

Original Research Article

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Assessing core body temperature in a cool marathon using two pill ingestion strategies

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Abstract

Objectives: The purpose was to directly assess in-competition thermoregulatory responses in recreational runners during a city marathon conducted in cool, ambient conditions using a two-pill ingestion strategy.

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Methods: Thirty-two recreational runners (age: 38.7 ± 10.2 years, mass: 73.9 ± 11.0 kg, height: 177 ± 8 cm) were invited to participate in this study. Core temperature was continuously assessed using telemetric ingestible pills. Each runner swallowed two pills: the first pill (Pill 1) 11 h:47 min $\pm$ 1 h:01 min pre-race (before overnight sleep) and the second (Pill 2) 2 h:35 min $\pm$ 0 h:54 min pre-race (on waking).

Results: Pre-race core temperature for Pill 1 was significantly different from Pill 2, with values of 37.4 ± 0.4 °C and 37.1 ± 0.6 °C, respectively ($p=0.006$). The mean core temperature during the race was higher for Pill 1 compared to Pill 2 (38.5 ± 0.5 °C and 37.8 ± 1.0 °C, respectively; $p<0.001$). Peak core temperature was higher for Pill 1 compared to Pill 2 (39.1 ± 0.5 °C and 38.8 ± 0.5 °C, respectively; $p=0.03$). Post-race core temperature was higher for Pill 1 compared to Pill 2 (38.8 ± 0.7 °C and 38.1 ± 1.3 °C, respectively; $p=0.02$).

Conclusions: The timing of pill ingestion significantly impacted core temperature and hence timing of pill ingestion should be standardised (5 h:30 min–7 h prior to measurement). Despite the relatively cool ambient conditions during the race, a significant number of runners achieved a high core body temperature (≥ 39 °C), which was not accompanied by any signs of heat illness.

Keywords: core temperature; marathon; pill ingestion; telemetric pills; monitoring

Introduction

Climate change is increasing the frequency and intensity of extreme heatwaves [1] which is causing a subsequent rise in the heat-related deaths worldwide; a trend expected to continue [2]. To maintain homeostasis, humans thermoregulate through autonomic and behavioural mechanisms [3]. Under heavy heat loads resulting from exogenous and endogenous heat, the thermoregulatory ability of the human body may be saturated and result in a spectrum of heat-related illnesses. Heat stroke is the most severe presentation which can be life-threatening. In the context

of exercise this is known as exertional heat stroke [4], with an increased risk when body temperature rises to $>40.5^{\circ}\text{C}$ [5]. The incidence of exertional heat stroke in endurance running events increases from about 1 in 10,000 runners in cool weather to 2 in 1,000 runners in hot weather [6]. Sudden death occurs in 0.6–1.9 per 100,000 runners [7].

While recreational and competitive long-distance runners are at higher risk of heat illness [8–10] due to their elevated metabolic rate and frequent exposure to hot environments [6], high core temperatures have been observed in numerous events including Ironman triathlon [11, 12]. Additionally, the risk of suffering exertional heat illness is not confined to exercise in high temperature (i.e., $>30^{\circ}\text{C}$), as high core temperatures have also been reported in temperate conditions (13°C – 16°C) during competitive cycling (National Series Road Race) [13].

Major international sporting events such as the summer Olympic Games and the FIFA World Cup are held during the hottest months of the year, threatening the health of athletes, especially those not acclimatised to exercising in the heat [14]. Core temperature monitoring of athletes during training and competition in the heat, has become a mainstay in the safeguarding of athletes. The monitoring of core temperature has been traditionally conducted using either tympanic, gastrointestinal, or rectal thermometry with this assessment limited to post-event data evaluation. Recent developments in telemetric ingestible pills is now allowing for real-time monitoring of core temperature, alongside a variety of other important performance related parameters [15]. These advances in technology would permit the athletes' technical team to follow the athlete's data in real-time from anywhere with internet access [15], allowing for an early detection of heat stroke symptoms and accelerate a cooling intervention if needed. In order to obtain accurate core temperature, it is crucial to ensure that other factors such as fluid intake, do not affect the measurement obtained by the pill (i.e., cooling down the ingestible pill within the stomach). Previous research has supported the ingestion of telemetric pills the night prior to morning competitions, with this ingestion timing offering the best possibility to avoid any external factors [15, 16]. In contrast, other studies stipulate pill ingestion 3–6 h before the race [17–20]. To the best of our knowledge, no study has examined two different pill ingestion strategies before a marathon race in cool ambient conditions.

This is of crucial importance considering the physiology of intestinal passage of the pill: the gastrointestinal tract, comprising the stomach, small intestine, and large intestine, move ingested material via peristalsis [21]. After ingestion, the telemetric pill travels down the esophagus into the stomach, where it may remain for 30 min to several hours, with stomach acidic and churning affecting initial temperature data transmitted by the pill. The pill then enters the small intestine, starting in the duodenum and mixing with bile and pancreatic

juices [22]. Moving through the jejunum and ileum, temperature readings stabilize, reflecting a more accurate core temperature due to a reduced influence from ingested materials. Upon reaching the large intestine via the ileocecal valve, the pill's transit slows as water is absorbed and faces form. Finally, the pill reaches the rectum and is expelled within 12–72 h post-ingestion. Transit time can be influenced by factors such as food presence, fluid intake, gastrointestinal motility, and hormonal and neural regulation [23]. These factors cause a great inter-individual variability and an additional difficulty to standardize pill ingestion timings. Ideally, an individual assessment of the gastrointestinal transit time would be needed to personalize pill ingestion timing, as previously suggested using magnet tracking systems [24]. However, when testing athletes during a race this would not be possible, so a general approach should be taken.

Therefore, the purpose of this study was to assess thermoregulatory responses in amateur marathon runners during a city marathon conducted in cool, ambient conditions using two pill ingestion strategies. The results of this study are expected to inform researchers and practitioners on the best practice for future core temperature monitoring in individuals at risk of exertional heat illness. The summary of this article is presented in Figure 1.

Materials and methods

Participants

Forty-four (36 males and 8 females) non-elite distance runners (age: 38.7 ± 10.2 years, mass: 73.9 ± 11.0 kg, height: 177 ± 8 cm, BMI: 23.4 ± 2.6 kg/m²) were recruited to participate in this study. Individuals with a history of muscle disorder, cardiac, or kidney disease or those taking medications during the 2-week period before the competition were excluded from the study. Participants were informed of any potential risks associated with the experimental before providing written informed consent. The procedures followed the Helsinki declaration of 1975, as revised in 2000, and favourable opinion was received from the University of Brighton Research Ethics Committee.

Experimental protocol

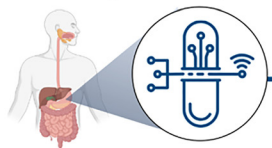
This study investigated in-race monitoring of core temperature during the Brighton marathon (10 April 2022, Brighton, UK), held in cool, ambient conditions. Mean dry temperature and relative humidity during the event ranged from 0 to 12°C and 42–64 %, respectively (Figure 2). The race start time was 9:45 am.

The day before the race, participants visited our testing area near the marathon finishing line and height

Assessing core body temperature in a cool marathon using two pill ingestion strategies

INTRODUCTION

Recent developments in telemetric ingestible pills is now allowing real-time monitoring of core temperature.



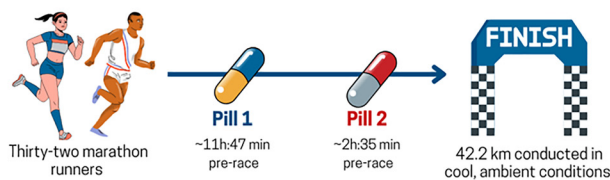
However, no study has examined two pill ingestion strategies before a marathon race in cool ambient conditions.



Objectives: to directly assess in-competition thermoregulatory responses in recreational runners during a city marathon conducted in cool, ambient conditions using a two-pill ingestion strategy.



