Physiological and Thermoregulatory Demands of Epee Fencing

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Submitted to the University of Hertfordshire in partial fulfilment of the requirement of the degree of Doctor of Philosophy

University of Hertfordshire

Submitted March 2022

Abstract

Epée fencing involves repeated bouts of high-intensity intermittent exercise with competitions lasting 9-11 hours consisting of Poule (3-minute or first to 5 points) and Direct Elimination (DE; 3x3-minute bouts or first to 15 points) fights. Fencers are required to wear thick protective clothing which could create a hot micro-climate and impede heat loss during exercise.

Chapter 4 assessed the physiological demands of epée during simulated competition comprising of Poule and DE fights. Results showed epée is reliant on phosphocreatine and aerobic energy systems shown by decreasing blood lactate concentration from Poule to DE (Poule 1 ~4.5 $mmol.L^{-1}$; DE 7 ~2.0 $mmol.L^{-1}$). Maximum heart rate, ratings of perceived exertion, peak speed, training load per minute and percentage of zone 2 accelerations were greater in DE than Poule fights indicating greater physiological strain. There was a considerable energy demand (~13 $kcal.min^{-1}$) exhibited during the competition.

Chapter 5 focussed on the thermoregulatory demands of epée, using the same competition protocol as chapter 4. There was a moderate thermoregulatory demand during Poule fights (gastrointestinal temperature (T_{gast}) ~38.0°C and mean skin temperature (T_{skin}) ~34.5°C) and high thermoregulatory demand during DE fights (T_{gast} >38.0°C pre and >38.5°C post fight and T_{skin} >35.0°C, thermal sensation ~7.0). Mask temperature was greater than ambient temperature highlighting a hot micro-climate created by protective clothing. Mean skin temperature also increased during recovery between fights for Poule and DE. There was a decrease from DE 1 to DE 7 for distance covered (~900m vs. ~600m) and distance covered per minute (~80.6 $m.min^{-1}$ vs. ~71.4 $m.min^{-1}$).

Previous research has shown thermoregulatory and performance benefits of cooling on exercise performance. Chapter 5 showed a high thermoregulatory demand of epée especially during DE rounds. Therefore, chapter 7 assessed the effects of external (EXT; evaporative cooling vest (ECV)), and mixed-method (MIX; ECV + cold water ingestion) cooling on physiological, thermoregulatory, perceptual, performance, and cognitive components of epée. Results showed there was a significantly lower T_{skin}

~0.8-0.9°C and thermal sensation in EXT and MIX cooling interventions than control (CON). There was a limited performance benefit of cooling with greater points difference in MIX compared to CON and EXT.

Wheelchair fencing competition structure and protective clothing is similar to able-bodied fencing. Physiological, thermoregulatory, and performance variables were recorded during Poule and DE fights during wheelchair fencing. Results showed a need to ensure training intensity mirrors competition when mixing category A and B fencers through appropriate fight durations and work to rest ratios. Individual thermoregulatory responses existed for each participant for T_{gast} and T_{skin}. Mask temperature increased during DE fights (0.34-3.04°C) and T_{skin} increased during recovery between Poule and DE fights.

In conclusion, results of this thesis demonstrate a high physiological and thermoregulatory demand of epée. Furthermore, practical cooling methods between fights lowered T_{skin} and thermal sensation during DE fights and with a limited performance benefit of MIX for points difference. This thesis provides novel data on thermoregulatory responses of able-bodied and wheelchair epée fencing and movement data of epée using an accelerometer-based athlete tracking system.

Key words: fencing, thermoregulation, protective clothing, physiological demands, cooling

Declarations

I would like to thank Dr Xavier Iglesias who very kindly loaned the Cosmed K4 gas analysis equipment and came over to the U.K. to perform the gas analysis data collection for chapter 4. Without this equipment I would have been unable to collect the gas analysis data. I would also like to thank my fellow PhD students (Dr Terun Desai and Dr Camilla Holland), Dr Daniel Muniz-Pumares and Dr Lindsay Bottoms for their assistance in data collection during the fencing competitions in chapter 4 and 5. I would also like to thank Dr Lindsay Bottoms and fellow PhD student Freya Bayne for assistance with data collection in chapter 7. Without their assistance it would have been impossible to test multiple fencing participants at once.

