



Fluid balance and thermoregulatory responses of competitive triathletes

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ABSTRACT

As little as 2% total body mass (BM) loss from sweat has been shown to compromise physiological functioning during prolonged exercise in the heat, subsequently compromising endurance performance. Purpose: This observational study aims to describe the fluid balance and thermoregulatory responses of competitive triathletes racing at a major international competition in a cool environment. Methods: Fluid balance and thermoregulatory responses was measured in six (3 male, 3 female) national-level triathletes competing at the ITU World Triathlon Grand Finale in ambient temperatures of 19–20 °C (relative humidity (RH) ~55%). Dry, nude BM was recorded before and immediately following the race. Fluid intake was monitored throughout the race. Pre-race urine samples were measured for specific gravity (USG). Each athlete ingested a core temperature (T_c) pill 5 h prior to the event and was monitored before and after the race. Results: Three of six triathletes arrived at the race mildly dehydrated (USG 1.021, 1.024, 1.030). One of these athletes (1F) subsequently withdrew from the race providing no further data. Another athlete (1M) ended the race vomiting providing invalid hydration data. The four remaining competitors' sweat loss was on average 2.15 L (range: 1.65–2.80 L), while fluid intake was 0.66 L (0.50–0.85 L). A mean loss of 3.3% (2.2–4.5%) BM was recorded. T_c increased by 2.0 °C (1.1–2.9 °C) and 4/5 athletes' (2M, 2F) T_c exceeded 39 °C by race-end. Both female athletes self-reported feelings of heat-related exhaustion at the completion of the race. Conclusions: Despite cool environmental conditions, elite triathletes lost ~3.3% BM, replacing only 33% of sweat losses, and achieved a T_c > 39 °C by race-end.

1. Introduction

Triathlon is a three-event sport where athletes compete sequentially in swimming, cycling, and running, with participation by millions of amateur and elite athletes in thousands of events worldwide. The International Triathlon Union (ITU) annual series encompasses eight rounds of competitions culminating in the World Triathlon Grand Finale race. Success in triathlon is multi-factorial ranging from general aerobic characteristics such as, aerobic capacity, movement economy, and fractional utilization of maximal capacity (O'Toole and Douglas, 1995). Performance is also unique to the sport specific demands of the swim, bike, and run, along with technical and tactical approaches to a race situation with research demonstrating that performance during the run largely dictates overall Olympic distance (OD) triathlon performance (Ofoghi et al., 2015). As well, environmental demands (i.e. temperature, humidity, wind) influence thermal load and perception effecting triathlon success. Research is consistent in demonstrating significant aerobic performance detriments with mild progressive dehydration ($\geq 2\%$) combined with high T_c (≥ 39 °C) during lab-based exercise in warm and hot ambient conditions (Sawka et al., 2007; Logan-Sprenger et al., 2015; Maughan and Meyer, 2013). The research

is limited however, when evaluating the impact of mild dehydration and rises in core temperature on performance of elite endurance athletes during (in-field) competition in cool-environments. The combined effect of various modes of exercise (i.e. swim, bike, and run) where access to fluid is limited, coupled with the intense nature of triathlon provoking high sweat rates, may create situational factors that promote progressive dehydration and thermal strain. Moreover, due to the swim leg and the dynamic nature of the run, the opportunity to consume adequate fluid may be limited in elite OD triathletes. The purpose of this case study is to describe the fluid balance and thermoregulatory responses of Junior, Under-23, and Elite triathletes during the ITU Grand Finale race in cool (~19–20 °C) conditions.

2. Methods

2.1. Subjects

Six (n = 6) elite triathletes volunteered to participate in this study (22 y (19–26 y), 175 cm (163.9–185.7 cm), 67.8 kg (56.4–77.2 kg); mean (range)) while competing in the ITU Grand Finale. 3 of 6 athletes (n = 3) competed in the Under-23 Women's category with race

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distances of 1500 m swim, 43.2 km bike, and 10 km run. one male ($n = 1$) competed in the Elite Men category and one male ($n = 1$) in the U-23 Men's category with the same race distances as the U23 women. One male ($n = 1$) competed in the Junior Men category with race distances of 750 m swim, 20.4 km bike, and 5 km run. All athletes were informed of the experimental protocol, both orally and in writing, before written informed consent was obtained. The study was approved by the Research Ethics Board at the Canadian Sport Institute Ontario (Toronto, Ont., Canada).