METHODS



Each participant received **two e-Celsius ingestible capsules** for the measurement of core temperature. The variables of interest were: pre- and post-race **core temperature**, **peak core temperature**, **mean core temperature** (during the race), and **time to peak core temperature**.

RESULTS



Pre-race core temperature for **Pill 1** was $37.4 \pm 0.4^\circ\text{C}$ and for **Pill 2** was $37.1 \pm 0.6^\circ\text{C}$ with significant differences between pills.

Mean race core temperature was higher for **Pill 1** ($38.5 \pm 0.5^\circ\text{C}$) than **Pill 2** ($37.8 \pm 1.0^\circ\text{C}$). Similar results were observed for peak core temperatures and post-race core temperatures.



Despite the relatively cool ambient conditions, half of the participants ($n=16$) achieved a core temperature in excess of 39°C without signs of heat illness.

CONCLUSION

Pill ingestion timing significantly affected core temperature, suggesting a standardized ingestion time (5h:30 min to 7h pre-race). Despite cool conditions, many runners reached high core temperatures ($\geq 39^\circ\text{C}$) without signs of heat illness.



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Figure 1: Graphical representation of this study. Key points: (1) Pre- and post-race core temperatures were higher for Pill 1 than Pill 2 ($+0.4$ and $+0.7^\circ\text{C}$, respectively, on average). (2) Mean and peak core temperatures during the race were higher for Pill 1 compared to Pill 2 ($+0.7$ and $+0.3^\circ\text{C}$ respectively, on average), highlighting the importance of controlling the timing of ingestion to potentially identify early signs of heat-related illness. (3) A 5 h:30 min–7 h pre-race ingestion time is recommended. Despite cool conditions, a number of runners reached a core temperature of $\geq 39^\circ\text{C}$ without signs of heat illness. Figure created with BioRender.

[Correction added after online publication, 20 November 2024: the original caption “Graphical representation of this article. Figure created with BioRender.” was updated as seen above.]

and body mass were recorded (Seca model 220, Seca, Hamburg, Germany). Body mass was again recorded on race completion. Each participant received two e-Celsius ingestible capsules (BodyCap®, Caen, France) for the measurement of core temperature and were instructed to swallow one before going to bed and the second as soon

as they woke up. The race day during the warm-up, athletes arrived at the technical tent and were instrumented with a gateway (the device needed to receive and store core temperature data), which was placed in either a pocket or on the wrist with the use of a wrist band, according to the runners’ preference. After the race and as

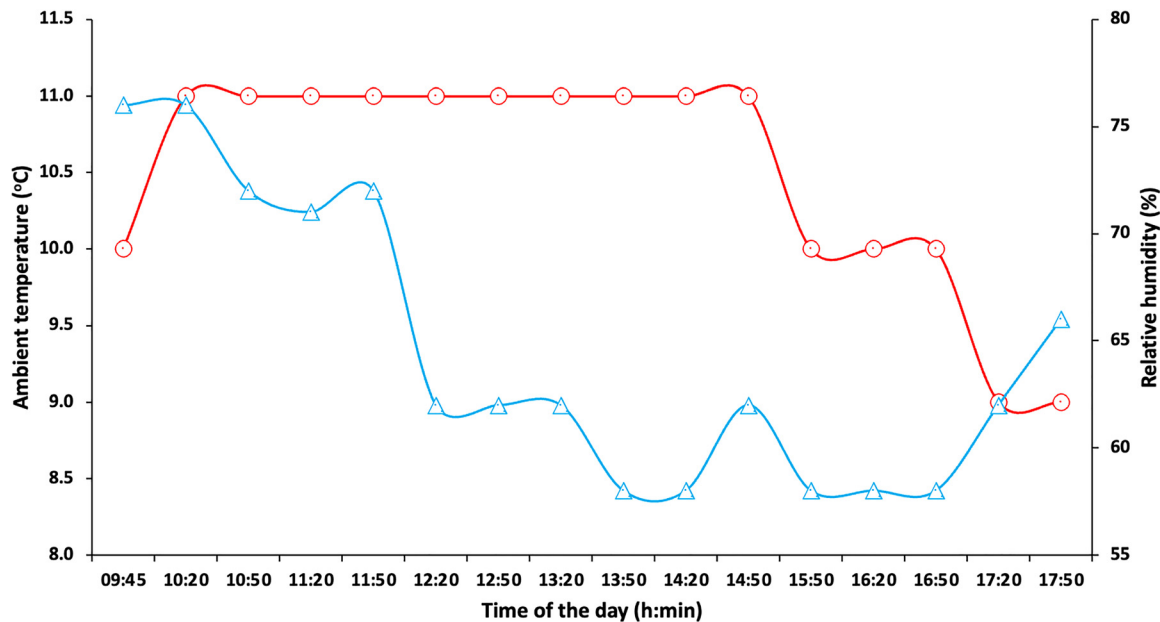


Figure 2: Ambient temperature and relative humidity during the 2022 Brighton marathon (weather temperature circles in the left Y-axis, humidity triangles in the right Y-axis). Data extracted from time and date (<https://www.timeanddate.com>).

soon as runners finished, they had their post-race weight measured and gave the Gateway back to the researchers. This swallowable pill passes through the gastrointestinal tract without affecting bodily functions, typically within 12–72 h. Additionally, this pill has the Food and Drug Administration (FDA) approval. No specific instructions were given regarding pace, hydration, or fuel ingestion strategies.

Measures

Core temperature

Two ingestible telemetric pills (precision 0.1 °C; recording every 30 s) were provided to each runner the day before the race, which were labelled as Pill 1 and Pill 2. Participants were instructed to swallow the two telemetric pills at different times prior to the race: the first (Pill 1) was ingested the evening preceding competition (11 h:47 min $\pm$ 1 h:01 min [range=10 h:26 min–15 h:35 min]), and the second (Pill 2) ingested the morning of the event (2 h:35 min $\pm$ 0 h:54 min [range=1 h:36 min–5 h:30 min] before the competition), encouraging transit through the stomach into the gastrointestinal tract, while minimising pill-loss through defaecation [25]. A gateway is used to capture the radio wave emitted by the pill and store the data transmitted by the telemetric pill [26]. Data access is provided via a wired connection (USB) to PC software for archiving. The assessment of pills affected by

fluids after ingestion was performed visually, when a sudden drop in core temperature was observed. Configured to start recording core temperature at 9:45 am, and official times were used to filter the data so the core temperature during competition was accurately determined. The variables of interest were: pre-and post-race core temperature, peak core temperature, mean core temperature (during the race) and time to peak core temperature.

Statistical analysis

Results are presented as mean $\pm$ standard deviation. Following the checking of normality assumption using Shapiro–Wilk and Levene’s test for homogeneity of variance, data were analysed using a paired sample t-test, whereas changes in core temperature from pre to post race, as well as the change in core temperature over time and distance during the race was analysed using a factorial repeated measures ANOVA (pill number $\times$ time; 2×2). A Pearson’s correlation coefficient was used to test the statistical relationship between different variables, such as core temperature during the race, core temperature post-race and race time. The magnitude of the difference was assessed by Hedges’ g (g), and was considered small ($0.2 < g \leq 0.5$), moderate ($0.5 < g \leq 0.8$), or large ($g > 0.8$). Data were analysed with Jamovi (Version 2.0.0.0), RStudio (v2022.07.155) and the tidyverse [27]. Statistical significance was set at $p < 0.05$ for all analyses.

