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Thermoregulatory demands of épée fencing during competition

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ABSTRACT

The International Olympic Committee recently introduced a consensus statement on recommendations for outdoor sports in the heat. However, indoor sports such as fencing whereby athletes are required to wear full body protective clothing when competing have received no recommendations. Such scenarios could cause high thermoregulatory demands particularly as competition progresses into latter rounds (direct elimination; DE). Therefore, the aim of this study was to determine the thermoregulatory responses of épée fencing across different phases of competition (Poule and DE). Seven well-trained fencers competed in a simulated competition comprising of seven Poule and seven DE fights. Gastrointestinal temperature (T_{gast}), skin temperature (T_{skin}), mask temperature (T_{mask}), heart rate (HR), thermal sensation, differentiated ratings of perceived exertion (RPE), and movement characteristics were collected for all fights. There was a moderate thermoregulatory demand during Poule rounds shown by post-fight T_{gast} (38.1 ± 0.4°C), T_{skin} (34.4 ± 0.7°C), and thermal sensation ratings (6 ± 1). A greater thermoregulatory and perceptual demand observed during DE rounds evidenced by T_{gast} (38.7 ± 0.3°C post fight), T_{skin} (35.1 ± 0.7°C), thermal sensation (7 ± 1), increases in T_{mask} across DE rounds (~1.1°C), and RPE (~15). Furthermore, a significant ($p < 0.05$) reduction in distance covered from DE 1 to DE 7 suggests a thermoregulatory based impact on performance. This is the first study demonstrating the thermoregulatory demands of épée fencing, highlighting the need to develop heat exertion guidelines within fencing.

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Introduction

Many sports have developed heat policies over the last 20 years to reduce the incidence of heat related injury. In 2022, the International Olympic Committee (IOC) has published a consensus statement on recommendations and regulations for sport events in the heat [1]. Many indoor sports though have not considered this issue as there are no effects of direct sun light and air conditioning may be available. However, many sports venues across the world do not have air conditioning which could result in increasing high ambient temperatures (>30°C). Furthermore, hot indoor environments decrease exerciser satisfaction and comfort and can have lower air quality [2,3]. Olympic sports, such as fencing, where lots of thick protective clothing is worn and is performed indoors, should consider developing a heat policy to protect athletes from heat related injury.

The Olympic sport of fencing poses thermoregulatory challenges to the body. Firstly, fencing competitions can last between 9 and 11 hours [4] with multiple fights throughout the day and subsequently large amounts of heat production due to the high-intensity intermittent activity during a fight [5,6]. During a fight it has been shown fencing elicits an average heart rate of 86.5 ± 6.3% [6] with an 80–90% aerobic energy contribution and importance of alactic energy sources for high-intensity movements [5,6]. Increased body temperature could cause an increased heart rate to increase skin blood flow to dissipate heat, thus decreasing working muscle blood flow reducing oxygen delivery. Furthermore, when exercising with hot skin there is an increased percentage of maximal oxygen uptake utilised compared to temperate conditions [7]. This response could be further exaggerated by dehydration [7] due to high sweat rates in fencing. Secondly, whilst

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competing, fencers are covered head to toe in thick protective clothing consisting of a protective outer jacket made from cloth, a protective underplastron (to protect the vital areas of the upper body), breeches, long socks, glove for the sword arm, protective chest guard (females only), and fencing mask [8]. Furthermore, foil and saber fencers wear an additional metallic garment on the upper body. This protective clothing limits all heat loss mechanisms available to the fencer, with the potential to cause high core and skin temperatures leading to performance detriments and ultimately heat stress. Indeed, Oates et al. (2019) observed gastrointestinal temperature (T_{gast}) of ~38.5°C during direct elimination (DE), with some fencers reaching T_{gast} greater than 39°C. However, skin temperatures or perceptual measures of temperature were not reported which may provide important thermoregulatory information. Moreover, it has been shown the protective clothing temperature worn by fencers increases during fencing activity [9]. Thus, our understanding of the thermoregulatory responses during fencing is limited [8].

The fencing mask could pose a thermoregulatory challenge due to impeding a vital source of heat loss from the head [10], resulting in increased face temperature which has been shown to negatively influence thermal sensation and comfort [11,12]. The fencing protective clothing may, therefore, pose challenges to heat loss from the body and increase perceptions of heat. During longer and high-pressure knockout fights (i.e. DE) such responses may be accentuated as has been observed in other sports requiring protective clothing such as American football, motor racing, and ice hockey [13–16]. An important consideration within fencing is that fencers, anecdotally, do not remove protective clothing between fights, and this may further impede heat loss in the recovery period between fights, and cause heat to accumulate in subsequent fights [8]. Hot skin temperatures (>35°C) have been proposed to impair aerobic performance due to an increase in skin blood flow requirements [7,17]. Hot skin temperature causes an increased heart rate to maintain cardiac output and reduces the thermal gradient between core and skin temperatures causing heat stress [7].

In addition, the indoor environmental conditions can have an impact on performance and health during fencing. Hot indoor temperatures, high metabolic activity, and clothing requirements could cause an increased perception of effort resulting in thermal discomfort which could negatively influence fencing performance [18,19]. Furthermore, it has been discussed that indoor air quality can impact performance and health during exercise [20]. Indoor air quality decreases during high-intensity activity (such as fencing) due increased ventilation causing increased levels of pollutants which could impact oxygen delivery due to increased carboxyhemoglobin within the blood [20].

There is a lack of research discussing the thermoregulatory demands of fencing [8]. Further, due to the protective clothing, high-intensity activity, and indoor environmental conditions during fencing competition, it is important to understand the thermoregulatory demands placed on the athletes. The aim of this study was to investigate the thermoregulatory responses of épée fencing during competition. This is the first study to explore the thermoregulatory responses of fencing which could provide useful information to inform future heat policies for fencing governing bodies.

Methods

Participants

Seven male well-trained épée fencers free from injury volunteered to take part in this study which received University ethical approval (Ref: aLMS/PGR/UH/02960(2)). All fencers competed at a club or international level (ranked within the top 65 in Great Britain at the time of testing) with participant characteristics shown in Table 1. All testing was performed with participants wearing

Table 1. Participant characteristics (mean ± standard deviation (SD)).

