High thermoregulatory strain during competitive paratriathlon racing in the heat

Original Investigation

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ABSTRACT

Purpose: Paratriathletes may display impairments in autonomic (sudomotor and/or vasomotor function) or behavioural (drinking and/or pacing of effort) thermoregulation. As such, this study aimed to describe the thermoregulatory profile of athletes competing in the heat.

Methods: Core temperature (T_c) was recorded at 30 s intervals in 28 mixed-impairment paratriathletes during competition in a hot environment (33^{o}C, 35-41% relative humidity, 25-27^{o}C water temperature), via an ingestible temperature sensor (BodyCap e-Celsius). Furthermore, in a subset of 9 athletes, skin temperature (T_{sk}) was measured. Athletes' wetsuit use was noted whilst heat illness symptoms were self-reported post-race.

Results: Twenty-two athletes displayed a $T_c \geq 39.5^{o}$C with 8 athletes $\geq 40.0^{o}$C. There were increases across the average T_c for swim, bike and run sections ($p \leq 0.016$). There was no change in T_{sk} during the race ($p \geq 0.086$). Visually impaired athletes displayed a significantly greater T_c during the run section than athletes in a wheelchair ($p \leq 0.021$). Athletes wearing a wetsuit (57% athletes) had a greater T_c when swimming ($p \leq 0.032$) whilst those reporting heat illness symptoms (57% athletes) displayed a greater T_c at various timepoints ($p \leq 0.046$).

Conclusions: Paratriathletes face significant thermal strain during competition in the heat, as evidenced by high T_c, relative to previous research in able-bodied athletes, and a high incidence of self-reported heat illness symptomatology. Differences in the T_c profile exist depending on athletes' race category and wetsuit use.

Key words: Thermoregulation, disability, triathlon, elite, Paralympic

INTRODUCTION

Paralympic athletes are a population group with unique challenges in autonomic or behavioural thermoregulatory function, relative to able-bodied (AB) athletes. Whilst this has been acknowledged by researchers,[1] there is still a dearth of research in elite athletes with physical impairments. The finite literature concerning thermoregulation in Paralympic sport has centred on athletes with a spinal cord injury (SCI) due to their high propensity for thermal strain caused by impaired autonomic function and therefore sudomotor and vasomotor control.[2] Research has characterised the thermoregulatory responses to wheelchair rugby and tennis,[2, 3] whilst a case study exists in a single handcyclist.[4] However, other impairment groups are also at risk of thermal strain. Athletes with amputations, neurological impairments or visual impairments face: limited body surface area for heat loss due to missing limbs, skin grafts or wearing prosthetic liners;[1, 5, 6] increased metabolic heat production from movement inefficiencies;[7, 8] weakened venous return from high muscular tone or paralysed muscle,[9, 10] and impaired pace or hydration awareness.[10, 11] Yet, these impairments are severely understudied despite athletes' commonality in Paralympic sports and similarly increased risk of thermal strain.

Competitive events in paratriathlon, the Paralympic variant of triathlon, are commonly held in environments with high ambient temperatures; however, prolonged exercise in hot environments limits the capacity of the body to dissipate heat.[12] As heat gain exceeds heat loss elevations in core (T_c) and skin (T_{sk}) temperature occur. Such elevations have been attributed to well-documented performance impairments in the heat through central and peripheral processes.[13] Furthermore, elevated body temperatures have been implicated in the development of heat illness.[14] Whilst laboratory-based studies have defined the thermoregulatory strain imposed on athletes exercising in the heat,[15] these studies lack applicability to field-based competitive races.[14, 16, 17] Consequently, research has sought to typify outdoor competition.[14, 17-20] This is in accordance with the recommendations to characterise the sport- and event-specific thermal strain profiles of international athletes competing in the heat to improve athletes' safety.[21]

Several studies have now presented the thermoregulatory responses to able-bodied (AB) triathlon races of varying distances.[14, 18, 19, 22] This work has shown that AB triathletes' T_c can reach 38.4 ± 0.7°C[18] to 38.8 ± 0.7°C[19] at the end of half-Ironman races in the heat (27-29°C). Additionally, by acquiring in-race T_c readings, Baillot and Hue[18] presented a trend for T_c changes across swim, bike and run sections. In shorter distance racing, with a presumed greater relative exercise intensity and less opportunities for fluid consumption more akin to paratriathlon, Logan-Sprenger present data in a small group of Olympic (*n*=4) and sprint distance triathletes (*n*=1).[22] Even in cool conditions (~19°C), T_c reached 39.2 ± 0.4°C and this was accompanied by two of the athletes with T_c ≥39.2°C reporting symptoms of heat illness post-race.[22] Nonetheless, data are still restricted to infrequent T_c sampling, commonly pre- and post-race measurement, during field-based research. Furthermore, although studies have attempted to determine the correlates to in-race T_c such as fluid intake or race performance,[14, 16-18, 23] as no study has researched Paralympic athletes, it is not possible to discern any relationship between physical impairment and thermal strain imposed. Thus, it is pertinent to better describe the thermoregulatory strain profiles of paratriathletes using ingestible temperature pills, in line with the recommendations of Bergeron *et al*[21], and determine the risk to athletes' health through heat illness genesis. Consequently, the aims of this study were to characterise the T_c and T_{sk} responses to paratriathlon competition in the heat.