Results

The body mass of participants decreased $1.9 \pm 2.0\%$ after the marathon race (pre-race body mass: 73.9 ± 11.0 kg, post-race body mass: 72.5 ± 10.5 kg, $p < 0.001$). All participants completed the race asymptomatic of heat illness in a time of $4 \text{ h}:05 \text{ min} \pm 45 \text{ min}$ (range=2:33–6:01 h:min) at an average pace of $5:56 \pm 1:11 \text{ min km}^{-1}$. Core temperature from both the Pill 1 and Pill 2 was obtained from 32 runners (26 males and 6

females, age: 39.1 ± 10.5 years, body mass: 72.7 ± 10.3 kg, height: 176.6 cm, BMI: $23.2 \pm 2.3 \text{ kg/m}^2$). Twelve runners (27 % loss) were removed from the original dataset of 44 runners as they only retained Pill 2; only runners that retained both pills were included in the final analysis. These 12 runners passed the first pill $9 \text{ h}:57 \text{ min} \pm 1 \text{ h}:33 \text{ min}$ (range=7 h:02 min–12 h:29 min) after taking the pill. All 44 runners retained Pill 2 and this was ingested $2 \text{ h}:35 \text{ min} \pm 0 \text{ h}:54 \text{ min}$ (range=1:36–5:30 h:min) before the race.

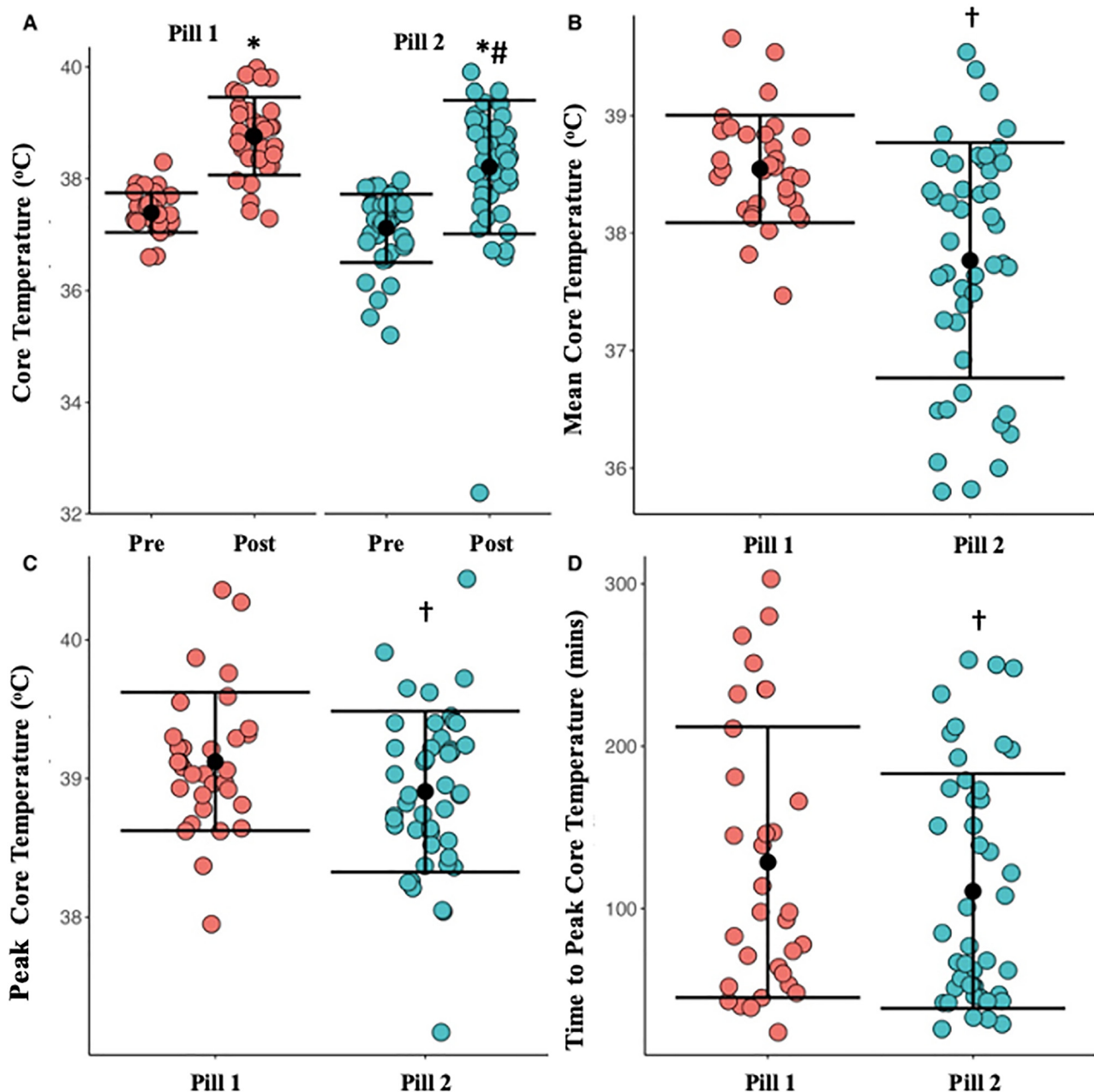


Figure 3: Core temperature and time to peak core temperature during the race as assessed through the two telemetric pills. A: Pre and post race core temperature; B: Mean core temperature; C: Peak core temperature; D: Time to peak core temperature; obtained from runners ($n=32$) competing in the 2022 Brighton Marathon. Data shown is mean $\pm$ standard deviation alongside individual data. * $p < 0.05$ pre-vs. post-race, # $p < 0.05$ post-race Pill 1 vs. Pill 2, † $p < 0.05$ Pill 1 vs. Pill 2. TCore; core temperature.

Pre-race core temperature for Pill 1 was $37.4 \pm 0.4^\circ\text{C}$ and for Pill 2 was $37.1 \pm 0.6^\circ\text{C}$ with significant differences between pills ($p=0.006$) (Figure 3A). Pre-race core temperature was lower than post-race core temperature for both pills ($F_{(1-31)}=64.82$, $p<0.05$, $g=1.9$), as well as being higher for Pill 1 compared to Pill 2 for pre and post-race ($F_{(1-31)}=9.48$, $p<0.05$, $g=0.4$), there was no interaction of core temperature across Time and Pill ($F_{(1-31)}=2.78$, $p>0.05$) (Figure 3A). The peak core temperature was higher for Pill 1 (39.1 ± 0.5 [range= 38.0 – 40.4] $^\circ\text{C}$) compared to Pill 2 (38.8 ± 0.5 [range= 37.2 – 39.9] $^\circ\text{C}$, $t_{(31)}=2.28$, $p=0.03$, $g=0.6$) (Figure 3C). Sixteen of the 32 runners who had core temperature measured using both pills, achieved a peak core temperature $\geq 39^\circ\text{C}$ and the remaining 16 runners achieved core temperature $\geq 38^\circ\text{C}$. At the end of the race, core temperature was $38.8 \pm 0.7^\circ\text{C}$ and $38.1 \pm 1.3^\circ\text{C}$ for the Pill 1 and Pill 2, respectively (Figure 3A). The time at which runners achieved their peak core temperature was 129 ± 84 min for Pill 1 and 99 ± 67 min for Pill 2, with no differences between the two pills ($t_{(31)}=1.89$, $p=0.07$, $g=0.4$) (Figure 3D). The mean core temperature during the race was higher for Pill 1 (38.5 ± 0.5 [range= 37.5 – 39.7] $^\circ\text{C}$) compared to Pill 2 (37.8 ± 1.0 [range= 35.8 – 39.5] $^\circ\text{C}$, $t_{(31)}=3.85$, $p<0.001$, $g=0.8$) (Figure 3B). Core temperature before the 35th km for Pill 1 was $38.5 \pm 0.5^\circ\text{C}$ and for the Pill 2 was $37.8 \pm 0.9^\circ\text{C}$, with significant differences between two pills ($t_{(31)}=2.97$, $p=0.001$, $g=0.9$). Core Temperature after the 35th km of the race for the Pill 1 was $38.6 \pm 0.6^\circ\text{C}$ and for Pill 2 was $37.9 \pm 1.3^\circ\text{C}$, with no differences between the two pills ($t_{(31)}=2.63$, $p=0.07$, $g=0.7$). Core temperature measured

by both pills significantly increased after the 35th km of the race (Figures 4 and 5). Individual core temperature responses during the race illustrating the impact of fluid intake on core temperature assessment in all runners is depicted in Figure 6. Of the 44 runners that ingested both pills, only 32 runners were included in this study as 12 runners only retained Pill 2. Among these 32 runners, Pill 2 core temperature responses were affected by fluid intake in 21 runners (given visual observations of sudden drops in core temperature evolution), while responses in 11 runners were not affected. The Pill 2 ingestion time of these 21 and 11 runners was $2\text{ h}:49\text{ min} \pm 1\text{ h}:00\text{ min}$ (range= $1\text{ h}:00\text{ min}$ – $4\text{ h}:44\text{ min}$) and $2\text{ h}:27\text{ min} \pm 0\text{ h}:38\text{ min}$ (range= $1\text{ h}:22\text{ min}$ – $3\text{ h}:20\text{ min}$) respectively, with significant differences between 21 and 11 runners ($p<0.001$, $g=0.4$).

