Journal of Science and Medicine in Sport 18 (2015) 333–337

Contents lists available at ScienceDirect

Journal of Science and Medicine in Sport

journal homepage: www.elsevier.com/locate/jsams

Original research

Incidence and predictors of exertional hyperthermia after a 15-km road race in cool environmental conditions

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ARTICLE INFO

Article history:
Received 23 December 2013
Received in revised form 10 April 2014
Accepted 17 April 2014
Available online 26 April 2014

Keywords:
Heatstroke
Heat stress disorders
Body temperature regulation
Exercise
Body temperature

ABSTRACT

Objectives: Current knowledge about the incidence and risk factors for exertional hyperthermia (core body temperature ≥40 °C) is predominantly based on military populations or small-sized studies in athletes. We assessed the incidence of exertional hyperthermia in 227 participants of a 15-km running race, and identified predictors for exertional hyperthermia.
Design: Observational study.
Methods: We measured intestinal core body temperature before and immediately after the race. To identify predictive factors of maximum core body temperature, we entered sex, age, BMI, post-finish dehydration, number of training weeks, fluid intake before and during the race, finish time, and core body temperature change during warming-up into a backward linear regression analysis. Additionally, two subgroups of hyperthermic and non-hyperthermic participants were compared.
Results: In a WBGT of 11 °C, core body temperature increased from 37.6 ± 0.4 °C at baseline to 37.8 ± 0.4 °C after warming-up, and 39.2 ± 0.7 °C at the finish. A total of 15% of all participants had exertional hyperthermia at the finish. Age, BMI, fluid intake before the race and the core body temperature change during warming-up significantly predicted maximal core body temperature ($p < 0.001$). Participants with hyperthermia at the finish line had a significantly greater core body temperature rise ($p < 0.01$) during the warming-up compared to non-hyperthermic peers, but similar race times ($p = 0.46$).
Conclusions: 15% of the recreational runners developed exertional hyperthermia, whilst core body temperature change during the warming-up was identified as strongest predictor for core body temperature at the finish. This study emphasizes that exertional hyperthermia is a common phenomenon in recreational athletes, and can be partially predicted.

1. Introduction

Current knowledge about the incidence and risk factors for exertional hyperthermia (core body temperature (CBT) ≥ 40 °C)[1] and heat illness is largely based on retrospective studies investigating military populations during military exercises.[2–4] These studies involved well-trained soldiers performing continuous exercise (e.g. long-distance running) superimposed by bouts of high-intensity anaerobic exercise (e.g. heavy lifting). This type of exercise is substantially different from a typical athletic event popular in the general public, during which the athletes typically only perform continuous high-intensity exercise. Furthermore, paramount to the general public is that it is characterized by a wide range of individual traits, including a wide diversity in body mass, age and training and health status.[5] As all these factors may affect thermoregulatory responses differently, each individual may be subject to a different risk for developing heat-related problems, such as exertional hyperthermia or heat illness.[6–8] Previous studies that did focus on thermoregulation in participants of athletic events or outdoor time trials in cool to moderate conditions are based on relatively small to moderate sample sizes.[9–11] These studies reported exertional hyperthermia in 0–23% of their participants, mostly after performing marathon races, and this wide range makes it tenuous to draw any firm conclusions. In addition, no previous authors have confirmed whether this knowledge is applicable to the general public

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http://dx.doi.org/10.1016/j.jsams.2014.04.007
1440-2440/

based on measurements in a large and heterogeneous sample size. Based on previous literature, risk factors for heat illness such as metabolic rate (i.e. running speed),[9,12,13] dehydration at the finish line and low fluid intake before and during the race,[1,14,15] increased body mass index,[1,4,16] poor training,[4] advanced age[14] and male sex[17] could significantly predict CBT at the finish line. However, it has never been confirmed whether these risk factors can be applied to identify athletes at risk of developing hyperthermia during large sports events.

Therefore, the main purpose of this study was to assess the CBT in a large ($n = 227$) heterogeneous group of participants of a 15-km running race (Seven Hills Run, Nijmegen, the Netherlands). This is one of the largest running events held in the Netherlands (>30,000 participants), and holds the men's and women's 15-km world records set in 2010 and 2009 respectively. Secondly, we identified factors that significantly predicted CBT at the finish line using a backward linear regression analysis. Thirdly, we aimed to assess the differences between athletes finishing with a high CBT versus those with a low CBT, in order to identify key features that may explain the CBT rise during exercise. To that end, we compared body and race characteristics in athletes with a finish CBT ≥ 40 °C (hyperthermic athletes) to an equally sized group of athletes that finished with the lowest CBT of all participants (non-hyperthermic athletes).