Variable	Mean ± SD
Age (years)	24.7 ± 10.5
Stature (cm)	181.4 ± 5.6
Body Mass (kg)	81.4 ± 13.3
Fencing (Hours per Week)	6.9 ± 1.6
Strength and Conditioning (Hours per Week)	4.1 ± 3.1
Previous Fencing Experience (years)	10.9 ± 4.6

their International Fencing Federation approved fencing equipment [21]. Before testing all participants provided written informed consent. Due to drop out on the day a well-trained female epée fencer (Commonwealth Fencing Championship fencer) was also recruited to ensure the correct number of fights could be completed, but no data collected.

Procedures

Participants were required to attend a simulated fencing competition with a format of Poule and DE rounds using the protocol of Oates et al. (2019). Participants were instructed to warm-up as they usually would for competition. The Poule rounds involved participants competing in seven, 3-minute bouts or first to 5 points as per typical fencing competition rules. If the score was level at the end of 3 minutes, an extra minute was added to determine the winner. Based upon the results of the Poule participants were subsequently seeded prior to beginning the DE rounds. Each DE fight consisted of 3×3-minute bouts or first to 15 points, as with the Poule fights an extra minute was added if the points were even after the 3×3 minutes. In contrast to a standard fencing competition procedure, each participants fought each other in the DE phase of the competition rather than being eliminated after each fight to provide sufficient data for statistical analysis of the DE component and to replicate reaching the final of a competition. Between the end of Poule 7 and DE 1 there was a break of 1 hour 35 minutes as per most competition scenarios. To invoke a competitive element to the fencing protocol and ensure maximal effort throughout a staggered monetary incentive was given for all competition placings (based on the number of wins as well as points won and lost) within the competition, and a trophy for the winner.

Preliminary measures

A schematic diagram representing the variables measured pre, during, and post fight for the Poule and DE phases of the simulated competition is shown in Figure 1. Body mass was recorded to the nearest 0.1 kg using electronic weighing scales (Seca Clara 803, Birmingham, UK) pre and post Poule and DE phases to estimate sweat loss. Participants were instructed to towel dry before body mass measurements and wear minimal clothing. All fluid consumed was recorded to determine fluid intake. Unfortunately, urine output could not be measured, therefore sweat rate could not be calculated. One participant did not have fluid intake recorded; therefore, six participants' data were used to determine fluid intake. Environmental conditions were continuously monitored using a wet bulb globe temperature monitor (HT30, Extech Instruments, Nashua, NH, USA). Environmental conditions for the protocol are shown in Table 2.

Thermoregulatory measures

Gastrointestinal temperature measurements

Upon arrival participants were required to consume an ingestible telemetric core temperature pill (CorTemp, HQ Inc., Palmetto, FL, USA) at least 2 hours before the start of the testing in accordance with manufacturer's instructions. This allowed the pill to enter the digestive tract for accurate T_{gast} measurements [22]. During the competition, T_{gast} (°C) was measured pre and post Poule 1 and 7 (P1 and P7) and each DE fight (DE 1 to DE 7). The change in T_{gast} (ΔT_{gast}) pre and post fight was calculated for P1, P7, and all DE fights. One of the participants had a contraindication (gastrointestinal disorder) for use of the CorTemp pills so had aural temperature (T_{au}) measured using an infrared ear thermometer by inserting the thermometer into the auditory canal (Braun Thermoscan 6013, Braun, Kronberg, Germany).

In-house Intraclass Correlations (ICC) reliability of the CorTemp pills showed ICC (Standard Error of Measurement (SEM)) of 0.947 (0.032), 0.962 (0.026), 0.901 (0.052) for 36°C, 38°C, and 41°C, respectively, when comparing two pills using a water bath.

Skin and mask temperature measurements

Wireless skin thermochrons (iButtons DS1992L, Maxim Integrated Products Inc., San Jose, CA, USE, resolution 0.0625°C) were attached to the participants on the following sites: biceps, chest,