Regarding core temperature during the race, the Pearson's correlation coefficient demonstrated no significant associations between core temperature during marathon and running speed for Pill 1 ($r=-0.022$, $p=0.90$) and Pill 2 ($r=-0.056$, $p=0.76$). Similarly, no relationship was observed between the core temperature post-race and running speed for Pill 1 ($r=0.030$; $p=0.87$) and Pill 2 ($r=0.080$, $p=0.67$).

Pre-race (baseline) core temperature measured by Pill 1 (male: $37.3 \pm 0.3^\circ\text{C}$, female: $37.7 \pm 0.3^\circ\text{C}$, $p=0.028$, $g=1.2$) and Pill 2 (male: $37.1 \pm 0.6^\circ\text{C}$, female: $37.5 \pm 0.2^\circ\text{C}$, $p=0.003$, $g=0.7$) were significantly higher in female runners compared to males. During the marathon, the core temperature of female runners were significantly higher than males as assessed by Pill 2 (male: $37.7 \pm 1.1^\circ\text{C}$, female: $38.4 \pm 0.5^\circ\text{C}$, $p=0.025$, $g=0.7$)

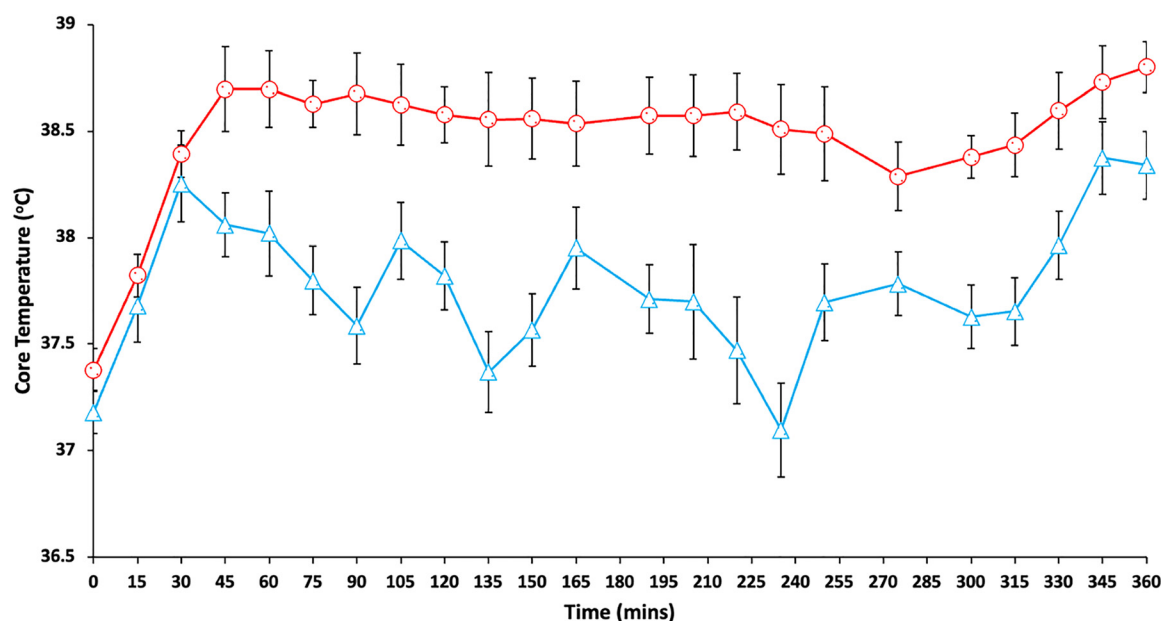


Figure 4: Core temperature recorded by two ingestible pills (Pill 1 in red; Pill 2 in blue) every 15 min during the 2022 Brighton Marathon. Data shown is mean $\pm$ standard deviation.

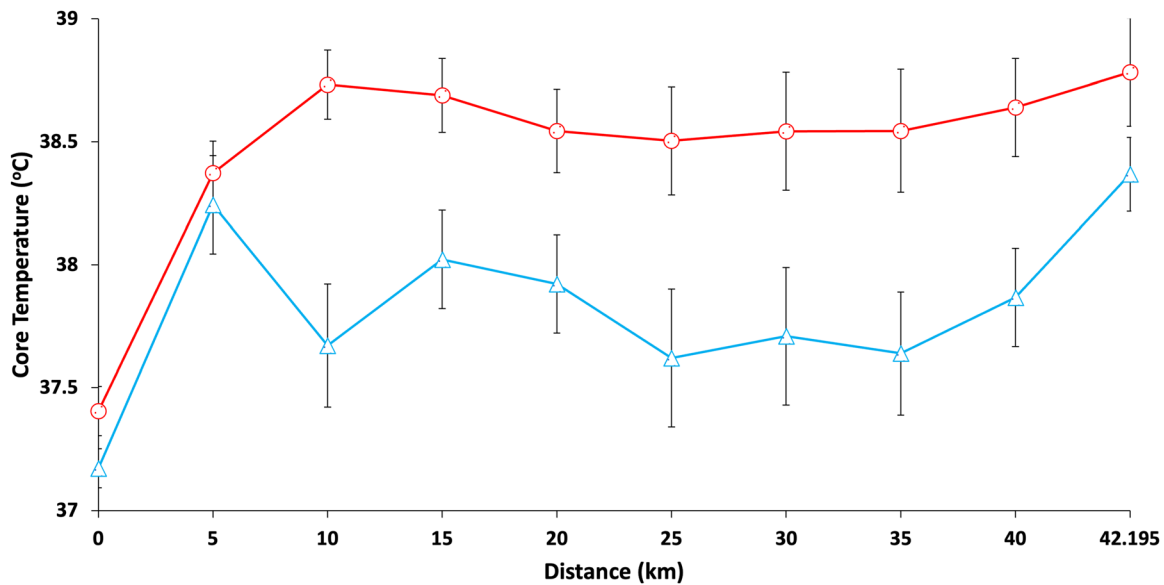


Figure 5: Core temperature recorded by two ingestible capsules (Pill 1 in red, Pill 2 in blue) every 5 km during the 2022 Brighton Marathon. Data shown is mean $\pm$ standard deviation.