2. Methods

Five-hundred participants of the Seven Hills Run were randomly contacted and, if interested, were sent a study protocol. All volunteers were screened for the presence of any exclusion criteria for using the temperature pill: (1) a history of obstructive or inflammatory bowel disease, or any prior abdominal surgery, (2) the presence of any implanted electric (medical) device, (3) a scheduled MRI scan within 1 week after the event, or (4) pregnancy. Two hundred twenty-seven participants were included in the study: 111 men and 116 women were aged 45 ± 11 years and had a BMI of 22.7 ± 2.7 kg/m^2 (Table 1). Study procedures were approved by the Radboud University Medical Centre Ethics Committee, accorded to the principles of the Declaration of Helsinki, and all participants provided written informed consent before participation.

Prior to the race, participants completed a questionnaire pertaining to their physical training. Participants self-reported their fluid intake from the time of getting out of bed on the day of the race and during the race. Body weight was measured before and after the race in a laboratory set up 50 m from the finish line. CBT was measured at baseline in the laboratory about 2 h before the start, 1 min before the start (i.e. after warming-up), and within 15 s after finishing. Due to the large total number of participants in the race, runners started the race phased into in 9 separate 'waves' over a 1 h period. Ten research assistants measured CBT in 25 ± 1 participants per wave using 5 wireless receivers. Participants with a CBT ≥ 40 °C upon finishing were compared to an equal number of participants that finished with the lowest CBT.

Participants ingested an individually calibrated telemetric temperature pill at least 5 h (8 a.m.) before the race (start 1 p.m.) to prevent interaction of the CBT measurements with fluid ingestion during testing.[18] CBT was measured using a portable telemetry system (CorTemp™ system, HQ Inc., Palmetto, USA). This measuring system has been demonstrated to safely and reliably measure CBT.[19,20] The average of three consecutive measurements for each time point was used for further analyses. The change in CBT during warming-up was calculated by subtracting CBT at baseline from the CBT before the start of the race.

Body weight was measured to the nearest 0.1 kg using an automatically calibrated balance (Seca 888; Hamburg, Germany) before and within 10 min after the race. The relative change in body

Table 1
Participant demographics, physical activity pattern, race characteristics, CBT, body weight, and fluid intake in the total group, a subgroup of hyperthermic participants at the finish line and a subgroup of non-hyperthermic participants.

	Total group	Exertional hyperthermia	Non-hyperthermia	*p*-Value
Characteristics				
Sex (male: female)	111:116	15:16	16:15	0.80
Age (years)	45 ± 11	43 ± 11	45 ± 11	0.49
Body mass index (kg/m^2)	22.7 ± 2.7	23.0 ± 2.4	22.1 ± 2.6	0.17
Physical activity pattern				
Number of previous participations in this event	5 ± 4	4 ± 3	5 ± 4	0.30
Training (weeks)	28 (range 0–52)	30 (range 3–52)	24 (range 0–52)	0.32
Running exercise (sessions/week)	2.5 ± 0.9	2.4 ± 0.8	2.7 ± 1.0	0.21
Race characteristics[a]				
Split time 0–5 km (min)	26.2 ± 3.7	25.8 ± 3.0	25.4 ± 4.0	ANOVA (split times):
Split time 5–10 km (min)	26.4 ± 3.9	26.0 ± 3.1	25.5 ± 4.0	Time/group/time × group
Split time 10–15 km (min)	26.6 ± 6.7	26.4 ± 3.5	25.3 ± 4.1	$p = 0.16/p = 0.46/p = 0.10$
Total race time (min)	79.1 ± 12.8	78.3 ± 9.4	76.2 ± 11.9	0.46
Total race speed (km/h)	11.7 ± 1.8	11.7 ± 1.5	12.1 ± 1.9	0.34
Core body temperature				
Baseline	37.6 ± 0.4	37.6 ± 0.4	37.4 ± 0.4	0.26
CBT change during warming-up	0.2 ± 0.5	0.5 ± 0.5	0.1 ± 0.4	<0.01
Start	37.8 ± 0.4	38.0 ± 0.5	37.5 ± 0.3	<0.001
Finish	39.2 ± 0.7	40.4 ± 0.4	38.1 ± 0.3	–
Body weight				
Baseline body weight (kg)	71.7 ± 11.9	72.3 ± 11.4	70.0 ± 12.8	0.46
Finish body weight (kg)	70.8 ± 11.7	71.3 ± 11.6	69.0 ± 12.6	0.48
ΔBody weight (%)	−1.5 ± 0.6	−1.7 ± 0.6	−1.5 ± 0.6	0.39
Classifying as dehydrated[b] (%)	21	29	24	0.67
Fluid intake				
Fluid intake before race (L)	1.18 ± 0.47	1.0 ± 0.4	1.3 ± 0.5	<0.05
Fluid intake during race (L)	0.06 ± 0.12	0.04 ± 0.06	0.07 ± 0.13	0.24

[a] Differences in split times were tested using a Two-Way Repeated Measures ANOVA.
[b] Participants classified as 'dehydrated' if body weight at the finish line was reduced ≥2%.