remained stable from two days before the race to before and after the race, but rose significantly during the following 12 hours. [K^+] two days before the race was significantly higher than immediately before the race, but no change was observed during the race. The concentration 12 hours after the race had declined significantly from that immediately after the race (table 1). [Cl^-] did not change significantly throughout the event (table 1). Urine specific gravity had increased significantly after the race compared with immediately before (table 1), but did not indicate that subjects were hypohydrated.[15]

Correlations

Changes in body mass were not related to finishing core temperature ($r = -0.16$; n = 9), plasma [Na^+] ($r = 0.31$; n = 10), or urine specific gravity ($r = -0.37$; n = 10). Total finishing time was not significantly related to changes in body mass ($r = -0.32$; n = 10), finishing core temperature ($r = 0.18$; n = 9), plasma [Na^+] ($r = 0.01$; n = 10), or urine specific gravity ($r = 0.59$; n = 10). Heart rate was not significantly related to core temperature ($r = 0.35$; n = 6) during the event. After the swim phase, faster swim finishers tended to have a higher core temperature ($r = -0.72$; n = 5), but this relation was not significant ($p = 0.08$), probably because of the small sample size.

DISCUSSION

Although core temperature has been reported during field marathon running[17 18] and after an Ironman triathlon,[11] this is, to our knowledge, the first study to report the core temperature response during an Ironman triathlon in the field. The important finding of this study is that, despite an average loss of body mass of 2.3 (1.2) kg (~3%), core body temperature in these well trained triathletes averaged only ~1℃ above normal resting core body temperature (~38.1 (0.3)℃; fig 2). This modest increase in core body temperature occurred despite subjects performing at a moderately high exercise intensity (~83 (6)% of maximum heart rate) for about 10 hours in conditions of 23.3 (1.9)℃ and 60 (14)% relative humidity (fig 1). Thus our alternative hypothesis was confirmed, as subjects were able to adequately thermoregulate during their event. From these data then, we could find no evidence to suggest that a 3% reduction in body mass during an Ironman competition in moderate ambient conditions causes athletes to reach core body temperatures that would lead to heat stroke, as is currently implied by the ACSM hydration guidelines[3] and that of others.[4 5]

Noakes[8] has recently commented that the ACSM guidelines on fluid replacement[3] have been made based on laboratory studies in which exercise was performed in conditions not representative of field based levels of convective cooling.[19–21] Saunders *et al*[10] have now clearly shown that higher wind velocities reflective of those encountered in the field result in significantly lower rectal temperatures and a longer exercise time to exhaustion. In

Table 1 Body mass, plasma sodium (Na^+), potassium (K^+), and chloride (Cl^-) concentrations, and urine specific gravity measured two days before the race, immediately before the race, after the race, and 12 hours after the race

	2 days before	Before	After	12 h after
Body mass (kg)	77.7 (5.4)	78.5 (5.5)*	76.2 (5.5)†	77.3 (5.9)
[Na^+] (mmol/l)	139.0 (0.7)	137.6 (2.0)	137.0 (3.6)	139.6 (1.1)‡
[K^+] (mmol/l)	4.2 (0.2)	4.9 (0.6)*	4.6 (0.6)	4.0 (0.3)‡
[Cl^-] (mmol/l)	106.3 (1.4)	107.5 (2.0)	106.1 (3.8)	106.1 (1.2)
Urine specific gravity (g/ml)	–	1.011 (0.005)	1.017 (0.008)†	–

Values are mean (SD).
*$p<0.05$ compared with 2 days before the race.
†$p<0.05$ compared with immediately before the race.
‡$p<0.05$ compared with after the race.

particular, higher levels of fluid replacement (80% *v* 60% replacement of sweat loss) had no effect on rectal temperature or exercise performance under these high wind conditions.[10] Indeed, the current ACSM position stand states that replacement of fluids by thirst alone is not sufficient and that athletes will become dehydrated if they do not consume fluids at rates of 600–1200 ml per hour;[3] failure to follow these guidelines will lead to dehydration, a reduction in sweat rate, hyperthermia, and ensuing heat illness.[3] However, as a result of greater convective cooling and more moderate environmental conditions in many endurance competitions, such as the Busselton Ironman triathlon, such a drinking strategy may be superfluous, and may actually hinder performance by adding extra body mass and by potentially creating a state of hyponatraemia.[22]