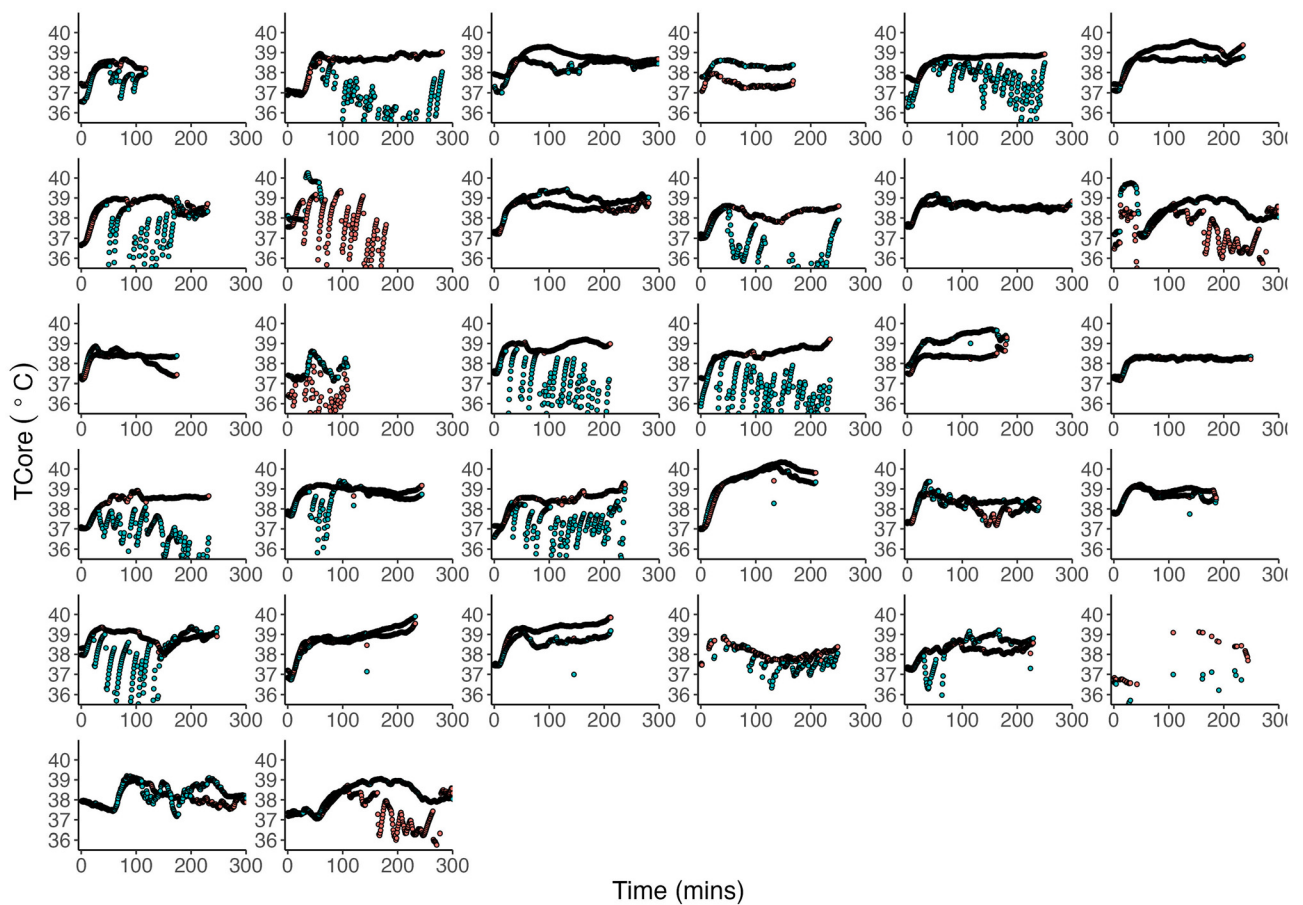


Figure 6: Individual core temperature responses during the race illustrating the impact of fluid intake on core temperature assessment in all runners (Pill 1 in red, Pill 2 in blue).

but not by Pill 1 (male: $38.6 \pm 0.5^\circ\text{C}$, female: $38.5 \pm 0.3^\circ\text{C}$, $p=0.89$, $g=0.2$). There were no other sex differences in core temperature assessment between pills either in terms of peak core temperature (Pill 1 male: $39.1 \pm 0.5^\circ\text{C}$, female: $39.3 \pm 0.6^\circ\text{C}$, $p=0.57$, $g=0.4$; Pill 2 male: $38.8 \pm 0.5^\circ\text{C}$, female: $38.9 \pm 0.6^\circ\text{C}$, $p=0.83$, $g=0.2$), end of race temperature (Pill 1 male: $38.7 \pm 0.7^\circ\text{C}$, female: $38.9 \pm 0.7^\circ\text{C}$, $p=0.68$, $g=0.3$; Pill 2 male: $38.1 \pm 1.4^\circ\text{C}$, female: $38.5 \pm 0.5^\circ\text{C}$, $p=0.24$, $g=0.3$), and time to peak core temperature (Pill 1 male: 135 ± 88 min, female: 101 ± 52 min, $p=0.24$, $g=0.4$; Pill 2 male: 101.7 ± 71.8 min, female: 89.5 ± 43.9 min, $p=0.60$, $g=0.2$).

Discussion

The aim of this study was to evaluate the thermoregulatory responses of amateur marathon runners during a city marathon held in cool ambient conditions, using two pill ingestion strategies. To our knowledge, the current study is the first to demonstrate the critical importance of the pill ingestion timing for accurately monitoring of core temperature during prolonged exercise, thereby avoiding underestimation of accurate core temperature data. We found core temperature readings were significantly lower post-race when the pill was ingested on mean average 2 h:30 min prior to the race, as opposed to 12-h prior to the race (Figure 3A). The ingestion of the pill approximately 2 h:30 min prior to the race also resulted in lower core temperatures (Figure 3B), reduced peak (Figure 3C) and (non-significantly $p=0.07$) shorter time to peak (Figure 3D) core temperature when compared to the pill ingested the night before to the race. In the current study, the results showed significant differences between the two pill ingestion strategies in the peak core temperature before the race, post-race, and during the race, with Pill 1 leading to higher core temperature before the race than Pill 2. These results reflect the great importance of the timing of the pill ingestion prior to a competition. Pill location in the intestinal tract may influence temperature measurements and the measured response during body heating or cooling [19]. If the pill is located in the stomach or upper intestinal tract, it may be influenced by ingestion of saliva, food, or liquids [19].

In the study by Notley et al. [28], it is discussed how different compartments of the intestinal system exhibit varying temperatures due to differences in blood perfusion. Areas with higher perfusion show greater temperature changes in response to external factors such as workload or running speed. This suggests that the location of the pill within the intestinal tract can significantly affect the temperature readings. A pill located deeper in the intestinal tract might be less influenced by rapid changes, as

fluctuations in blood perfusion and conductive heat transfer reach deeper tissues more slowly. This could provide more stable temperature measurements, making it a potentially better location for accurate core temperature assessments [28]. These insights highlight the importance of considering pill placement depth within the intestinal tract to enhance the reliability of temperature measurements, especially during carrying physical exertions.

Our data reported pre-race core temperature readings (Pill 1 was $37.4 \pm 0.4^\circ\text{C}$ and for the Pill 2 was $37.1 \pm 0.6^\circ\text{C}$) similar to previous studies conducted by Byrne et al. [29] and Olcina et al. [17] prior to half-marathon race and Ironman triathlon in hot environments (26.5°C and 24.7°C , respectively). Our data suggest that pre-race core temperature is not lower in cool ambient conditions ($0\text{--}12^\circ\text{C}$) compared to hot environments.

An important finding of this study was that the maximum core temperature recorded during this study was $39.1 \pm 0.5^\circ\text{C}$. Despite the relatively cool ambient conditions, half of the participants ($n=16$) achieved a core temperature in excess of 39°C and all runners ($n=32$) achieved a peak core temperature of at least 38°C . This is in line with previous studies using other exercise modalities such as Ross et al. [13] who measured core temperature during cycling in cool environmental temperatures ($13\text{--}16^\circ\text{C}$) and most participants also reached relatively high peak core temperatures in excess of 39°C , suggesting that amateur runners reach high core temperatures even when exercising in cool ambient conditions. This study also showed similar maximum core temperatures to those reported in numerous studies during official competitions in hot environments, including temperatures of $39.2 \pm 0.4^\circ\text{C}$ in elite cyclists [30], $39.6 \pm 0.6^\circ\text{C}$ in elite race-walkers and marathon runners [25], 38.1°C in Ironman triathletes [12], 39.5°C in football players [31], and 38.7°C in tennis players [32].