METHODS

Participants

Twenty-eight paratriathletes volunteered to participate in the present study (Table 1). Athletes' paratriathlon world ranking at the time of the study was 1st to 24th place. Athletes were competing in the 2017 Iseo-Franciacorta ITU Paratriathlon World Cup (8th July) or 2018 Iseo-Franciacorta ITU World Paratriathlon Series (30th June) (Iseo, Lombardy, Italy; elevation 185 m). Athletes were asked to provide details of their training for the preceding four weeks to determine heat acclimatisation or acclimation status. Those who reported daily, or alternate days, training in temperatures ≥30.0°C for ≥60 $min \cdot d^{-1}$, with a total number of heat exposures ≥5 were classed as heat acclimated/acclimatised, dependent on the training environment. Athletes provided written informed consent and the procedures were approved by the Loughborough University Ethical Advisory Committee in the spirit of the Helsinki Declaration.

Insert Table 1 here

Methodology

The race consisted of a single lap, 750 m open-water lake swim, 21 km (3 laps of 7 km) non-drafting cycle and a 4.8 km run (2017: 3 laps of 1.6 km; 2018: 4 laps of 1.2 km). The cycle course was largely flat with an elevation change of ~49 m per lap. The races started between 16:00-16:30 (2017 event) and 17:00-18:30 local time (2018 event), depending on athletes' race category. Environmental conditions during the 2017 race were: 33°C air temperature, 41% relative humidity, 27°C water temperature and 11 $km \cdot h^{-1}$ wind velocity and during the 2018 race were: 33°C air temperature, 35% relative humidity, 25°C water temperature and 18 $km \cdot h^{-1}$ wind velocity (RH390, Extech Instruments, Nashua, NH, USA). The cloud cover, whilst not measured, was minimal, and no precipitation was recorded during either race. Due to the similar environmental conditions, data were pooled into one group. All athletes wore a swim-cap when swimming. Twelve athletes wore a trisuit for the whole race, with cycling shoes during cycling and trainers when running, whilst sixteen athletes chose to additionally wear a wetsuit during the swim stage. Aligned to ITU paratriathlon competition rules, PTWC athletes used a handbike and racing wheelchair for bike and run sections, respectively, whilst PTVI athletes raced with an AB guide and used a tandem bicycle. Ambulant sport categories (PTS2-PTS5) used prostheses or adaptations to bicycles, where necessary.

Athletes were provided with a telemetric T_c pill (e-Celsius, BodyCap, Caen, France) which they were asked to ingest ~6 h pre-race.[24] Whilst differences in gastrointestinal transit time were likely present among individuals, especially considering the potential effects of athletes' impairments, a standardised ingestion timing was employed to align with previous research,[16-18, 22] including studies in athletes with an SCI.[2] The e-Celsius device permitted remote temperature measurement and storage without the need for constant communication to a receiving monitor. Although no individual calibration of pills was performed, previous research has shown the equipment to be highly accurate and reliable.[25] T_c was recorded at 30 s intervals thus providing a greater sampling frequency than previous field-based studies.[23] Athletes were free to warm-up and complete the race as normal. Similarly, athletes were free to consume fluids *ad libitum* during the race, but intake was self-reported post-race. Due to the logistical demands of studying elite athletes in-competition, and the challenges associated with weighing athletes with physical impairments, it was not possible to collect meaningful body mass changes directly pre- and post-race. Immediately post-race, athletes reported to investigators for wireless T_c data download. Athletes were asked to state if they had felt any symptoms of heat illness during the race such as confusion, dizziness, fainting, muscle or abdominal cramps, nausea, vomiting, diarrhoea, heat sensations on the head or neck, chills or stopping sweating.[26]