2.2. Measurements

Athletes arrived at the race location at their usual pre-race time. Participants were asked to defecate if necessary, provide a mid-stream urine sample for pre-race urine specific gravity (USG) using a handheld pocket refractometer (Model PAL-10S, ATAGO USA Inc., Bellevue, WA), and then completely empty their bladder. Dry, nude body mass (BM) was measured ~60 min before the race on a portable digital scale accurate to ± 0.1 kg. Participants were instructed to swallow a calibrated ingestible thermistor (HQ Inc., Palmetto, FL) 5 h before the race to ensure progression past the stomach, and therefore not influenced by subsequent fluid ingestion. Ambient temperature ($^{\circ}\text{C}$) and relative humidity (%) were measured using a digital thermometer at the start and finish of the race. After the pre-race BM measurement any urine passed during the race was accounted as fluid loss from micturation. All fluid intake was carefully monitored. Each athlete's water bottle was weighed prior to and following the race to determine mass. Athletes were instructed to drink as they normally would during a race. Dry, nude BM was measured at the end of the race with an empty bladder to account for sweat loss.

2.3. Statistical analysis

All data were tested for normality of distribution and presented as the means \pm SD. Correlations between variables were assessed using a Pearson's correlation analysis.

3. Results

3.1. Ambient conditions

The mean pre- and post-race temperature and relative humidity for all races was 19.3 ± 0.2 $^{\circ}\text{C}$ and $55 \pm 1\%$.

3.2. Pre-race USG

On average athletes arrived at the race in a hydrated state (USG 1.019 ± 0.004 , Table 1). Three athletes (1F, 2M) arrived at the race dehydrated (USG 1.030, 1.024, 1.021). The female athlete who arrived dehydrated subsequently withdrew from the race providing no further data. The U23 male athlete vomited multiple times at the end of the race providing invalid hydration data which has been excluded from the results section.

Table 1

Ambient conditions, hydration and core temperature responses of elite triathletes during the ITU Grand Finale.

	Age (y)	Temp ($^{\circ}\text{C}$)	RH (%)	USG	Pre-BM (kg)	Post-BM (kg)	FI (L)	SL (L)	BML (%)	Tc Pre ($^{\circ}\text{C}$)	Tc Post ($^{\circ}\text{C}$)	Tc Rise ($^{\circ}\text{C}$)
Jr Men	19	19.6	54	1.019	73.6	72.8	0.9	1.7	2.2	37.9	39.0	1.1
U23 Men	23	19	54	1.024	72.4	–	–	–	–	36.4	38.8	2.4
Elite Men	26	20	58	1.021	77.2	75.5	0.5	2.2	2.9	36.5	39.4	2.9
U23 F	22	19	55	1.030	65.0	DNF	–	–	–	37.9	–	–
	21	19	55	1.003	56.4	55.1	0.6	1.9	3.4	37.8	39.7	1.9
	22	19	55	1.003	62.1	60.0	0.7	2.8	4.5	37.5	39.2	1.7

Abbreviations: Temp, ambient temperature; Relative humidity (RH); BM, body mass; FI, fluid intake; SL, sweat loss; BML, body mass loss; Tc, core temperature; U23 F, Under 23 female race category. Total Thermal Strain, area under the curve calculated using core temperature change and race time.

3.3. Sweat loss, fluid intake, and BM loss

Mean total sweat loss during the race was 2.2 ± 0.3 L ($n = 4$; 1.7–2.8 L). Athletes consumed on average 0.7 ± 0.1 L of fluid throughout their respective race (0.6–0.9 L, Table 1). Mean sweat rate was 1.3 L/h (0.9–1.7 L/h). Water was the only fluid consumed throughout the race for all athletes. No athlete urinated throughout the race. Athletes voluntarily replaced $\sim 33 \pm 7\%$ of sweat losses during the race. Athletes lost on average $3.3 \pm 0.5\%$ (2.2–4.5%) BM.