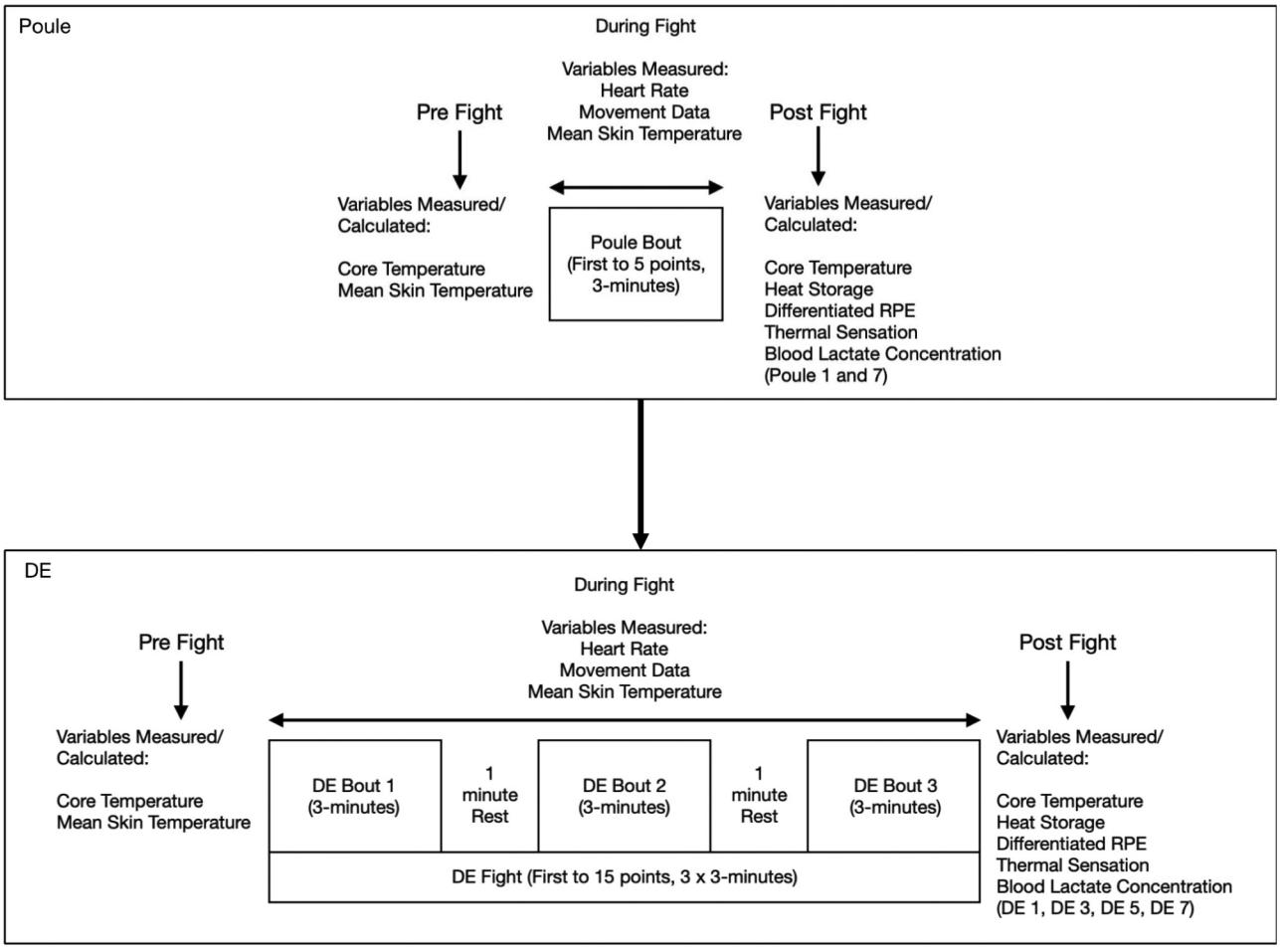

Figure 1. Schematic diagram representing variables measured and calculated pre, during and post fight for the Poule and DE phases of the simulated competition. DE = direct elimination, RPE = ratings of perceived exertion.

Table 2. Environmental conditions during the competition protocol (mean ± SD).

Variable	Poule	DE
Indoor Air Temperature (°C)	25.6 ± 0.9	29.1 ± 0.7
Globe Temperature (°C)	25.3 ± 0.9	29.0 ± 0.7
Relative Humidity (%)	53.6 ± 1.1	45.4 ± 2.4

DE = direct elimination.

thigh, and calf to calculate mean skin temperature (T_{skin}). A further thermochron was placed inside the top of the fencing mask to measure fencing mask temperature (T_{mask}). This was to give an indication of whether there was a difference in head temperature compared to the environment which may impact thermal sensation. Prior to placing the thermochrons on the participants they were programmed following manufacture instructions. Each thermochron's real-time clock was time synchronized with that of the computer and set to a resolution of 0.0625°C and set to record every 15 seconds during the testing. Mean skin temperature was calculated using the formula of [23], where:

$$T_{skin} = 0.3*(\text{Chest} + \text{Biceps}) + 0.2*(\text{Thigh} + \text{Calf})$$

Mean skin temperature was calculated for the following time points 1-minute pre and the final minute (post T_{skin}) of P1, P7, and all DE fights. Core to skin temperature gradient was calculated by subtracting post T_{skin} from post fight T_{gast} at the same time points. Mask temperature was recorded at the same timepoints as skin

temperature. The change in T_{mask} (ΔT_{mask}) was calculated by subtracting the first minute T_{mask} from the last minute T_{mask} for P1, P7, and all DE fights. Mean skin temperature was determined as cold/cool (<30°C), warm (30–34.9°C), and hot (>35°C) based upon Sawka et al. (2012).

In house reliability using a water bath showed excellent reliability (ICC (SEM), reported as mean ICC ± SD for all iButtons) between 6 iButtons and traditional wired skin thermistors (EUS- K-N5-3, Grant Instruments Ltd., Cambridge, UK, resolution 0.1°C) of 0.977 ± 0.004, 0.768 ± 0.043, 0.817 ± 0.034, 0.926 ± 0.010, and 0.884 ± 0.032 at 26°C, 32°C, 36°C, 38°C, and 41°C, respectively. The iButtons also showed excellent reliability (reported as ICC (SEM)) when compared to each other with ICC of 0.995 (0.061), 0.988 (0.085), 0.986 (0.088), 0.995 (0.092), and 0.983 (0.113) at 26°C, 32°C, 36°C, 38°C, and 41°C, respectively.

Heat storage

Heat storage was calculated for P1, P7, and all DE fights using the equation of Havenith et al. (1995), where:

$$Heat\ Storage\left(\mathrm{J.g^{-1}}\right) = (0.8 * Tgast + 0.2 * Tskin) * Cb$$

where $\Delta T_{gast} = Post\ T_{gast} - Pre\ T_{gast}$ for each fight, $\Delta T_{skin} = Post\ T_{skin} - Pre\ T_{skin}$ for each fight, and C_b is the specific heat of body tissues (3.49 $\mathrm{J.g^{-1}.°C^{-1}}$) [24].

Heart rate and movement data

Participants were fitted with a heart rate monitor and athlete-tracking system just below the chest (Polar Team Pro 2, Polar Electro, Kempele, Finland). Heart rate (HR) was recorded at 1 Hz, and movement data were recorded using a tri-axial accelerometer, gyroscope, and digital compass-based system recording at 200 Hz. Maximum HR was determined in the software based upon the participant's age predicted maximum heart rate (HR_{APM}) and was calculated as 208-(0.7*age) [25] which has been shown to have greater accuracy than other predictive methods [26]. Both absolute HR ($\mathrm{beats.min^{-1}}$) and relative HR (%HR_{APM}) as well as average HR (HR_{av}) and maximum HR (HR_{max}) for P1, P7, and all DE fights were recorded. Distance covered (m) and distance covered per minute ($\mathrm{m.min^{-1}}$) during P1, P7, and all DE fights were also calculated.

Blood lactate and glucose concentrations

Blood lactate and glucose concentrations were measured from 10 µl fingertip capillary blood samples on the non-sword arm. Blood lactate and glucose concentrations were then measured in duplicate using a Biosen C-Line lactate analyzer which was calibrated following manufacturer instructions using 12.0 $\mathrm{mmol.L^{-1}}$ calibration standard (Biosen C-Line, Ekf Diagnostics, Cardiff, UK). The Biosen-C line has been reported to have a coefficient of variation of <3% [27]. Capillary blood samples were collected at baseline, post P1, post P7, and post DE after every other round, i.e. DE fights 1, 3, 5, and 7 (Figure 1). Capillary blood samples at baseline were collected after a minimum of 10 minutes seated rest. Post fight capillary blood samples were collected within 3 minutes of the fight terminating.