In a subset of 9 athletes, T_{sk} was measured via temperature loggers (DS1922L Thermochron iButton®; Maxim Integrated Products, Inc., Sunnyvale, CA, USA) placed on the *pectoralis major* and *rectus femoris* muscle belly under waterproof adhesive patches (Tegaderm +Pad, 3M, St. Paul, MN, USA). This permitted the calculation of weighted mean T_{sk} using an adaptation of the methods of Ramanathan[27] whereby T_{sk} was taken as 0.6(*pectoralis major* temperature) + 0.4(*rectus femoris* temperature). These sites were chosen to minimise any distraction to athletes when racing and the risk of loggers coming loose. No athletes in whom T_{sk} was measured wore a wetsuit during the swim section. Due to the inability to fully insulate thermocouples and minimise convective heat transfer during swimming, T_{sk} data from the swim section were not included in data analysis.

Data analyses

Athletes were grouped based on their impairment into one of four groups: PTWC for wheelchair athletes (*n*=9), NEURO for athletes with a neurological impairment (*n*=6 PTS2 and PTS3 athletes), AMP for athletes with an amputation (*n*=7 PTS2-PTS5 athletes) and PTVI for athletes with a visual impairment (*n*=6). They were also grouped based on self-reported heat acclimatisation/acclimation status, heat illness symptomatology and wetsuit use.

Athletes' segment times for swim, bike, run and transitions were recorded by the race organiser and published online. Athletes' T_c during the race was averaged into modality-specific segments for swim, bike, run and transitions: $SWIM_{av}$, $BIKE_{av}$, RUN_{av}, T1, T2. Further, actual temperatures for immediately pre-race (PRE), the end of the swim ($SWIM_{end}$), the end of each bike lap ($BIKE_1$, $BIKE_2$, $BIKE_3$), midway through the run section (RUN_{mid}) and the end of the run (RUN_{end}) were calculated, assuming evenly paced efforts. Absolute changes in T_c were calculated for each race segment: $SWIM_{\Delta}$, $BIKE_{\Delta}$, RUN_{Δ}.

Statistical analyses

All statistical analyses were conducted using SPSS Statistics 23.0 software (IBM, NY, USA). Statistical significance was set at $p<0.05$. Data were checked for normal distribution using the Shapiro-Wilk between-group test and for homogeneity of variance using Levene's test. Where sphericity could not be assumed, the Greenhouse-Geisser correction was used. Changes in T_c and T_{sk} during the race were assessed as a group via one-way repeated measures analysis of variance. Similarly, to determine any relationship with athletes' impairment group, acclimatisation/acclimation status, wetsuit use and reporting of heat illness symptoms, changes in T_c were assessed via two-way repeated measures analysis of variance with group and time factors. The Bonferroni post-hoc test was used to evaluate pairwise comparisons of time points. Spearman's correlation coefficient was employed to determine the degree of correlation to peak T_c from: T_c during race time points; changes in T_c across race segments; race performance; finishing position; fluid intake; body mass and paratriathlon world ranking. A paired-samples t-test was used to determine differences in T_{sk} changes between bike and run sections.

RESULTS

The mean ± standard deviation time to complete the race was 74.9 ± 11.2 min with a range of 54.6 to 103.9 min. The times for swim, bike and run were 14.3 ± 2.6 min (10.5 to 20.0 min), 36.4 ± 6.0 min (28.8 to 52.9 min) and 21.1 ± 5.1 min (13.1 to 36.2 min), respectively.

There was a significant change in T_c over time when all athletes were pooled together. Specifically: PRE was lower than all other time points ($p<0.001$); RUN_{mid} was greater than $SWIM_{end}$, T1 and T2 ($p\leq0.039$); RUN_{end} was greater than all other time points ($p\leq0.031$); whilst there was a significant increase across PRE, SWIM_{av}, BIKE_{av} and RUN_{av} ($p \leq 0.016$) (Figure 1). There was an impairment-specific interaction as RUN_{Δ}, changes in T_c T2-RUN_{mid} and RUN_{mid}-RUN_{end} were significantly greater for PTVI than PTWC ($p \leq 0.021$) (Table 2).

Fourteen of the twenty-eight athletes reported being heat acclimatised/acclimated prior to the study. Those reporting being heat acclimatised/acclimated displayed a greater RUN_{end} (39.78 ± 0.55 vs 39.22 ± 0.41°C) and change in T_c RUN_{mid}-RUN_{end} (0.47 ± 0.30 vs 0.16 ± 0.14°C) ($p \leq 0.044$). Athletes that wore a wetsuit had significantly greater SWIM_{end} (38.76 ± 0.40 vs 38.31 ± 0.40°C) and SWIM_{av} (38.45 ± 0.34 vs 38.03 ± 0.35°C) ($p \leq 0.032$). Sixteen athletes reported experiencing symptoms of heat illness during the race, of which ten wore a wetsuit. Those that were symptomatic had a significantly greater SWIM_{end}, SWIM_{av}, SWIM_{Δ} (0.80 ± 0.50 vs 0.38 ± 0.37°C), T1, BIKE_1, BIKE_2, BIKE_{av} and RUN_{av} than those asymptomatic ($p \leq 0.046$) (Figure 2).