The highest core temperature recorded in this study was 40.4°C which is similar to elite athletes competing in hot conditions. For example, 85 % of individuals participating in UCI Road World Championships (34 of 40 cyclists) reached a peak core temperature of at least 39° , while 25 % (10 of 40 cyclists) reached 40°C or more [30]. Similarly, Byrne et al. [29] showed that 18 heat-acclimatised male soldiers participating in a 21 km running race reached a peak core temperature of at least 39°C , with 56 % reaching 40°C or more and 11 % reaching a minimum of 41°C .

In our study, at the end of the race, core temperature was $38.8 \pm 0.7^\circ\text{C}$ and $38.1 \pm 1.3^\circ\text{C}$ for the Pill 1 and Pill 2, respectively. Our findings are in line with previous studies; for example, during the 2019 World Athletics Championships in Doha post-race core temperature was $39.6 \pm 0.6^\circ\text{C}$ [25], while Byrne et al. [29] reported a core temperature at the

end of the half-marathon race of $39.9 \pm 0.8^\circ\text{C}$. On the other hand, Stearns et al. [12] observed at the end of the race core temperatures of $38.3 \pm 0.6^\circ\text{C}$ in the fastest athletes, while the slowest remained in normothermia with a core temperature of $37.3^\circ\text{C} \pm$ when competing in the Kona Ironman. In our study, the finishing time of runners did not influence core temperature. The conflicting results from our study compared to the study of Stearns et al. [12] may be due to the different subjects' characteristics and different pills ingestion strategies. For example, in the study of Stearns et al. [12] the subjects were elite triathletes participating in the Ironman World Championship, who likely attained a greater metabolic heat production and were more acclimatised to the heat, while in our study the participants were all recreational runners.

Our findings for the time at which athletes achieved their peak core temperature was at 129 ± 83.4 min for Pill 1 and 99.4 ± 67 min for Pill 2 with a statistical trend of $p=0.07$. This is of crucial importance as the differing time to peak temperature could hinder an effective early diagnosis of exertional heat stroke. In the study of Byrne et al. [29] during the half-marathon race, the time at which runners achieved their peak core temperature was 86 ± 36 min. In the study of Olcina et al. [17] the core temperature of Ironman triathletes remained high (hyperthermic state) for at least 60 min after the Ironman World Championship ($38.7 \pm 0.4^\circ\text{C}$), which represents a somewhat surprising and novel finding. After cessation of exercise, the rate at which body produces heat decreases while the mechanisms used to dissipate heat remain in operation until the core temperature returns to its normal level. The effectiveness of the thermoregulatory system in regulating body temperature is influenced by the acclimatization state of the individual [33]. The possible explanations for these discrepancies could be related to different athletic events, subjects' characteristics and timing of the pill ingestion. In the study of Byrne et al. [29] the subjects were heat-acclimatised male soldiers participating in half-marathon race and ingested the pill 8–10 h before the race. In addition, in the study of Olcina et al. [17] the participants were highly trained triathletes participating in Ironman triathlon and the time pill ingestion was 3 h before the race.

The data in the Figure 5 suggest that the rate of increase in the core temperature per km was higher during the first 10 km and at the end of the race (after 35th km). This finding alerts us to the observation that core temperature increases significantly towards the end of the marathon even in cool ambient conditions. This occurrence proves that core temperature monitoring during a marathon is of crucial importance, even in cool ambient conditions but when other factors interfere (i.e. solar radiation).

In our study the body mass decreased a mean average of $1.9 \pm 2.0\%$ after the marathon race, similar to the study of Del Coso et al. [34] that found body mass reduction by $2.2 \pm 1.2\%$ after the marathon race. Some research claims that a loss in body mass during marathon events (avoiding hot ambient conditions) contributes to an athletes' success, especially for those who lose substantially more than 3–4 % body mass weight during competition [17]. A limitation in our study is that pre-race body mass was measured the day before the race (morning and evening) and not the morning of the race.

In this study, we observed a significant relationship between core temperature during the marathon and core temperature post-race for Pill 1, but not for Pill 2, reflecting the greater variability in the temperature monitoring by Pill 2. Previous studies have suggested that an ingestion time 6–12 h before competition would render the body temperature unaffected by subsequent fluid ingestion [18, 35, 36]. Likewise, in our study, there is no correlation between core temperature during marathon and running speed and between core temperature post-race and running speed for both the two pills. Numerous studies in the literature examined the impact of high core temperature on performance in distance runners and reported that faster runners experience greater decreases in performance than slower runners. Faster runners perform the same task at a higher metabolic intensity than slower runners, and therefore hot environmental conditions may affect their performance to a greater extent [37, 38]. In the study of Stearns et al. [12] the slowest triathletes remained in normothermia compared to the fastest. These studies illustrate how exercise intensity is a major driver of core temperature, which suggest that if our study would have included faster runners, core temperatures could have been even higher. Another explanation for the different physiological responses to heat is the acclimation status of the runners. Almost all runners participating in this study lived and trained in the city of Brighton (and surrounding areas) and may have been acclimatised to cool ambient conditions.

Although there were very unequal numbers of male ($n=26$) and female ($n=6$) subjects in the present study and the study was almost certainly underpowered for sex comparisons, the results are intriguing as they revealed significantly higher core temperature responses in the female runners (both pills) at baseline (Pill 1 male: $37.3 \pm 0.3^\circ\text{C}$, female: $37.7 \pm 0.3^\circ\text{C}$, $p=0.028$, $g=1.2$; and Pill 2 male: $37.1 \pm 0.6^\circ\text{C}$, female: $37.5 \pm 0.2^\circ\text{C}$, $p=0.003$, $g=0.7$) and during the marathon for Pill 2 (i.e., male: $37.7 \pm 1.1^\circ\text{C}$, female: $38.4 \pm 0.5^\circ\text{C}$, $p=0.025$, $g=0.7$). While some studies reported no sex differences in body temperature during exercise [39], others demonstrated a lower sweat capacity in females than

in males for a given amount of metabolic heat generation [40]. As a result, heat dissipation was decreased but only at very high exercise workloads [40]. Notably, our sex differences in core temperature at baseline and during exercise may reflect the higher intensity of running in the female runners as evidenced by their faster marathon finishing time than the male runners (males: 4 h:19 min $\pm$ 51 min, females: 3 h:52 min $\pm$ 39 min), and therefore the higher metabolism being the major driver of the core temperature in the female runners. Sex-related differences in thermoregulation and thermal balance during whole-body cold exposure primarily stem from anthropometric and body composition characteristics [41], as males and females have similar shivering sensitivity [42]. For example, when comparing males and females with the same total body mass, their surface areas are comparable. However, females generally have a higher proportion of body fat, which improved their insulation capabilities. In cases where males and females have equivalent subcutaneous fat thickness, females typically have a larger surface area but smaller total body mass than males. This results in increased convective heat transfer and greater total heat loss during rest in cold conditions. Therefore, unless shivering thermogenesis adequately compensates, females may experience a faster decline in core temperature than males, especially in severe cold, due to their reduced capacity for thermogenic response [43].

In hot environments the thicker subcutaneous fat layer in women can slow down heat loss, making it more challenging to dissipate heat efficiently. This can result in a higher risk of hyperthermia during prolonged exercise in the heat. Conversely, men, with relatively thinner subcutaneous fat layers, might dissipate heat more effectively in hot conditions but may be more susceptible to heat loss in cold environments [44]. These differences highlight the complex interactions between body composition, environmental conditions, thermoregulatory responses and sex. Therefore, it is crucial to analyze sex-based variations in thermoregulation during exercise.