Perceptual measurements

Differentiated ratings of perceived exertion (RPE) were recorded using the Borg 6–20 category scale [28,29]. Participants subjectively rated exertion for their arms (RPE_A), legs (RPE_L), and overall (RPE_O) which have been used previously in fencing [30]. Subjective ratings of thermal sensation were recorded using a 9 point category scale [31]. Differentiated RPE and thermal sensation were collected immediately post fight for P1, P7, and all DE fights (Figure 1).

Statistical analysis

Data are presented as mean ± SD with 95% confidence intervals (95% CI), unless stated otherwise. Data were analyzed using a statistical software package (SPSS version 25, IBM, Armonk, NY, USA). Statistical significance was set a priori $p < 0.05$. Data were checked for normality using the Shapiro–Wilk test.

Paired Students t-test analysis was undertaken to compare pre T_{gast} and T_{skin} between P1 and

DE 1 to determine if participants T_{gast} and T_{skin} had returned to baseline levels and whether DE performance was potentially impacted by heat production in the Poule rounds. There was no significant differences between pre P1 and pre DE 1 in T_{gast} (37.7 ± 0.4°C vs. 37.7 ± 0.2°C; p = 0.994, ES = 0.00) or T_{skin} (34.4 ± 0.5°C vs. 34.0 ± 0.5°C; p = 0.213, ES = −0.77). Therefore, the Poule and DE were analyzed separately. To determine thermoregulatory and physiological responses during the Poule rounds paired-Students t-test analysis was also carried out to compare: T_{gast}, T_{skin}, T_{mask}, thermal sensation, differentiated RPE, HR, blood lactate concentration, blood glucose concentration, heat storage, distance covered, and core to skin temperature gradient between P1 and P7. Paired-Students t-test analysis was also conducted to compare body mass across Poule (pre P1 and Post P7) and DE (Pre DE 1 and Post DE 7) rounds. Effect sizes (ES) were calculated using Cohen's d [32] and considered to be trivial (ES < 0.20), small (0.21–0.60), moderate (0.61–1.20), large (1.21–2.00), or very large (ES > 2.00) [33].

To determine the thermoregulatory and physiological response across the DE rounds one-way repeated measures analysis of variance (ANOVA) tests were performed for: T_{gast}, T_{skin}, T_{mask}, thermal sensation, differentiated RPE, HR, blood lactate concentration, blood glucose concentration, heat storage, distance covered, and core to skin temperature gradient. For ANOVA analysis partial eta squared (η^2) effect sizes [32] were calculated considered to be small (η^2 0.10–0.24), moderate (η^2 0.25–0.39), and large (η^2 >0.40) [32].

Results

Body mass

There was no significant difference between body mass pre Poule and post Poule (81.4 ± 13.2 kg vs. 81.2 ± 13.4 kg; p = 0.248, ES = 0.02). There was a significantly lower body mass post DE 7 than pre DE 1 (81.0 ± 13.3 kg vs. 81.5 ± 13.2 kg; p = 0.015, ES = 0.04). Average fluid intake during the competition was 2.4 ± 1.4 L (n = 6; range 1.1–4.3 L).

Thermoregulatory and physiological responses during poule rounds

There was a significantly greater (p < 0.05) pre fight T_{gast}, post fight T_{gast}, post fight T_{mask}, in P7 compared to P1 (Table 3). There was a significantly lower (p < 0.05) blood lactate concentration and distance covered per minute in P7 compared to P1 as shown in Table 3. There were no other significant differences (p > 0.05) for thermoregulatory or physiological responses between P1 and P7 (Table 3).

Thermoregulatory and physiological responses during DE rounds

There was a significant difference (p = 0.002, η^2 = 0.567) determined for T_{gast} pre fight during the DE rounds, Figure 2. There was a lower pre fight T_{gast} in DE 1 than DE 2 (p = 0.022), DE 3 (p = 0.006), and DE 7 (p = 0.007). There was also a greater pre fight T_{gast} in DE 3 than DE 6 (p = 0.011). There were no other significant differences determined for pre fight T_{gast} during the DE rounds. Further, there was a significant difference (p = 0.035, η^2 = 0.439) determined for T_{gast} post fight during the DE rounds, Figure 2. There was a greater post fight T_{gast} in DE 2 than DE 1 (p = 0.025), and DE 7 (p = 0.018). There were no other significant differences determined for post fight T_{gast} during the DE rounds.

There was a significant difference (p < 0.001, η^2 = 0.557) determined for T_{skin} pre fight during the DE rounds, Figure 3. There was a greater pre fight T_{skin} in DE 2 than DE 1 (p = 0.002), and DE 7 (p = 0.025). There were no other significant differences determined for pre fight T_{skin} during the DE rounds. There was also a significant difference (p < 0.001, η^2 = 0.682) determined for post fight T_{skin} during the DE rounds, Figure 3. There was a greater post fight T_{skin} in DE 1 than DE 6 (p = 0.016). There was also greater post fight T_{skin} in DE 2 than DE 4 (p < 0.001), DE 5 (p = 0.022), DE 6 (p = 0.020), and DE 7 (p = 0.010). There were no other significant differences determined for last minute fight T_{skin} during the DE rounds.

There was a significant difference (p < 0.001, η^2 = 0.760) determined for post fight T_{mask} during the DE rounds (Figure 4). There was a lower post fight

Table 3. Thermoregulatory, physiological, and perceptual responses, and movement characteristics between P1 and P7 (mean ± SD (95%CI)).