Insert Table 2 here

Twenty-six out of twenty-eight athletes (93%) reached a peak Tc ≥39.0°C, 22 athletes ≥39.5°C (79%), 8 athletes ≥40.0°C (29%) and 2 athletes ≥40.5°C (7%). There were significant positive correlations between peak T_c and: change in T_c T1-BIKE_1 (p=0.001; r=0.629), BIKE_1 (p<0.001; r=0.735), BIKE_2 (p<0.001; r=0.762), BIKE_3 (p=0.003; r=0.546), BIKE_{av} (p=0.001; r=0.624), T2 (p=0.016; r=0.475), RUN_{mid} (p<0.001; r=0.845), RUN_{end} (p<0.001; r=0.902), RUN_{av} (p<0.001; r=0.871), change in T_c RUN_{mid}-RUN_{end} (p=0.036; r=0.420). There was no significant correlation between peak T_c and overall race finishing time, race segment times, finishing position, fluid intake or body mass ($p \geq 0.143$; $r \leq 0.284$).

There was no significant difference in T_{sk} over time (p=0.086; Figure 3). , However, there was a significant difference in the change in T_{sk} across the bike and run sections, as the absolute change was greater during the bike than run (-1.70 ± 1.15 vs. 1.03 ± 1.67°C; p=0.017).

DISCUSSION

This is the first study to characterise the thermoregulatory strain imposed by field-based paratriathlon performance in the heat via continuous T_c measurement. Paratriathletes face significant thermoregulatory strain as shown by 22 of the 28 athletes displaying a peak T_c ≥39.5°C, of which were 8 athletes ≥40.0°C. Furthermore, a high proportion of athletes (57%) experienced self-reported symptoms of heat illness. This may be related to wetsuit use which effected the early rise in T_c during the first phase of the race.

During competition, T_c was significantly elevated from pre-race with marked increases during the run segment, as consistent with previous research of AB athletes.[18] Moreover, considering race segment averages, there was a significant rise in T_c throughout the race. Given the impairment types within paratriathlon, it was not surprising to find T_c greater than previously reported in AB Olympic and sprint distance races in cool environments and half-Ironman events in the heat.[18, 19, 22] Paratriathletes may display myriad impairments that diminish thermoregulatory capacity and thus elevate T_c during competition, relative to AB athletes. Depending upon their impairment, paratriathletes may display a diminished capacity for evaporative heat loss, augmented metabolic heat production or impaired pace awareness,[1, 5, 6, 7-11] thus elevating their risk of thermal strain and heat illness symptomatology. , Due to the greater race durations for Olympic (~110) half-Ironman events (~320 min) than is typical in paratriathlon races, the relative intensity is markedly lower in longer races, thus representing a discrepant metabolic heat production.[28]

The proportion of athletes with a peak T_c ≥39.0°C (93%) was slightly less than in previous studies of AB athletes running a half-marathon in a tropical climate (96-100%).[17, 23]

Furthermore, in these studies there was a greater proportion of individuals with a T_c ≥40.0°C (40-56%) which is likely due to the greater oppressiveness of the environment and heat production from running for >90 min. However, in the current study, the percentage of athletes ≥40.0°C (29%) was still higher than AB individuals competing in sprint or Olympic distance triathlons (0%),[22] running 15 km in a temperate environment (13%),[17] or elite AB cyclists in a recent World Championships in a hot, dry climate (25%).[20] These findings provided context to the level of strain faced by paratriathletes in the heat. As paratriathletes display such significant thermoregulatory strain in the heat, event organisers must consider first aid provision at races with challenging environmental conditions, such as the 2020 Tokyo Paralympic Games,[29] for the rapid treatment of potential heat illness. This may be particularly pertinent when ambulant athletes are running, and their T_c is greatest, as shown here. Furthermore, cut-off values for event postponement or distance modification should be considered to lessen the thermoregulatory strain imposed by environmental conditions.