I would lastly like to thank Dr Mike Price for allowing me to use the facilities at Coventry University to undertake the peak oxygen uptake testing in chapter 8.

Acknowledgements

I would firstly like to thank my supervisory team (Dr Lindsay Bottoms, Dr Mike Price and Prof. Ian Campbell) for their continued support, advice, feedback, and encouragement during my PhD, and for their patience to see me through to completion during a difficult period. I would like to thank Dr Xavier Iglesias for coming over to the U.K. from Barcelona to help with data collection in chapter 4. I would also like to thank my fellow PhD students (Dr. Lynsey Northeast, Dr Camilla Holland, Dr Terun Desai, Ben Hunter, Lauren Baker and Freya Bayne) for getting me through my PhD, providing many laughs along the way, and for their support and advice when I needed it. I would also like to thank the coaching and playing staff at Saracens Mavericks Netball for allowing me to work as a practitioner alongside my PhD and being an escape from the PhD.

I would also like to thank all the participants who took part in my studies for their dedication, effort, and interest in my PhD studies. I would also like to thank the Leon Paul Fencing Centre, Reading Fencing Club, Milton Keynes Fencing Club, and the staff working there for allowing me to use their facilities for my testing.

Lastly, I would also like to thank my family for their support during my PhD. A massive thank you must go to my amazingly supportive wife Emma for always being there for me, making me smile, and laughing at my craziness. I met you at the start of my PhD journey and we have been through so much including a wedding, buying a house, and having our amazing baby boy William together (during COVID). A thank you should also go to William, who won’t even remember his daddy doing a PhD, for being the best child I could ever ask for.

Doing a PhD, getting a full-time lecturing job (halfway through the PhD), working part time in elite sport, getting married, buying a house, having a baby and a global pandemic all in the space of 5 years… It has been a roller coaster ride, but we got there in the end!

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Abbreviations

Abbreviation	
~	Approximately
% HR_{APM}	Relative heart rate of age predicted maximum
% HR_{max}	Relative heart rate of maximum heart rate recorded during peak oxygen uptake testing
#1	Number 1 ranked
95% CI	95% confidence intervals
ACE	Arm crank ergometer
ANOVA	Analysis of variance
AU	Arbitrary units
°C	Degrees Celsius
C	Convection
C_b	Specific heat of body tissues = $3.49\ J.g^{-1}.°C^{-1}$
CMJ	Counter movement jump
CON	Control Cooling Intervention
CV	Coefficient of variation
CWI	Cold water immersion
DE	Direct Elimination
E	Evaporation
ECV	Evaporative cooling vest
EE	Energy Expenditure
ES	Effect size
EXT	External Cooling Intervention
FAN_{wet}	Electric fans with skin wetting
GPS	Global Position System

H	Hypothesis
HR	Heart Rate (beats.min^{-1})
HR_{av}	Average heart rate (beats.min^{-1})
HR_{APM}	Age predicted maximum heart rate
HR_{av}	Average heart rate recorded during testing
HR_{max}	Maximum heart rate recorded during testing
ICC	Intraclass correlation
ICE	Ice towels placed on neck and upper legs
K	Conduction
LAB	Laboratory fencing protocol
M	Metabolic rate
m	meter
MEMS	Micro-electrical mechanical systems
MIX	Mixed-Method Cooling Intervention
η^2	Partial eta squared
NS	Not stated
P	Poule
PACKS	Ice packs on upper legs
PCr	Phosphocreatine
PEBL	Psychology Experiment Building Language software
PVA	Polyvinyl alcohol
R	Radiation
RER	Respiratory exchange ratio
RPE	Ratings of perceived exertion
RPE_A	Differentiated ratings of perceived exertion for arms
RPE_L	Differentiated ratings of perceived exertion for legs
RPE_O	Differentiated ratings of perceived exertion overall