In the present study, 12 runners were removed from the original dataset of 44 runners as they only retained Pill 2 (only runners who retained both pills were included in the final analysis). The pill 1 of these 12 runners was evacuated before the race. Pill retention time in these 12 runners was less than the pill retention time of the 32 runners who retained Pill 1 until the start of the race (i.e., 11 h:47 min $\pm$ 1 h:01 min [range=10 h:26 min–15 h:35 min]). In contrast, all 44 runners retained Pill 2 until the end of the race and was ingested 2:35 $\pm$ 0:54 h:min (range=1:36–5:30 h:min) before the race. However, this close proximity to the start of the race meant that Pill 2 was retained

in the stomach, allowing fluid intake to impact on the measurement of core temperature (Figures 4 and 5). Individual core temperature responses during the race demonstrate this impact of fluid intake on core temperature in 21 of the 32 runners using Pill 2 (Figure 6). Collectively and considering the results obtained in the present study together with the findings of previous literature, we suggest the best timing of pill ingestion being between 5 h:30 min to 7 h before the race. This timing is in agreement with the study by Ruddock et al. [19] that recommended a pill ingestion time of 6 h prior to the intestinal temperature measurement to account for sensor gastric emptying and expulsion time. This ingestion time has been reported to be sufficient to allow the telemetry pill to pass into the gastrointestinal tract and produce valid intestinal temperature measurement [45]. This pill ingestion time is also supported by Notley et al. [20] and Lee et al. [18] that recommended abstinence from food and fluid consumption during data collection to avoid the associated artifacts, which can persist for about 6 h.

On the other hand, there are other studies that use a pill ingestion time of 6–12 h before measurement [18, 29, 30]. For example, Wilkinson et al. [16] reported that ingesting the pill before overnight sleep (for morning competitions) and allowing for at least 10 h before core temperature measurement appears to offer the best possibility of the pill being unaffected by subsequent fluid ingestion. Similarly, Gant et al. [46] reported that the ingestion period of 10 h seems to have enabled sufficient progress of the sensor through the gastrointestinal tract. More recently, O'Brien et al. [36] suggested that their measurements were more stable because they had waited at least 12 h after pill ingestion to begin data collection. Batchelder et al. [47] suggested that to reduce the effect of drinking water on the temperature readings, participants should aim to ingest the pill between 7 and 8 h prior to the event. The conflicting pill ingestion times may be due to the different subject characteristics, pill characteristics, exercise and environmental conditions. For example, Wilkinson et al. [16] studied firefighters, O'Brien et al. [36] studies soldiers, Batchelder et al. [47] studied ice hockey players, while Gant et al. [46] studied football players.

In conclusion, we show that the timing of pill ingestion can significantly impact core temperature determination and hence timing of pill ingestion should be standardised. Specifically, our results suggested that pills should be ingested 5 h:30 min to 7 h prior to the race in order not to be affected by fluid intake and passed. Despite the relatively cool ambient conditions, a significant number of runners achieved a high body core temperature (16 of the 32 runners achieved a peak core temperature $\geq 39^\circ\text{C}$ and the remaining 16 runners achieved core temperature $\geq 38^\circ\text{C}$). This finding

suggests that exercise intensity is a major driver of core temperature during a marathon in recreational, non-acclimatised, runners. This high body temperature was not accompanied by any signs and symptoms of heat illness.

Limitations

A major limitation of the present study was the lack of dietary and exercise training control prior to marathon. An additional limitation was that pre-race body mass measured the day before the race (morning and evening) and not the day of the race. Another limitation in the present study was the very unequal numbers of male ($n=26$) and female ($n=6$) subjects that limits the interpretation of the sex differences in core temperature data during the marathon. Drinking strategies were not registered either, which also biased the results. Moreover, in this study, we did not collect other variables related to exercise-induced heat stress, such as heart rate or other biomarkers (e.g., IL-6), which should be further explored in future studies.

Our results suggest that the pills should be ingested 5 h:30 min–7 h prior to the race to avoid being affected by fluid intake and to ensure they pass through the digestive system. However, a major limitation is that this timing would require athletes to wake up in the middle of the night to ingest the pill. A potential alternative for morning races and athletes with sleeping issues is to introduce the pill via rectum before the race. We have recently used this strategy during a World Triathlon competition with athletes unable to ingest the pill orally and this has been observed to be a feasible and good alternative.

Finally, while telemetric pills provide significant benefits for health monitoring, it is essential to address their sustainability concerns. Telemetric pills are made of plastic and electronics and are single-use, which means they are disposed of in the toilet and water, posing a negative impact on the environment. By emphasizing reusable designs, eco-friendly materials, and improved disposal methods, the environmental impact of these devices can be mitigated. Balancing technological innovation with environmental responsibility is crucial for sustainable healthcare solutions.

Future directions

The fact that even in cool ambient conditions >50 % non-collapsed runners achieved core temperature higher than 39 °C suggests the need for other measures in combination with core temperature to assess the risk of exertional heat

stroke during competition. In particular, combining core and skin temperature responses that are associated with collapse and/or withdrawal from competition with biomechanical parameters that can help identifying disturbances in gait, could help in early identification by medical staff of possible aggravated hyperthermia situations.

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Research ethics: This study was approved by the Ethics Committee of the University of Brighton. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013).

Informed consent: All runners were informed of the procedures and risks of the study and provided informed consent.

Author contributions: GG, BMP, FG, AP, MM, DF, AR, LK, TL, MS, SR, and YP conceived and designed the research. GG, AP, RB, MM, DF, AR, LK, TL, MS, and YP performed the study. GG, FG, AP, and YP analysed the data. GG and FG conducted statistical analysis. GG, FG, BMP and YP interpreted the results of the experiment. GG, BMP, FG, and YP drafted the manuscript. The author(s) have (has) accepted responsibility for the entire content of this manuscript and approved its submission.

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References

1. Romanello M, McGushin A, Di Napoli C, Drummond P, Hughes N, Jamart L, et al. The 2021 report of the lancet countdown on health and climate change: code red for a healthy future. *The Lancet* 2021;398: 1619–62.
2. Watts N, Amann M, Arnell N, Ayeb-Karlsson S, Beagley J, Belesova K, et al. The 2020 report of the lancet countdown on health and climate change: responding to converging crises. *The Lancet* 2021;397: 129–70.
3. Sorensen C, Hess J. Treatment and prevention of heat-related illness. *N Engl J Med* 2022;387:1404–13.
4. Zamanian Z, Sedaghat Z, Hemehrezaee M, Khajehnasiri F. Evaluation of environmental heat stress on physiological parameters. *J Environ Health Sci Eng* 2017;15:24.
5. Hosokawa Y, Racinais S, Akama T, Zideman D, Budgett R, Casa DJ, et al. Prehospital management of exertional heat stroke at sports competitions: international olympic committee adverse weather impact expert working group for the olympic games Tokyo 2020. *Br J Sports Med* 2021;55:1405–10.