To date, research typifying the thermoregulatory strain of Paralympic sports has been predominantly confined to wheelchair court sports of athletes with an SCI.[2-4] The sole study of a Paralympic endurance sport described a peak T_c of 40.4°C at the end of a 42 km race, in temperature conditions (20.0 to 22.0°C), in a single, male, handcyclist.[4] This study, which now extends scientific understanding by including athletes of mixed impairments, found there were differences in the temperature responses between impairment groups. Specifically, changes in T_c during the run segment were significantly greater for PTVI than PTWC, comprised mostly of athletes with an SCI. This is presumably due to the considerably disparate race demands across paratriathlon, depending on athletes' race categories. During the run segment, PTWC athletes in a racing wheelchair utilise less active musculature and travel at a greater velocity, thus are exposed to greater air flow for convective heat loss compared to ambulant runners. Therefore, it is not surprising that changes in T_c were significantly greater for PTVI athletes when running compared to those in PTWC as heat production was greater whilst heat dissipative potential was lower.

At the time of data collection, ITU paratriathlon races permitted wetsuit use up to a water temperature of 28.0°C although this has subsequently been changed to 24.6°C based on the findings of the present study.[30] Here, it was shown that wetsuit use resulted in a significantly elevated $SWIM_{end}$ and $SWIM_{av}$ T_c. It is noteworthy that of the 16 athletes reporting symptoms of heat illness, 10 wore a wetsuit. Moreover, those that were symptomatic also displayed a significantly greater $SWIM_{end}$, $SWIM_{av}$, $SWIM_{\Delta}$, T1, $BIKE_1$, $BIKE_2$, $BIKE_{av}$ and RUN_{av}. A high T_c rise early in exercise has been suggested to be implicated in heat illness genesis.[23] Furthermore, the incidence of heat illness symptomatology was greater in the current study than elsewhere in AB athletes.[16, 18, 20, 22, 31] This may relate to paratriathletes' greater susceptibility for excessive thermoregulatory strain because of their physical impairments or lower aerobic fitness.[32] Due to the significantly greater T_c at various time points in the heat illness symptomatic group, the negative health consequences of elevated body temperatures during paratriathlon competition are highlighted. This supports recent evidence from Logan-Sprenger where two athletes with a T_c ≥39.2°C also displayed symptoms of heat illness.[22]

In the present study, there were differences in the T_c responses between those who reported being prior acclimatised or acclimated to the heat. This is the first study to acknowledge this aspect during triathlon competition of any format. Specifically, RUN_{end} T_c and change in T_c RUN_{mid}-RUN_{end} were greater for those with prior chronic heat exposure. Racinais *et al*.[31] have previously shown that peak T_c during a 43 km cycling time-trial in the heat was unchanged by heat acclimatisation, albeit with a greater cycling power output than pre-acclimatisation. This may relate to the beneficial thermoregulatory adaptations of chronic heat exposure permitting a greater relative intensity and thus metabolic heat production during racing. However, it is not known how other thermoregulatory variables (e.g., T_{sk}, heart rate, sweat rate) may have differed between groups in the current study.

A novel feature of this study was to record T_{sk} changes throughout a field-based competitive triathlon. In the subset of athletes in whom T_{sk} was measured, there was no significant change over time. although large variation present with a small sample size. There was a significant difference in the T_{sk} changes across the race segments; specifically, the change was greater during cycling than running. The drop in T_{sk} during the cycling segment is presumably due to greater wind velocity augmenting convective cooling at the periphery.[18]

PRACTICAL APPLICATIONS

The current study builds on previous research of thermoregulation during competitive sporting events by investigating the sport of paratriathlon whilst utilising regular sampling frequencies. However, the small sample size limited the ability to determine further impairment-specific responses. Similarly, the restricted number of athletes in whom T_{sk} was measured constrains the likelihood of revealing true changes throughout triathlon races. Lastly, the study relied upon participant reports of several parameters (e.g., fluid intake, heat acclimation/acclimatisation state, heat illness symptoms) which were not confirmed objectively. Similarly, there was no account of, or control for, the use of contraception in female athletes nor so athletes' hydration status pre-race.

Nonetheless, from these data, coaches, practitioners and medical staff now have a better understanding of the thermoregulatory strain imposed by paratriathlon competition in the heat. This should subsequently prompt the implementation of strategies to alleviate such strain. For example, athletes would be prudent to look to utilise heat acclimation/acclimatisation strategies due to the potential for improvements in thermoregulatory variables.[12] Furthermore, pre- or per-race cooling strategies may be employed and modified depending on athletes' race category and expected T_c responses (e.g., the use of cooling strategies when handcycling for PTWC athletes and when running for ambulant athletes).[12] Additionally, athletes should seek strategies to ameliorate thermal strain in races such as by minimising fluid losses[22] and adopting an evenly-paced race. Event organisers ought to consider medical provision in similar situations to the present study due to the high propensity for heat illness symptomatology whilst also reflecting upon utilising defined weather limits, using wet-bulb globe temperature or otherwise, to determine the need for race alteration or postponement.