Variable	P1	P7	*P* value	Effect Size
Thermoregulatory Responses				
Pre T_{gast} (°C)	37.6 ± 0.4 (37.3, 38.0)	38.3 ± 0.2 (38.2, 38.5)	0.003	2.25
Post T_{gast} (°C)	37.9 ± 0.2 (37.7, 38.0)	38.7 ± 0.1 (38.5, 38.8)	<0.001	4.90
Pre T_{skin} (°C)	34.3 ± 0.5 (33.9, 34.7)	34.6 ± 0.7 (34.0, 35.3)	0.081	0.59
Post T_{skin} (°C)	34.0 ± 0.6 (33.5, 34.6)	34.4 ± 0.7 (33.8, 35.1)	0.223	1.03
Post T_{mask} (°C)	26.4 ± 0.4 (26.0, 26.8)	27.4 ± 0.7 (26.7, 28.0)	0.015	1.68
Core to Skin Temperature Gradient (°C)	3.9 ± 0.6 (3.3, 4.4)	3.9 ± 0.8 (3.2, 4.6)	0.961	0.04
Heat Storage ($J.g^{-1}$)	0.6 ± 0.8 (−0.8, 1.3)	0.2 ± 0.9 (−0.6, 1.1)	0.213	0.46
Thermal Sensation	5.5 ± 0.5 (5.0, 6.0)	6.0 ± 1.0 (5.0, 6.5)	0.356	0.69
Physiological Responses				
HR_{av} (% HR_{APM})	86.6 ± 5.2 (81.7, 91.4)	85.4 ± 8.1 (77.9, 92.9)	0.685	0.18
HR_{max} (%HR_{APM})	93.9 ± 4.2 (90.0, 97.8)	92.4 ± 8.7 (84.3, 100.5)	0.659	0.22
Blood Lactate Concentration ($mmol.L^{-1}$)	3.5 ± 1.6 (2.1, 4.9)	2.3 ± 1.3 (1.1, 3.5)	0.006	0.82
Blood Glucose Concentration ($mmol.L^{-1}$)	4.9 ± 0.5 (4.4, 5.4)	5.7 ± 0.8 (5.0, 6.4)	0.074	1.24
Perceptual Responses and Movement Characteristics				
RPE_A	10 ± 3 (7, 14)	12 ± 2 (10, 14)	0.467	0.78
RPE_L	12 ± 2 (10,13)	13 ± 2 (11, 14)	0.231	0.50
RPE_O	13 ± 2 (12, 15)	13 ± 1 (12, 14)	0.736	0.00
Distance (m)	353 ± 82 (277, 429)	230 ± 110 (129, 332)	0.023	1.27
Distance per minute ($m.min^{-1}$)	83 ± 19 (65, 100)	79 ± 14 (67, 92)	0.573	0.24

P = Poule, T_{gast} = Gastrointestinal temperature, T_{skin} = Mean skin temperature, T_{mask} = Mask temperature, HR_{av} = Average heart rate, HR_{max} = Maximum heart rate, HR_{APM} = Age predicted maximum heart rate, RPE_A = Ratings of perceived exertion for the arms, RPE_L = Ratings of perceived exertion for the legs, RPE_O = Overall ratings of perceived exertion.

T_{mask} in DE 1 than DE 6 ($p = 0.012$), and DE 7 ($p = 0.049$). There was also a lower post fight T_{mask} in DE 2 than DE 4 ($p = 0.009$), DE 5 ($p = 0.025$), DE 6 ($p = 0.028$), and DE 7 ($p = 0.008$). Moreover there was a lower post fight T_{mask} in DE 3 than DE 6 ($p = 0.009$) and DE 7 ($p = 0.043$). There were no other significant differences determined for post fight T_{mask} during the DE rounds.

Table 4 shows thermoregulatory and physiological responses during DE rounds. There was a significant difference ($p < 0.001$, $\eta^2 = 0.644$) determined for core to skin temperature gradient during the DE rounds. Post hoc analysis could not determine where the difference for core to skin temperature occurred. There was a significant difference ($p = 0.004$, $\eta^2 = 0.396$) determined for heat storage during the DE rounds. There was a greater heat storage in DE 1 than DE 3 ($p = 0.016$) and DE 6 ($p = 0.017$). There were no other significant differences determined for heat storage during DE rounds. There was a significant difference ($p = 0.026$, $\eta^2 = 0.315$) determined for distance covered during the DE rounds. Post hoc analysis could not determine where the difference for distance covered occurred. There were no significant differences ($p > 0.05$) determined for thermal sensation, HR_{av}, HR_{max}, blood lactate concentration, fight

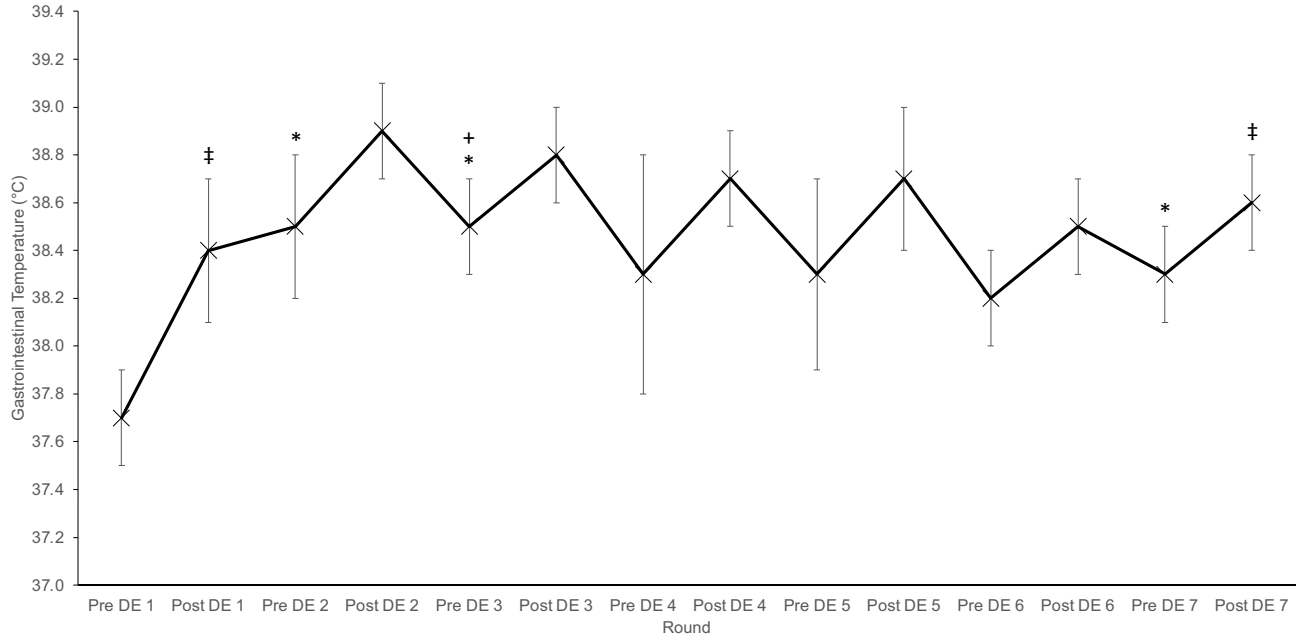

Figure 2. Gastrointestinal temperature (°C) during DE rounds (mean ± SD).
*= significant difference to pre DE 1 ($p < 0.05$), + = significant difference to pre DE 6 ($p < 0.05$), ‡ = significant difference to post DE 2 ($p < 0.05$). DE = direct elimination.