3.4. Core temperature responses

Mean pre-race Tc was 37.3 ± 0.3 $^{\circ}\text{C}$ (36.4–37.9 $^{\circ}\text{C}$). The mean rise in Tc over the race was 2.0 $^{\circ}\text{C}$ (1.1–2.9 $^{\circ}\text{C}$). All three male athletes had a greater rise in Tc for a shorter race time (Jr Male 1.1 $^{\circ}\text{C}$, 00:59; U23 Male 2.4 $^{\circ}\text{C}$, 1:55; Elite Male 2.9 $^{\circ}\text{C}$, 1:51 h: min) compared to the female athletes (1.9 $^{\circ}\text{C}$, 2:07 and 1.7 $^{\circ}\text{C}$, 2:12 h: min). Four of five athletes (2M, 2F) ended the race with a Tc that exceeded 39 $^{\circ}\text{C}$ by race-end (Table 1). Both female athletes self-reported feelings of heat-related exhaustion (nausea, dizziness, feeling very hot, and fatigue) at the completion of the race. No athlete used the water station on the run course for hydration or cooling purposes.

3.5. Performance

All athletes maintained a margin of $\sim 1.6\%$ (0.0–4.1%) and 0.98% (–0.05–2.5%) off the race winner's time in their respective events during the swim and cycle components of the triathlon respectively (Table 2). There was greater variance between athletes in their run split from the race winner's run time (1.9–17.5%).

4. Discussion

This case study describes the hydration habits and Tc responses of elite triathletes during the ITU World Triathlon Grand Finale in a cool environment (19–21 $^{\circ}\text{C}$). The results found that (i) 2 of 5 athletes arrived dehydrated for the race, (ii) average sweat rate was high at 1.3 L per hour of racing, (iii) the fluid that athletes voluntarily replaced $\sim 33\%$ of sweat losses, (iv) average BM loss was 3.3%, (v) 4 of 5 athletes reached a Tc > 39.2 $^{\circ}\text{C}$ by the end of the race.

4.1. Pre-race hydration status

Based on a pre-race hydration assessment, 40% of the athletes arrived dehydrated to the ITU Grand Finale. The impact of the level of pre-race dehydration on performance is unknown, however, research has demonstrated that when an athlete arrives to exercise in a mildly dehydrated state ($\sim 1\%$ BM loss) cardiovascular (i.e. heart rate), metabolic (i.e. carbohydrate oxidation) and cognitive responses (i.e. rating of perceived exertion (RPE)) are augmented when compared to when the same participant starts moderate exercise hydrated (USG < 1.020), which may lead to premature fatigue during longer high intensity aerobic events, such as a triathlon (Logan-Sprenger et al., 2015, 2013).

Table 2
Athlete performance based on race winner's split times.

Athlete race category	% off race winner's split time			
	% off swim time	% off bike time	% off run time	% off winner's race time
Jr Men	0.0	−0.1	17.5	4.7
U23 Men	2.6	2.5	1.9	2.3
Elite Men	4.3	1.1	2.5	2.1
U23 Women	DNF	DNF	DNF	DNF
	−0.4	0.1	6.7	2.5
	1.8	1.4	14.7	5.9

Abbreviations: U23, Under 23 race category.

Ultimately, pre-race dehydration can be combated by athlete education and, if necessary, implementation of a hydration plan in the hours leading into a competition.