CONCLUSIONS

Paratriathletes face significant thermoregulatory strain during competition in the heat, as evidenced by high T_c and prevalence of self-reported heat illness symptoms, although the effect on T_{sk} is still ambiguous. Athletes' T_c is typically greatest during the run segment whilst those with a VI display significant increases in T_c during this phase. Finally, it appears that the use of a wetsuit substantially elevates T_c and may be linked to the incidence of heat illness, but this requires verification by controlled laboratory studies or further field trials.

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FIGURE CAPTIONS

Figure 1: Whole-group core temperature changes throughout the race. Dots are individual data; black line indicates group mean. *Significantly lower than all other time points ($p<0.001$). †Significantly lower than RUN_{mid} ($p\leq0.039$). ‡Significantly greater than all other time points ($p\leq0.031$). §Significantly greater at each time point ($p\leq0.016$).

Figure 2: Core temperature changes and heat illness symptomatology throughout the race. Circles are symptomatic, triangles are asymptomatic individuals, lines are group means. *Significantly greater in symptomatic group ($p\leq0.046$).

Figure 3: Skin temperature changes throughout the race. Dots are individual data; black line indicates group mean.

Table 1. Participant characteristics. Data are mean ± standard deviation where appropriate.

Whole group	T_{sk}	Wetsuit	Non-wetsuit	Heat illness symptomatic	Heat illness asymptomatic	Heat acclimatised/ acclimated	Not heat acclimatised/ acclimated
28 (PTWC *n*=9, NEURO *n*=6, AMP *n*=7, PTVI *n*=6)	9 (NEURO *n*=2, AMP *n*=5, PTVI *n*=2)	16 (PTWC *n*=6, NEURO *n*=3, AMP *n*=2, PTVI *n*=5)	12 (PTWC *n*=3, NEURO *n*=3, AMP *n*=5, PTVI *n*=1)	16 (PTWC *n*=4, NEURO *n*=5, AMP *n*=4, PTVI *n*=3)	12 (PTWC *n*=5, NEURO *n*=1, AMP *n*=3, PTVI *n*=3)	14 (PTWC *n*=4, NEURO *n*=2, AMP *n*=5, PTVI *n*=3)	14 (PTWC *n*=5, NEURO *n*=4, AMP *n*=2, PTVI *n*=3)
Male *n*=17, female *n*=11	Male *n*=4, female *n*=5	Male *n*=11, female *n*=5	Male *n*=6, female *n*=6	Male *n*=9, female *n*=7	Male *n*=8, female *n*=4	Male *n*=10, female *n*=4	Male *n*=7, female *n*=7
31.2 ± 7.6	28.3 ± 6.0	33.1 ± 7.6	27.6 ± 5.7	31.4 ± 8.3	30.9 ± 6.9	33.7 ± 7.7	28.6 ± 6.9
64.3 ± 8.2	63.7 ± 11.1	65.1 ± 6.3	63.2 ± 10.2	61.6 ± 8.1	67.4 ± 7.5	64.5 ± 9.5	64.1 ± 7.3

PTWC –Athletes requiring the use of a wheelchair. NEURO – Athletes with a neurological impairment. AMP – Athletes with an amputation. PTVI – Athletes with a visual impairment.

Table 2: Changes in core temperature during the race. Data are mean ± standard deviation. *Significantly greater in PTVI than PTWC ($p \leq 0.021$).

Impairment	$SWIM_{\Delta}$ (ºC)	T1-$BIKE_1$ (ºC)	$BIKE_1$-$BIKE_2$ (ºC)	$BIKE_2$-$BIKE_3$ (ºC)	$BIKE_{\Delta}$ (ºC)	T2-RUN_{mid} (ºC)	RUN_{mid}-RUN_{end} (ºC)	RUN_{Δ} (ºC)
PTWC	0.49 ± 0.59	0.37 ± 0.33	0.20 ± 0.20	0.07 ± 0.30	0.64 ± 0.51	0.07 ± 0.15	0.19 ± 0.11	0.26 ± 0.15
NEURO	0.83 ± 0.37	0.15 ± 0.19	-0.08 ± 0.17	-0.02 ± 0.12	0.05 ± 0.33	0.43 ± 0.29	0.30 ± 0.26	0.73 ± 0.44
AMP	0.45 ± 0.38	0.43 ± 0.38	0.00 ± 0.28	-0.10 ± 0.22	0.33 ± 0.61	0.35 ± 0.26	0.15 ± 0.26	0.50 ± 0.36
PTVI	0.60 ± 0.57	0.18 ± 0.82	0.15 ± 0.17	-0.10 ± 0.14	0.23 ± 0.92	0.43 ± 0.16*	0.60 ± 0.29*	1.03 ± 0.25*

PTWC –Athletes requiring the use of a wheelchair. NEURO – Athletes with a neurological impairment. AMP – Athletes with an amputation. PTVI – Athletes with a visual impairment.