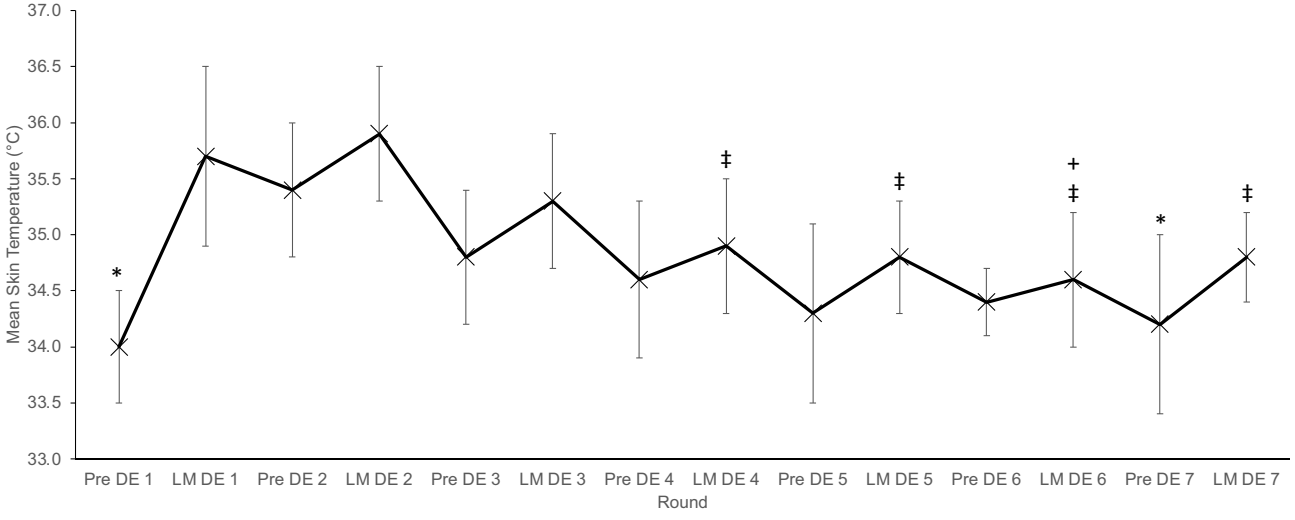

Figure 3. Mean skin temperature (°C) during DE rounds (mean ± SD).
*= significant difference to pre DE 2 ($p < 0.05$), + = significant difference to last minute fight DE 1 ($p < 0.05$), ‡ = significant difference to post fight DE 2 ($p < 0.05$). DE = direct elimination, LM = last minute of the fight.

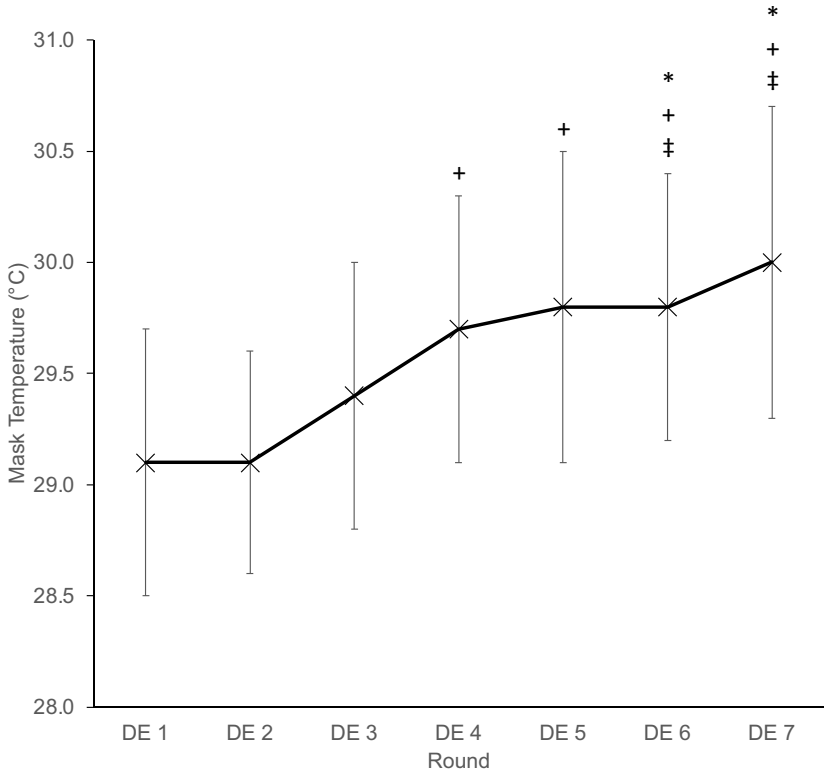

Figure 4. Mask temperature (°C) during DE rounds (mean ± SD).
*= significant difference to DE 1 ($p < 0.05$), + = significant difference to DE 2 ($p < 0.05$), ‡ = significant difference to DE 3 ($p < 0.05$). DE = direct elimination.

duration, RPE_A, RPE_L, and RPE_O during DE rounds as shown in Table 4.

There was a significant difference ($p < 0.001$, $\eta 2 = 0.760$) determined for distance covered per minute during the DE rounds, Figure 5. Post hoc analysis could not determine where the difference occurred.

Discussion

This is the first study to explore in detail the thermoregulatory responses of épée fencing. The key findings of this study indicated a moderate thermoregulatory response during Poule rounds with a subsequently greater thermoregulatory response during DE rounds. This study indicated that the earlier DE rounds produced a greater thermal load as evidenced by greater T_{gast}, T_{skin}, and a greater physical load as evidenced by greater distance covered than in later DE rounds.

During Poule rounds there was a moderate thermoregulatory response observed with T_{gast} post fight ~38.7°C and T_{skin} recorded as warm (~34.4°C) post P7. Furthermore, there was a consistent core to skin temperature gradient in P1 and P7 (~3.9°C) and thermal sensation was rated as warm to hot. Although, there were greater T_{gast} recorded for Poule fights in this study than Oates et al. (2019) (~37.6°C) there were similar physiological, physical, and perceptual responses (i.e. heart rate, rating of perceived exertion and distance covered). There is likely to be a moderate thermoregulatory response in Poule fights due to the short duration of the fights (~3 minutes). The greater temperature during this study (indoor air temperature 25–29°C vs ~19.5°C) could have accounted for some of the differences in T_{gast}, however it is unclear as to what fully caused the differences in T_{gast} between this study and Oates et al. (2019).