4.2. Sweat losses and fluid balance

The reality in sport is that the majority of athletes only replace ~50% of sweat losses during exercise leading to significant fluid deficits which may negatively effect endurance performance (Maughan and Meyer, 2013; Burke, 2007; Ebert et al., 2007). During the ITU Grand Finale race, athletes replaced ~33% of fluid losses and ended the race with a mean loss of ~3.3% BM. These results exceed previous reports studying male and female elite road cyclists during the Tour de France and the Tour de l'Aude cycling tours who lost on average 2.8% and 2.6% BM loss per stage over the 21- and 10-day tours, respectively (Ebert et al., 2007). Similarly, Bardis et al. reported that well-trained male endurance cyclists completed a 5-kilometer hill climb 5.8% faster when dehydration was minimized (1.4%) versus greater dehydration (2.2%) with a significantly higher Tc and RPE upon finishing the race (Bardis et al., 2013). Although it has been documented that some elite cyclists can sustain high levels of BM loss (> 4%) and perform well, these studies must be interpreted in context; that is, well-trained male cyclists exercising for 60 min in ambient conditions up to 33 °C and 60% relative humidity, and starting exercise in a euhydrated state (Goulet, 2011, 2013; Wall et al., 2015). Moreover, the intense nature of the ITU races coupled with two 'legs', swim and run, that have no to low access to fluids, create situational factors that negatively influence fluid consumption. As such, it is unreasonable to maintain fluid balance across a triathlon; rather, the goal of the athlete should be to minimize the extent of fluid loss (< 2% BM loss) through intentional drinking. None of the athletes in this study utilized the fluid stations on the run course for hydration or skin cooling purposes, which may have helped attenuate the performance decline in the run leg of the race by mitigating thirst and/or thermal perception (Racinais et al., 2015; Ruddock et al., 2017).

4.3. Core temperature responses

Four of the five athletes in this study achieved a Tc > 39 °C during the race, the length of time this Tc was sustained for is unknown. Both of the female athletes who presented with > 3% BM loss and Tc > 39 °C also had the greatest reduction in performance during the run portion of the Olympic distance triathlon (7% and 15% respectively). The same two female athletes self-reported symptoms of heat exhaustion, specifically faintness, dizziness, fatigue, and perceived over-heating, and a headache. Logan-Sprenger et al. (2015) reported a 12% reduction in time trial performance when cyclists were dehydrated by ~3% BM, and suggest that a critically high Tc is the more dominating factor determining performance when dehydrated by 2–3% BM, suggesting the presence of anticipatory pacing to ensure that a thermoregulatory failure does not occur, and as such, behavior

modification (i.e. slowing of self-selected pace) guarantees that homeostasis is protected under all conditions (Logan-Sprenger et al., 2015; Tattersson et al., 2000; Marino, 2004; Tucker et al., 2004). Subsequently, Ruddock et al. reported that cooling during exercise benefited ratings of perceived exertion and thermal perception during fixed-intensity exercise and improved self-pace exercise performance (Ruddock et al., 2017). As such, it is recommended that triathletes utilize race fluid stations for skin cooling and hydration purposes to prevent a potential decline in performance in the later stages of an Olympic distance triathlon due to perceived and physiological thermal discomfort.

4.4. Performance

Performance during the run largely dictates overall Olympic distance triathlon performance (Ofoghi et al., 2015). In this study, there was higher variability of run performance compared to the two other legs (swim & cycle) in all tested athletes. Although the small number of athletes tested is a limitation to this study, if the Olympic distance athletes were analyzed only (removal of Jr male data, n = 3) there appears to be a strong relationship between %BM loss and the percent decline in run time from the race winner's time (r = 0.99). Marginal gains in performance (~1%) may be the difference between making the podium or attaining a mere finishing result. In this paper, three of the five athletes had splits in the swim (range 0–1.8%) and bike (−0.1–1.4%) that were relatively close to the race winner's splits in each respective leg of the triathlon, however in the run their performance dropped by ~7–18% off the race winner's run split, which was strongly correlated to the %BM loss athletes presented with at the end of the race (r = 0.99). After two-thirds of the race was completed, these three athletes (1M, 2F) were in near podium contention, but ended with a 40th, 6th, and 16th place finish respectively.

Despite mounting evidence demonstrating the potentially negative impact progressive dehydration (> 2–3% BM loss) and heat-related fatigue have on aerobic performance, some elite triathletes competing at the ITU event series may be practicing insufficient hydration and cooling behaviours during competition. As such, it is encouraged that athletes be intentional about hydration and cooling; to use the race fluid stations to drink and cool the body to prevent the potential for a slowing of self-selected pace due to perceived and/or physiological thermal discomfort.

5. Conclusions

The observations from this study highlight that high sweat rates coupled with limited access to fluids during the swim leg combined with the dynamic nature of the run, limits the opportunity to consume adequate fluid promoting progressive dehydration (> 2–3% BM loss) and high Tc (> 39 °C) in Olympic distance (OD) triathlon during a pinnacle international competition in a cool environment (19–20 °C). In light of situational factors that influence access to fluid, OD triathletes need to be intentional about consuming fluid when available and using fluid aid stations to self-cool in an attempt to mitigate potential performance decrements in the later stages of the race due to physiological and perceived thermal discomfort.