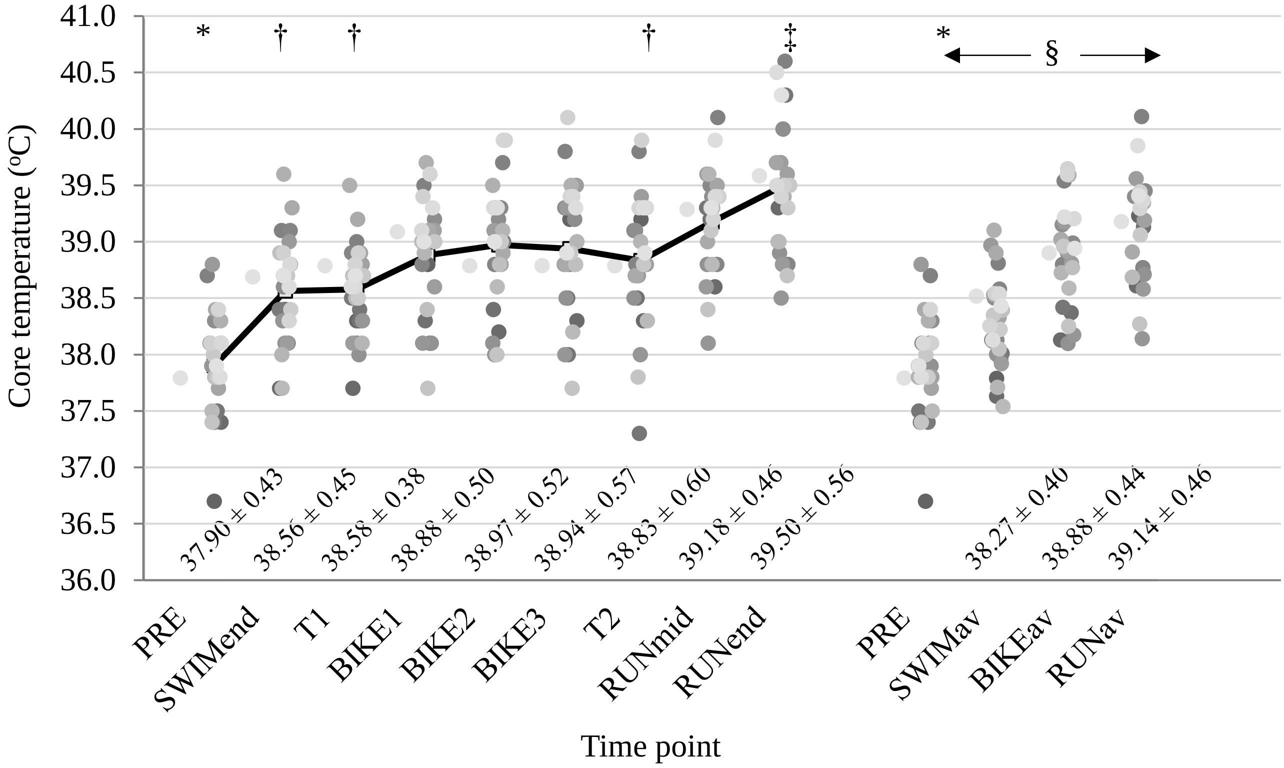

Figure 1: Whole-group core temperature changes throughout the race. Dots are individual data; line indicates group mean. *Significantly lower than all other time points ($p<0.001$). †Significantly lower than RUN_{mid} ($p \leq 0.039$). ‡Significantly greater than all other time points ($p \leq 0.031$). §Significantly greater at each time point ($p \leq 0.016$).