During DE rounds there was a greater thermoregulatory strain particularly in initial DE rounds. Post fight T_{gast} was greater than 38.6°C from DE 2 onwards with peaks of ~ 38.9°C in DE 2 with some participants eliciting T_{gast} greater than 39.0°C. Furthermore, pre fight T_{gast} was over 38.2°C from DE 2 onwards and did not decrease between

Table 4. Thermoregulatory and physiological responses during DE rounds (mean ± SD (95% CI)).

Variable	DE 1	DE 2	DE 3	DE 4	DE 5	DE 6	DE 7	*P* value	Partial Eta Squared
Thermoregulatory Responses									
Core to Skin Temperature Gradient (°C)	2.8 ± 1.0 (1.8, 3.7)	3.0 ± 0.7 (2.4, 3.6)	3.5 ± 0.6 (3.0, 4.1)	3.8 ± 0.5 (3.3, 4.3)	3.9 ± 0.5 (3.5, 4.4)	3.9 ± 0.6 (3.4, 4.5)	3.9 ± 0.5 (3.5, 4.3)	<0.001	0.644
Heat Storage ($J.g^{-1}$)	3.4 ± 1.0 (2.4, 4.3)	1.5 ± 1.4 (0.1, 2.8)	1.2 ± 0.6 (0.6, 1.7)	1.5 ± 1.0 (0.5, 2.4)	1.5 ± 1.6 (0.0, 3.0)	1.1 ± 1.0 (0.1, 2.0)	1.3 ± 0.7 (0.7, 1.9)	0.004	0.396
Thermal Sensation	6.5 ± 1.0 (5.5, 7.5)	7.0 ± 1.0 (6.0, 7.5)	7.0 ± 0.0 (7.0, 7.0)	7.0 ± 0.0 (7.0, 7.0)	7.0 ± 1.0 (6.0, 7.5)	6.5 ± 0.5 (6.0, 7.0)	6.5 ± 1.0 (6.0, 7.5)	0.761	0.085
Physiological Responses									
HR_{av} (% HR_{APM})	90.6 ± 5.4 (85.5, 95.6)	91.0 ± 4.7 (86.7, 95.3)	90.9 ± 3.0 (88.1, 93.6)	89.6 ± 3.6 (86.2, 92.9)	88.7 ± 4.8 (84.3, 93.2)	88.0 ± 6.4 (82.1, 93.9)	88.1 ± 6.0 (82.6, 93.7)	0.189	0.206
HR_{max} (%HR_{APM})	99.3 ± 6.5 (93.3, 105.3)	98.7 ± 2.9 (96.0, 101.4)	100.6 ± 2.4 (98.3, 102.8)	98.0 ± 3.5 (94.8, 101.2)	97.3 ± 5.7 (92.0, 102.6)	96.4 ± 7.3 (89.7, 103.2)	96.1 ± 6.0 (90.6, 101.7)	0.377	0.156
Blood Lactate Concentration ($mmol.L^{-1}$)	4.9 ± 2.6 (2.5, 7.3)		3.5 ± 0.4 (3.1, 3.9)		3.9 ± 1.3 (2.7, 5.1)		2.7 ± 1.2 (1.6, 3.9)	0.091	0.295
Blood Glucose Concentration ($mmol.L^{-1}$)	5.3 ± 0.7 02 (4.7, 6.0)		5.3 ± 0.5 (4.8, 5.8)		4.7 ± 0.8 (4.0, 5.4)		4.7 ± 0.5 (4.2, 5.2)	0.131	0.263
Perceptual Responses and Movement Characteristics									
RPE_A	14 ± 3 (11, 17)	13 ± 4 (9, 17)	13 ± 3 (11, 16)	13 ± 3 (10, 15)	14 ± 3 (12, 17)	14 ± 3 (12, 17)	15 ± 3 (13, 18)	0.538	0.125
RPE_L	15 ± 3 (13, 18)	15 ± 4 (11, 18)	15 ± 2 (13, 17)	14 ± 2 (12, 16)	15 ± 2 (13, 17)	14 ± 2 (12, 17)	15 ± 2 (14, 17)	0.959	0.039
RPE_O	16 ± 3 (13, 18)	15 ± 3 (12, 18)	16 ± 1 (15, 17)	14 ± 2 (13, 16)	16 ± 2 (14, 17)	15 ± 2 (13, 17)	15 ± 2 (13, 17)	0.692	0.097
Distance (m)	886 ± 318	787 ± 253	828 ± 201	692 ± 135	701 ± 223	582 ± 252	598 ± 67	0.026	0.315
Fight Duration (mins)	11:01 ± 3:58 (7:21, 14:43)	10:30 ± 3:10 (7:34, 13:26)	11:13 ± 3:18 (8:09, 14:17)	8:43 ± 1:02 (7:45, 9:40)	9:17 ± 1:49 (7:36, 10:58)	8:09 ± 2:49 (5:33, 10:45)	8:26 ± 0:52 (7:37, 9:14)	0.102	0.244

DE = Direct Elimination, HR_{av} = Average heart rate, HR_{max} = Maximum heart rate, HR_{APM} = Age predicted maximum heart rate, RPE_A = Ratings of perceived exertion for the arms, RPE_L = Ratings of perceived exertion for the legs, RPE_O = Overall ratings of perceived exertion.

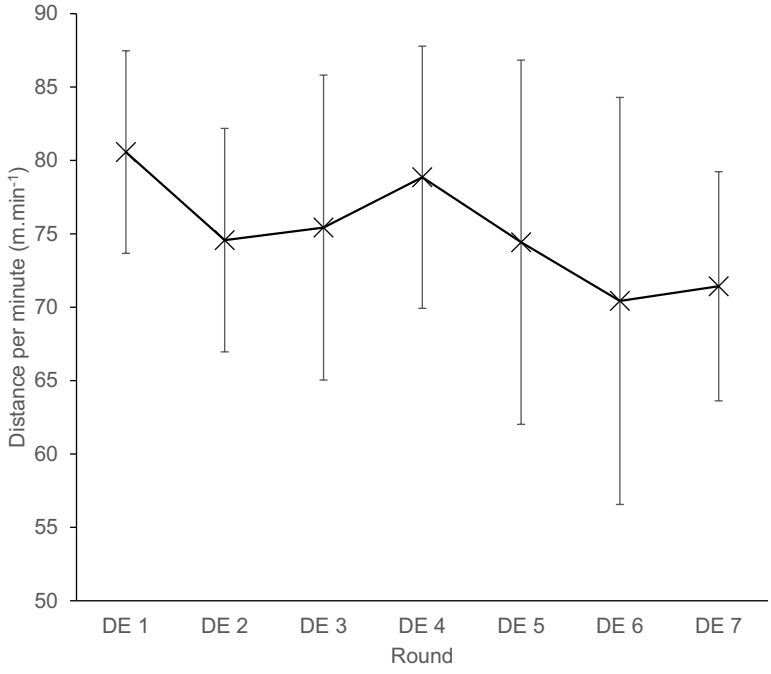

Figure 5. Distance per minute (m.min^{-1}) during the DE rounds (mean ± SD). DE = direct elimination.