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References

- Bardis, C.N., Kavouras, S.A., Arnaoutis, G., Panagiotakos, D.B., Sidossis, L.S., 2013. Mild dehydration and cycling performance during 5-kilometer hill climbing. *J. Athl. Train.* 48, 741–747.

- Burke, L.M., 2007. Fluid balance during team sports. *J. Sports Sci.* 15, 287–295.
- Ebert, T.R., Martin, D.T., Stephens, B., McDonald, W., Withers, R.T., 2007. Fluid and food intake during professional men's and women's cycling tours. *Int. J. Sports Physiol. Perform.* 2, 58–71.
- Goulet, E.D.B., 2011. Effect of exercise-induced dehydration on time-trial exercise performance: a meta-analysis. *Br. J. Sports Med.* 45, 1149–1156.
- Goulet, E.D.B., 2013. Effect of exercise-induced dehydration on endurance performance: evaluating the impact of exercise protocols on outcomes using a meta-analytic procedure. *Br. J. Sports Med.* 47, 679–686.
- Logan-Sprenger, H.M., Heigenhauser, G.J.F., Killian, K.J., Spriet, L.L., 2013. Effects of dehydration during cycling on skeletal muscle metabolism in females. *Med. Sci. Sports Exerc.* 44, 1949–1957.
- Logan-Sprenger, H.M., Heigenhauser, G.F.J., Jones, G.L., Spriet, L.L., 2015. The effect of dehydration on muscle metabolism and time trial performance during prolonged cycling in males. *Physiol. Rep.* 3, 1–13.
- Marino, F.E., 2004. Anticipatory regulation and avoidance of catastrophe during exercise-induced hyperthermia. *Comp. Biochem Physiol. Biochem Mol. Biol.* 139, 561–569.
- Maughan, R.J., Meyer, N.L., 2013. Hydration during intense exercise training. *Nestle Nutr. Inst. Workshop Ser.* 76, 25–37.
- O'Toole, M.L., Douglas, P.S., 1995. Applied physiology of triathlon. *Sports Med.* 19, 251–267.
- Ofoghi, B., Zeleznikow, J., Macmahon, C., Rehula, J., Dwyer, D.B., 2015. Performance analysis and prediction in triathlon. *J. Sport Sci.* 19, 607–612.
- Racinais, S., Lonso, J.M., Coutts, A.J., Flouris, A.D., Girard, O., Gonzalez-Alonso, J., Hausswirth, C., et al., 2015. Consensus recommendations on training and competing in the heat. *Br. J. Sports Med.* 49, 1164–1173.
- Ruddock, A., Robbins, B., Tew, G., Bourke, L., Purvis, A., 2017. Practical cooling strategies during continuous exercise in hot environments: a systematic review and meta-analysis. *Sports Med.* 47, 517–532.
- Sawka, M.N., Burke, L.M., Eichner, E.R., Maughan, R.J., Montain, S.J., Stachenfeld, N.S., 2007. American College of Sports Medicine position stand: exercise and fluid replacement. *Med. Sci. Sport Exerc.* 39, 377–390.
- Tattersson, A.J., Hahn, A.G., Martini, D.T., Febbraio, M.A., 2000. Effects of heat stress on physiological responses and exercise performance in elite cyclists. *J. Sci. Med. Sport* 3, 186–193.
- Tucker, R.L., Harley, R.Y.X., Noakes, T.D., 2004. Impaired exercise performance in the heat is associated with an anticipatory reduction in skeletal muscle recruitment. *Pflug. Arch.* 448, 422–430.
- Wall, B.A., Watson, G., Peiffer, J.J., et al., 2015. Current hydration guidelines are erroneous: dehydration does not impair exercise performance in the heat. *Br. J. Sports Med.* 49, 1077–1083.

Having been a two-sport national team athlete (ice hockey and cycling), Dr. Sprenger utilizes her knowledge and experience to answer key performance enhancing questions in the field of environmental physiology and high-performance sport.