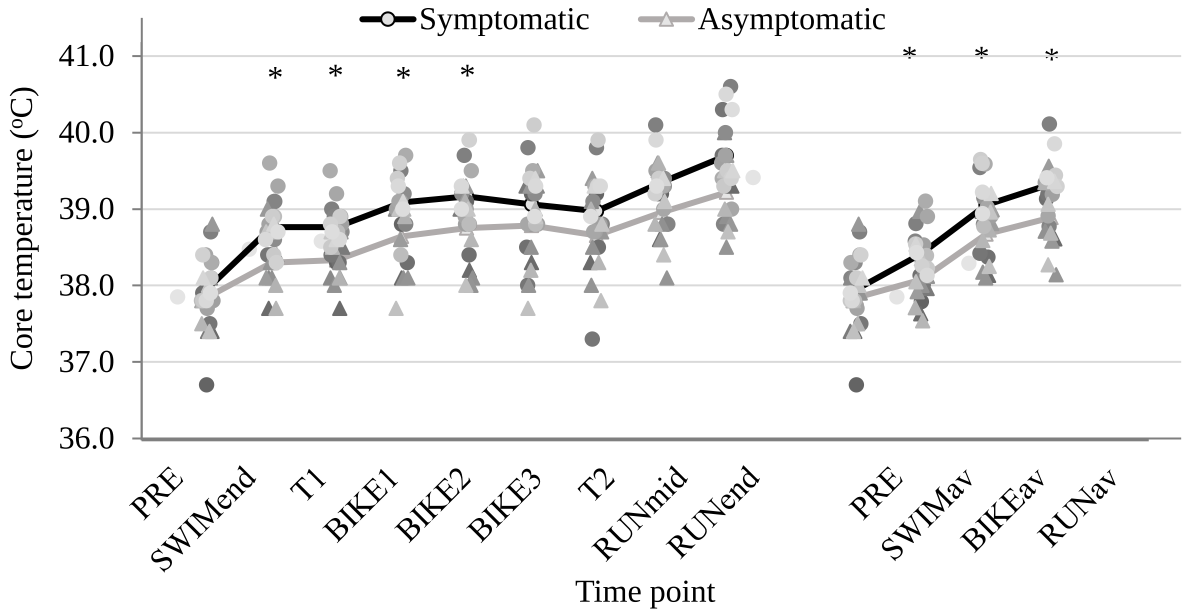

Figure 2: Core temperature changes and heat illness symptomatology throughout the race. Circles are symptomatic, triangles are asymptomatic individuals, lines are group means. *Significantly greater in symptomatic group ($p \leq 0.046$).

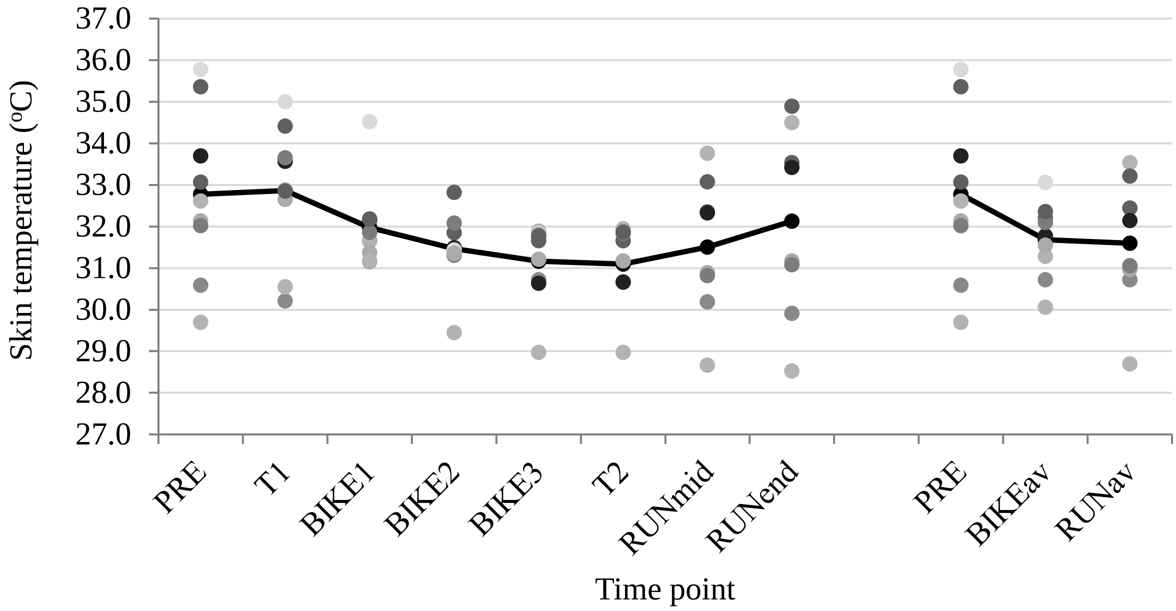

Figure 3: Skin temperature changes throughout the race. Dots are individual data; line indicates group mean.