Sawka and Coyle[1] define dehydration as the dynamic process of body water loss (p 168). Moreover, determination of hydration status is commonly determined by measuring the change in body weight after exercise (table 1). Although we typically perceive the word dehydration to mean loss of body water from the extracellular/cardiovascular fluid compartment, this is not the major region of fluid loss during exercise. Prolonged exercise will always result in water release from the liver and skeletal muscle cells during the process of glycogen oxidation,[1] as 2–3 g of water are stored with every gram of glycogen,[23] and a small amount of weight is also lost when stored triglycerides and glycogen are oxidised.[24] Thus coaches, athletes, and sport scientists need to be aware that loss of body mass during exercise does not necessarily imply dehydration from the cardiovascular fluid compartment, as is commonly inferred. Indeed, despite subjects in this study losing 2.3 kg (~3%) during the Busselton Ironman event, plasma [Na^+] and urine specific gravity measures were within normal ranges (table 1); these data support a normal and hydrated extracellular fluid composition.[15] In this sense, ''carbo-loading'' and its associated muscle glycogen storage may be viewed as a beneficial water storage compartment for the endurance athlete.[24] Data from the present study support such a water storage hypothesis, as body mass measured immediately before the race was significantly higher than two days before the race (table 1). As a result, the 3% reduction in body mass found in this study (table 1) is not likely to have caused significant extracellular hypohydration. Consequently, a component of the 3% body mass loss recorded here is likely to have occurred from loss of intracellular body water during the oxidation of stored glycogen and triglyceride.[23 24] Indeed, Pastene *et al*[24] have pointed out that, if an athlete loses 2 kg body mass during a marathon race, he may only be dehydrated by about 200 ml.[24] Our data support the belief of Noakes[8] that some losses in body mass during endurance events such as an Ironman triathlon are permissible. In effect, if the body mass measured two days before the race is used as the baseline measure (table 1), thereby removing the effect of extra body mass added as a result of an acute carbo-loading protocol, body mass in this study is only reduced during the race by 1.5 kg (1.9%). Thus, if pre-race glycogen storage is complete, a body mass loss of ~2 kg after an exercise bout of sufficient intensity or duration to deplete muscle glycogen stores should be discounted when calculating dehydration based on changes in body mass.

Pertaining to the relation between hypohydration and core temperature, the main reason for the disparity in findings between the classic laboratory studies[19–21] used to evaluate this relation[3] and the newly emerging findings from field studies in this area[11] is that the laboratory studies were completed in a climate chamber with abnormally low air velocities, limiting heat dissipation compared with actual field conditions where air velocity is greater.[19–21] Consequently, higher volumes of cold fluid replacement were shown to significantly lower core body temperature.[19–21] It is becoming increasingly clear that dehydration, as it is currently implied,[1 2] does not cause elevations in core temperature.[11] The most influential factor affecting the rise in core temperature is exercise intensity and/or the inability to dissipate metabolic heat.[6 25] Although the relation between core temperature and exercise intensity (% of heart rate maximum) in the present study was not significant ($r = 0.35$), this analysis is confounded by the fact that very few times during the course of an Ironman event would athletes experience high exercise intensities, with most of the race being performed at a moderate exercise intensity.[26 27] Moreover, the variance in ambient conditions (fig 1) during this moderate intensity event would add further noise to this analysis.[10] Indeed, the only time during the race that core temperature was found to be at a critical level was in the fastest swimmer (8th overall), who finished the swim phase in ~49 minutes with a core temperature reading of 40.5℃ (subject 5, fig 2). Thus there tended to be a trend between swim finish time and core temperature ($r = -0.72$; $p = 0.08$; $n = 5$), suggesting that core temperature is regulated primarily by metabolic rate,[6 25] and not by levels of body water, as this high core temperature reading was recorded at the beginning of the race when body water levels should have been at their highest. The high exercise intensity (103% of cycle heart rate maximum) in this subject during the swim, coupled with likely reductions in heat dissipation caused by the athlete's 3 mm thick wetsuit and relatively warm water conditions (19.5℃), are the most likely contributors to the high core temperature reading.[28] However, after this subject's high intensity swim performance, his exercise intensity fell to 90 (4)% of his cycle heart rate maximum for the remainder of the race, and core temperature paralleled this decline to 38.4 (0.7)℃ (subject 5, fig 2). During the triathlon, this subject

What is already known on this topic

- Numerous laboratory based studies and group position stands have been interpreted to suggest that aggressive hydration strategies (~1–2 litres/h) are required during exercise to minimise the rise in core body temperature and associated deleterious effects on exercise performance
- However, field data on the relations between hydration level, core body temperature, and performance are rare

What this study adds

- This study shows that, despite a decrease in body mass of 3% during an Ironman triathlon, subjects were in effect ''euhydrated'', as they had urine specific gravity and plasma [Na^+] measures within normal ranges
- Moreover, core body temperature during exercise was reported to be only ~1°C above normal, and no link was found between body mass loss and the development of hyperthermia in the field

lost 3.75 kg (4.6%) and had a negligible change in urine specific gravity (1.006 to 1.007 g/ml) and only a minor rise in plasma [Na^+] (141 to 144 mmol/l). Thus core temperature actually fell in this subject as he lost body mass (fig 2), which is the opposite prediction to that made by most fluid replacement position stands.[3–5] As a result of these findings, previous statements on hydration, such as ''People need to attempt to drink as much as possible during exercise'' (p 193 of Sawka and Coyle[1]) and ''a deficit of only 1% body weight elevates core temperature during exercise'' (p 194 of Sawka and Coyle[1]) are not necessarily correct in the context of an Ironman triathlon. Consequently, research re-evaluating the effect of such aggressive rehydration strategies under a variety of ambient conditions, particularly using air velocities similar to those experienced in the field,[10] is warranted.