6. Rodrigues Júnior JFC, McKenna Z, Amorim FT, Da Costa Sena AF, Mendes TT, Veneroso CE, et al. Thermoregulatory and metabolic responses to a half-marathon run in hot, humid conditions. *J Therm Biol* 2020;93:102734.
7. Waite O, Smith A, Madge L, Spring H, Noret N. Sudden cardiac death in marathons: a systematic review. *Phys Sportsmed* 2016;44:79–84.
8. Maffetone PB, Malcata R, Rivera I, Laursen PB. The Boston marathon versus the world marathon majors. *PLoS One* 2017;12:e0184024.
9. Miller-Rushing AJ, Primack RB, Phillips N, Kaufmann RK. Effects of warming temperatures on winning times in the Boston marathon. *PLoS One* 2012;7:e43579.
10. Roberts WO. Determining a ‘do not start’ temperature for a marathon on the basis of adverse outcomes. *Med Sci Sports Exerc* 2010;42: 226–32.
11. Laursen PB, Suriano R, Quod MJ, Lee H, Abbiss CR, Nosaka K, et al. Core temperature and hydration status during an Ironman triathlon. *Br J Sports Med* 2006;40:320–5.
12. Stearns RL, Nolan JK, Huggins RA, Maresh CM, Munöz CX, Pagnotta KD, et al. Influence of cold-water immersion on recovery of elite triathletes following the ironman world championship. *J Sci Med Sport* 2018;21: 846–51.
13. Ross ML, Stephens B, Abbiss CR, Martin DT, Laursen PB, Burke LM. Fluid balance, carbohydrate ingestion, and body temperature during men’s stage-race cycling in temperate environmental conditions. *Int J Sports Physiol Perform* 2014;9:575–82.
14. Racinais S, Hosokawa Y, Akama T, Bermon S, Bigard X, Casa DJ, et al. IOC consensus statement on recommendations and regulations for sport events in the heat. *Br J Sports Med* 2023;57:8–25.
15. Muniz-Pardos B, Angeloudis K, Guppy FM, Keramitsoglou I, Sutehall S, Bosch A, et al. Wearable and telemedicine innovations for olympic events and elite sport. *J Sports Med Phys Fit* 2021;61. <https://doi.org/10.23736/s0022-4707.21.12752-5>.
16. Wilkinson DM, Carter JM, Richmond VL, Blacker SD, Rayson MP. The effect of cool water ingestion on gastrointestinal pill temperature. *Med Sci Sports Exerc* 2008;40:523–8.
17. Olcina G, Crespo C, Timón R, Mjaanes JM, Calleja-González J. Core temperature response during the marathon portion of the ironman world championship (Kona-Hawaii). *Front Physiol* 2019;10:1469.
18. Lee SMC, Williams WJ, Schneider SM. Core temperature measurements during submaximal exercise: esophageal, rectal, and intestinal temperature. Houston (TX): NASA Johnson Space Center; 2000.
19. Ruddock AD, Tew GA, Purvis AJ. Reliability of intestinal temperature using an ingestible telemetry pill system during exercise in a hot environment. *J Strength Condit Res* 2014;28:861–9.
20. Notley SR, Meade RD, Kenny GP. Time following ingestion does not influence the validity of telemetry pill measurements of core temperature during exercise-heat stress: the journal *Temperature* toolbox. *Temperature* 2021;8:12–20.
21. Stillhart C, Vučićević K, Augustijns P, Basit AW, Batchelor H, Flanagan TR, et al. Impact of gastrointestinal physiology on drug absorption in special populations – an UNGAP review. *Eur J Pharmaceut Sci* 2020;147:105280.
22. Laulicht B, Tripathi A, Schlageter V, Kucera P, Mathiowitz E. Understanding gastric forces calculated from high-resolution pill tracking. *Proc Natl Acad Sci USA* 2010;107:8201–6.
23. Grosset C, Daniaux L, Guzman DS, Weber ES, Zwingenberger A, Paul-Murphy J. Radiographic anatomy and barium sulfate contrast transit time of the gastrointestinal tract of bearded dragons (*Pogona vitticeps*). *Vet Radiol Ultrasound* 2014;55:241–50.
24. Worsøe J, Fynne L, Gregersen T, Schlageter V, Christensen LA, Dahlerup JF, et al. Gastric transit and small intestinal transit time and motility assessed by a magnet tracking system. *BMC Gastroenterol* 2011;11:145.
25. Racinais S, Ihsan M, Taylor L, Cardinale M, Adami PE, Alonso JM, et al. Hydration and cooling in elite athletes: relationship with performance, body mass loss and body temperatures during the doha 2019 IAAF world athletics championships. *Br J Sports Med* 2021;55:1335–41.
26. Muniz-Pardos B, Sutehall S, Angeloudis K, Shurlock J, Pitsiladis YP. The use of technology to protect the health of athletes during sporting competitions in the heat. *Front Sports Act Living* 2019;1:38.
27. Wickham H, Averick M, Bryan J, Chang W, McGowan L, François R, et al. Welcome to the tidyverse. *J Open Source Softw* 2019;4:1686.
28. Notley SR, Mitchell D, Taylor NAS. A century of exercise physiology: concepts that ignited the study of human thermoregulation. Part 1: foundational principles and theories of regulation. *Eur J Appl Physiol* 2023;123:2379–459.
29. Byrne C, Lee JKW, Chew SAN, Lim CL, Tan EYM. Continuous thermoregulatory responses to mass-participation distance running in heat. *Med Sci Sports Exerc* 2006;38:803–10.
30. Racinais S, Moussay S, Nichols D, Travers G, Belfekih T, Schumacher YO, et al. Core temperature up to 41.5 °C during the UCI road cycling world championships in the heat. *Br J Sports Med* 2019;53:426–9.
31. Mohr M, Nybo L, Grantham J, Racinais S. Physiological responses and physical performance during football in the heat. *PLoS One* 2012;7: e39202.
32. Périard JD, Racinais S, Knez WL, Herrera CP, Christian RJ, Girard O. Thermal, physiological and perceptual strain mediate alterations in match-play tennis under heat stress. *Br J Sports Med* 2014;48:i32–8.
33. Racinais S, Havenith G, Aylwin P, Ihsan M, Taylor L, Adami PE, et al. Association between thermal responses, medical events, performance, heat acclimation and health status in male and female elite athletes during the 2019 doha world athletics championships. *Br J Sports Med* 2022;56:439–45.
34. Del Coso J, Salinero JJ, Abián-Vicen J, González-Millán C, Garde S, Vega P, et al. Influence of body mass loss and myoglobinuria on the development of muscle fatigue after a marathon in a warm environment. *Appl Physiol Nutr Metabol* 2013;38:286–91.
35. Edwards B, Waterhouse J, Reilly T, Atkinson G. A comparison of the suitabilities of rectal, gut, and insulated axilla temperatures for measurement of the circadian rhythm of core temperature in field studies. *Chronobiol Int* 2002;19:579–97.
36. O’Brien C, Hoyt RW, Buller MJ, Castellani JW, Young AJ. Telemetry pill measurement of core temperature in humans during active heating and cooling. *Med Sci Sports Exerc* 1998;30:468–72.
37. Gasparetto T, Nessler C. Diverse effects of thermal conditions on performance of marathon runners. *Front Psychol* 2020;11:1438.
38. Del Coso J, Fernández D, Abián-Vicen J, Salinero JJ, González-Millán C, Areces F, et al. Running pace decrease during a marathon is positively related to blood markers of muscle damage. *PLoS One* 2013;8:e57602.
39. Vargas NT, Chapman CL, Sackett JR, Johnson BD, Gathercole R, Schlader ZJ. Thermal behavior differs between males and females during exercise and recovery. *Med Sci Sports Exerc* 2019;51:141–52.
40. Gagnon D, Crandall CG, Kenny GP. Sex differences in postsynaptic sweating and cutaneous vasodilation. *J Appl Physiol* 2013;114:394–401.
41. Toner MM, McArdle WD. Human thermoregulatory responses to acute cold stress with special reference to water immersion [internet]. In: Prakash YS, editor. *Comprehensive physiology*. Wiley; 1996 [cited 2024 Jul 1]. 379–97 pp. Available from: <https://onlinelibrary.wiley.com/doi/10.1002/cphy.cp040117>.

42. McArdle WD, Magel JR, Gergley TJ, Spina RJ, Toner MM. Thermal adjustment to cold-water exposure in resting men and women. *J Appl Physiol* 1984;56:1565–71.
43. Castellani JW, Young AJ. Human physiological responses to cold exposure: acute responses and acclimatization to prolonged exposure. *Auton Neurosci* 2016;196:63–74.
44. Schoech L, Allie K, Salvador P, Martinez M, Rivas E. Sex differences in thermal comfort, perception, feeling, stress and focus during exercise hyperthermia. *Percept Mot Skills* 2021;128:969–87.
45. Domitrovich JW, Cuddy JS, Ruby BC. Core-temperature sensor ingestion timing and measurement variability. *J Athl Train* 2010;45:594–600.
46. Gant N, Atkinson G, Williams C. The validity and reliability of intestinal temperature during intermittent running. *Med Sci Sports Exerc* 2006;38:1926–31.
47. Batchelder BC, Krause BA, Seegmiller JG, Starkey CA. Gastrointestinal temperature increases and hypohydration exists after collegiate men's ice hockey participation. *J Strength Condit Res* 2010;24:68–73.