fights toward pre DE 1 values. As with Poule fights T_{gast} during the DE were greater in the current study than those reported by Oates et al. (2019) (post fight T_{gast} ~38.3). During the initial DE rounds mean skin temperature was also classified as hot with T_{skin} during the last minute of the fight being above 35.0°C for DE 1 to DE 4. The high skin temperatures recorded resulted in narrow core to skin temperature gradients which could cause increased skin blood flow requirements to dissipate heat and impact fencing performance [7]. Interestingly, there was a decreased T_{skin} in latter DE rounds, this could be due to less distance covered and decreased fight times being recorded and thus reduced heat production. Furthermore, dehydration during DE fights may have further impacted performance through changes in blood volume, increased heart rate, perception of effort and body temperature [34]. Therefore, performance may have been impacted due to increased heat strain from earlier DE rounds impacting decision making causing more mistakes to be made by the participants. This is hypothetical and further research should examine this hypothesis. Despite decreased distance covered, fight time and T_{skin} perceptions of thermal sensation (7.0 – very hot) and ratings of perceived exertion (RPE_O – hard) were similar throughout the DE rounds. This could have been impacted by greater body temperatures in early DE rounds affecting the perceptual responses of heat by the participants, as seen in exercise in indoor sports [18]. Therefore, cooling interventions during DE rounds or prior to DE fights may be beneficial to reduce the thermoregulatory, and perceptual responses to fencing, and could have performance benefits as seen in other sports [35–37].

This study was performed in the month of July with ambient temperature ~29.0°C. This study was performed in one of the biggest fencing salles in the UK and there is no air conditioning, which is commonplace in local, national, and international competitions. In the summer of 2022, environmental temperatures in the UK reached 40°C which will have led to high indoor temperatures. Importantly, the temperature inside the venue increased over the duration of the competition. As shown from this study, T_{gast} is already increased to near 39°C with T_{skin} >35°C, therefore, hotter and more humid environmental conditions in other countries could lead to much greater heat stress within fencing venues. Moreover, it has been shown that environmental conditions can impact indoor performance particularly in sports with a high metabolic rate [18,20].

A combination of the high indoor temperature and lower air quality could have affected perceptual and physiological responses impacting upon fencing performance. Furthermore, fencing also poses a thermoregulatory challenge with multiple protective clothing layers covering the whole body which further limits the body's ability to dissipate heat which could be an issue in hotter and more humid environments. This study has highlighted the need for further research to be undertaken to inform heat policy for the sport as seen in other sports [1]. This could include assessing historical environmental conditions at competition to replicate hot and humid environments within research studies to determine the thermoregulatory responses, potential health consequences, and performance impact within fencing. Furthermore, monitoring fencers physiological and thermoregulatory responses during competition could enable appropriate cooling strategies to be implemented. Heat policies should provide information for competition organisers, athletes, medical staff, and heat risk analysis for fencing competitions [1].

As with all research studies, the current study has a number of limitations. Firstly, only seven participants were recruited and with the simulated competition design it is difficult to create a true competitive environment without recruiting in multiples of 8. Nevertheless, the participants were representative of typical competitors at national and international events. Furthermore, only male participants were recruited, and the results may not be applicable to female fencers due to differences in thermoregulatory responses [38]. Future research should examine thermoregulatory responses in female fencers. Although, the DE component of the competition did not eliminate competitors per se, the design did allow for a complete data set to be evaluated over the entire competition. As a result, this study has provided an insight into the unique thermoregulatory responses of fencing competition. Furthermore, this study used well-trained participants, however for most fencing competitions there will be a range of different abilities and ages (~13-70+). Previous research has shown younger and older age groups are more prone to heat-related issues [39,40]. Secondly, the study was conducted within épée and the responses observed may not transfer to foil and saber disciplines. Within these weapons there is a requirement to wear an extra metallic garment to enable the scoring system which could add further heat stress. Finally, this study did not determine how specific fencing performance indicators may have been impacted during the competition and future research should incorporate methods to assess such performance measures such as cognitive function tests or fencing specific tests between fights such as those used previously [41,42].

Conclusions

Overall, this study determined the thermoregulatory responses to épée fencing during simulated competition. Within this study it was shown T_{gast} ~39°C, T_{skin} >35°C and potential dehydration during DE rounds with participants' thermal sensation rated very hot (7.0) even with decreasing T_{skin}, fight time and distance covered in latter DE rounds. During this study, indoor air temperature was ~29°C and relative humidity ~50%. With the current challenges of climate change and fencing competitions taking place in venues or countries with significantly greater environmental conditions many fencing competitions could face considerably greater thermal stress than in the current study. Thus, the risk of heat stress could be increased with the associated health complications, particularly in younger and older competitors. The current study, therefore, highlights the need for research to inform a heat policy for the sport of fencing with future research also focussing upon cooling interventions.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

List of abbreviations

95% CI	95% confidence intervals
ANOVA	Analysis of Variance
DE	Direct Elimination
ES	Effect size
HR	Heart rate
HR_{APM}	Age predicted maximum heart rate
HR_{av}	Average heart rate
HR_{max}	Maximum heart rate
ICC	Intraclass Correlations
IOC	International Olympic Committee
P	Poule
RPE	Ratings of perceived exertion
RPE_A	Ratings of perceived exertion for the arms
RPE_L	Ratings of perceived exertion for the legs
RPE_O	Overall ratings of perceived exertion
SD	Standard deviation
SEM	Standard error of measurement
T_{gast}	Gastrointestinal temperature
T_{mask}	Mask temperature
T_{skin}	Mean skin temperature

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