S	Heat storage
SCI	Spinal cord injury
SD	Standard deviation
SEM	Standard error of measurement
SIM	Simulated fencing protocol
SS	Steady state
T	Thoracic
T_{au}	Aural Temperature
T_{core}	Core temperature
T_{es}	Oesophageal temperature
T_{gast}	Gastrointestinal temperature
T_{mask}	Fencing mask temperature
T_{re}	Rectal temperature
T_{skin}	Mean skin temperature
TT	Time trial
TTE	Time to exhaustion
$\dot{V}E$	Minute ventilation
$\dot{V}E_{peak}$	Peak minute ventilation
$\dot{V}CO_2$	Carbon dioxide production
$\dot{V}O_2$	Oxygen consumption
$\dot{V}O_{2max}$	Maximum oxygen uptake
$\dot{V}O_{2peak}$	Peak oxygen uptake
W	External work done
WBGT	Wet bulb globe temperature

Chapter 1

1 Introduction

Fencing has been a part of every Olympic Games in the modern era with 36 fencing medals to be won. Fencing is split into three weapon categories: sabre, epée, and foil. Differences between the weapons are highlighted by different swords used, different areas of the body that can be targeted, and by a system of priority (Roi & Bianchedi, 2008). Priority in foil and sabre is whereby a point can only be scored by the fencer being judged to be attacking by the referee (International Fencing Federation, 2021). During competition fencers will compete in a number of fights over a 9-11 hour period comprising of Poule and Direct Elimination (DE) fights (Roi & Bianchedi, 2008). Poule fights are defined as first to 5 points bouts with a fight time of 3-minutes. If the 3 minutes are reached the winner is determined by most points won unless the fight is drawn, then an extra minute of fencing is completed. Fencers will compete in 5-7 Poule fights in a round-robin format after which fencers are seeded for knockout DE fights. Direct Elimination fights comprise of first to 15 points 3x3 minute bouts with 1 minute of rest between bouts. If scores are tied after the final 3-minute bout a 1-minute sudden death bout will determine the winner. Fencers could potentially compete in up to 8 DE fights during competition depending on participant numbers in the competition. However, due to interruptions during a fight a DE fight can last as longer with average fight times in the Tokyo 2020 Olympic games of 16:39 ± 3:19 mins (range: 8:58-25:44 mins) for epée, 18:21 ± 6:15 mins (range: 7:22-34:45 mins) for foil, and 11:31 ± 3:14 (range: 5:00-20:18) for sabre (The Tokyo Organising Committee of the Olympic and Paralympic Games, 2021). Due to the system of priority, foil and sabre points tend to be shorter in length than epée and therefore the fights can be shorter. Work to rest ratios have been calculated demonstrating this difference, the work to rest ratio for epée is ~1:1, for foil ~1:3 and sabre ~1:6 (Aquili et al., 2013). Fencers defend more in epée due to both fencers being able to score points. Fencers attack more in foil and sabre so they can be determined as having priority to score a point by the referee.

This thesis will focus on research in epée fencing due to the researcher's prior fencing knowledge and epée being a more objective weapon compared to foil and sabre due to no right of way rule. Therefore, when analysing performance variables such as points scored this is easier for the researcher to calculate without the need for specialist referees or coaches to help with the analysis. Furthermore, with epée having a greater work to rest ratio than foil and sabre epée fencers may be under greater physiological and thermoregulatory strain which needs investigating. Finally, the researcher had better access to epée athletes as participants for the research studies in this thesis. The overall aims of this thesis are to: determine the physiological, thermoregulatory, perceptual and movement demands of epée fencing; determine the effects of cooling on physiological responses, cognitive function, and performance of epée fencing; and determine the physiological and thermoregulatory responses of wheelchair fencing.

Due to the differences in work to rest ratios between the different weapons there is potential for differences in the physiological demands of epée, foil, and sabre. However, there is limited research determining the physiological demands of fencing with the majority of research involving epée in simulated or laboratory environments with no competitive element or a low number of fights conducted (Bottoms, Sinclair, Gabrysz, Szmatlan-Gabrysz, & Price, 2011; Bottoms, Sinclair, Rome, Gregory, & Price, 2013; Iglesias et al., 2019; Milia et al., 2013). This lack of competitive element may cause a lower catecholamine release and thus not show a true representation of physiological responses during fencing (Hoch, Werle, & Weicker, 1988; Viru et al., 2010). Understanding the demands of competitive fencing would allow coaches and practitioners to set appropriate training programmes to prepare athletes for competition by attempting to match training and conditioning sessions to competition demands.