One limitation to the present study that should be mentioned is that, whereas core temperature was measured intermittently throughout the event, hydration status was only assessed after the event. Thus, although we might assume that dehydration would follow a declining linear trend, it is impossible for us to know what hydration level triathletes experienced at the various core temperature data collection points during the race. Nevertheless, we can be certain that core temperature was not near hyperthermic levels after the Ironman race despite the occurrence of a ~3% reduction in body mass. Moreover, the data from this study do not support or refute the fact that performance would have been increased or decreased had these triathletes consumed more or less fluids during their event. However, it should be noted that seven of these 10 subjects finished with personal best times in under 10 hours (top 5% overall), and no relation was found between overall finish time and hydration level or core temperature. Finally, we acknowledge that the small sample size and/or valid data points (55 of 72; 76%) obtained from this study limits the use of a regression analysis for examining relations between our primary measured variables. Future studies to examine the relation between core temperature and hydration status should also attempt to document the food and fluid consumption of the subjects during the event and also attempt to examine the interaction between these variables in less well trained subjects.

In conclusion, although body mass declined during the course of a 10 hour Ironman triathlon by 2.4 (1.2) kg (3%), subjects competed with a core temperature only ~1°C above normal and presented with urine specific gravity and plasma [Na^+] within normal ranges after the event. Thus, in accordance with recent findings,[11] we report that a mild hypohydration (in terms of body mass loss) was observed in some of the top performing triathletes in an Ironman triathlon, and that no link was found between body mass loss and core temperature or the development of hyperthermia in the field. Thus our study refutes the common belief that loss of body mass is a critical determinant of core body temperature during exercise. Consequently, and in light of the evidence emerging in this field,[10–12] it would seem prudent that the ACSM[3] and others[4 5] review and adjust their current fluid replacement guidelines so as to be aligned with more contemporary wisdom in this area.[9]

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COMMENTARY

This paper represents a valid and justified challenge to the traditional hydration guidelines and understanding of thermodynamics during endurance exercise. Its validity lies in the collection of real time data, outside of the laboratory, and in a real ultraendurance event. Moreover, this is the first study of its kind to accurately assess thermodynamics during an endurance event. The results further support the suggestion that the current hydration guidelines may lack practical relevance to field events and are perhaps in need of revision.

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COMMENTARY

Increasingly over the past 20 years, the concept has arisen that the most important determinant of the rectal temperature response to prolonged exercise is the degree of dehydration that develops during exercise. This stems from the promotion during the same period of the cardiovascular model of thermal regulation during exercise. The core teaching of this model is that cardiac output is the key determinant of heat loss during exercise; thus any factor that impairs cardiac function during exercise will impair heat loss and promote the risk that heatstroke will develop during exercise. As dehydration supposedly impairs cardiac filling, this model necessarily predicts that dehydration is the major cause of heatstroke risk during exercise and thus must be prevented at all costs by drinking "as much fluid as tolerable". But this model conveniently ignores a number of established physiological truths, not least the following: that in out of water exercise, sweating is the major mechanism for heat loss during exercise (when convective heat losses are not high); that the control of sweating is independent of cardiovascular function but is directly regulated by the temperature elevation during exercise; that the sweat rate is unaffected by dehydration levels of at least 5–8%; that the rate of heat production during exercise is the real determinant of the extent to which the body temperature rises during exercise; and finally that the rate of heat production is regulated by the brain in an anticipatory manner specifically to ensure that a catastrophic elevation of body temperature is (usually) prevented during exercise. As the cardiovascular model of thermal regulation is industry favourable because it promotes the sales of sports drinks for the prevention of heat illness during exercise, it has flourished despite its roots in fantasy rather than in physiological fact. This paper shows that subjects competing at high level in the 224 km Ironman triathlon regulate their body temperatures at 1℃ above the resting value for more than 10 hours of demanding exercise despite body mass losses in excess of 3%. This confirms that the body regulates its thermal response during prolonged exercise within a very safe range, independent of the extent of weight lost. It is compatible with our finding, also reported in this journal,[1] that even weight losses of 10% or more are not associated with significant elevations in core body temperature in Ironman triathletes. It appears that Ironman triathletes can be assured that their brains will take care of their bodies during exercise and that there is no need to follow industry favourable guidelines to drink to excess to ensure their safety.

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REFERENCES

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