Heart rate (HR) responses to fencing vary in the literature and can reach between 85-100% of maximum heart rate during epée (Bottoms et al., 2011) and foil (Wylde & Yong, 2015). Furthermore, average oxygen consumption ($\dot{V}O_2$) during epée has been shown to be ~75% maximum oxygen consumption ($\dot{V}O_{2max}$) (Bottoms et al., 2011; Iglesias & Rodríguez, 2000). Both epée and sabre have also been shown to be reliant on phosphocreatine (PCr) energy system (Bottoms et al., 2011; Turner et al., 2018) and epée the aerobic energy system (Bottoms et al., 2011) due to relatively low blood lactate concentration reported, which tends to remain below 4mmol.L^{-1} (Bottoms et al., 2011; Turner et al., 2018, 2014). There could be a heavier reliance on aerobic energy systems as a competition progresses, especially in epée, when participants fatigue, and fights become more tactical in latter DE rounds with less repeated explosive anaerobic movements. Further, research needs to explore the physiological demands of competitive fencing during competition. Research designs could also incorporate a round-robin style DE section to achieve a higher number of participants reaching the "final" to generate more data to understand fencing performance. As in previous research by Turner et al. (2018) whereby competition data was collected in sabre there was only n = 2 in the final compared to n = 6 in the last 16.

Previous research in fencing has attempted to quantify movement data using time-motion analysis (Bottoms et al., 2013; Wylde, Tan, & O'Donoghue, 2013; Wylde & Yong, 2015). During fencing it has been determined a fight consists of ~40-45% low intensity, ~50% moderate intensity, and ~5-10% high intensity movements (Wylde et al., 2013; Wylde & Yong, 2015), highlighting the importance of the aerobic and PCr energy systems. With the subjective and time-consuming nature of time-motion analysis, as well as technological advances, analysing movement data has shifted towards GPS/accelerometer-based systems. These systems can provide immediate movement data such as speed, distance, accelerations etc. and have been validated for other intermittent sports such as soccer (Scott, Scott, & Kelly, 2016). However, there has been no previous studies reporting GPS/accelerometer-based movement analysis in fencing. Understanding movement data during fencing would allow coaches and practitioners to create a more in-depth view of fencing performance and to create training programmes to match the demands of competition.

Fencers are also required to wear thick protective clothing when competing that covers the whole body from head to toe. The protective clothing, in conjunction with the high physiological demands of fencing (85-100% maximum HR, 75% $\dot{V}O_{2max}$) could potentially pose a challenge to heat dissipation, causing a decrease in performance due to fatigue from rising core and skin temperatures. The protective clothing is likely to impede evaporative and convective heat loss and could cause a micro-climate that creates similar conditions to exercising in hot and humid conditions. It has been shown that endurance performance declines with elevated core temperatures (González-Alonso et al., 1999) and skin temperatures (B. R. Ely, Cheuvront, Kenefick, & Sawka, 2010) which narrows the core to skin temperature gradient. This causes increased cardiovascular strain through increased heart rate and skin blood flow to dissipate heat (Sawka, Cheuvront, & Kenefick, 2012). Previous research in sports wearing similar full-body protective clothing to fencing, such as American football, ice hockey and motor racing, have shown a high cardiovascular strain and thermal load during exercise with decreased performance (Armstrong et al., 2010; Batchelder, Krause, Seegmiller, & Starkey, 2010; Carlson, Ferguson, & Kenefick, 2014; Noonan, Mack, & Stachenfeld, 2007). There has been no previous research reporting the thermoregulatory demands of fencing. As well as decreased performance fencers could also be at risk of symptoms of heat illness due to the protective clothing creating a hot micro-climate. As fencing competitions can last between 9-11 hours it is possible there could be an accumulation of heat load, especially as fencers anecdotally do not remove protective clothing layers between fights. This could, therefore, impact performance as a competition progresses into the DE rounds where the fights become longer and more tactical. Understanding the thermoregulatory demands of fencing could enable coaches and practitioners to develop appropriate cooling strategies to lower body temperature and maintain exercise performance.

There are various cooling strategies (pre and per cooling) researched that have been shown to improve performance and lower the thermoregulatory demands during exercise (Bongers, Hopman, & Eijsvogels, 2017). However, protocols often used within the literature are not practical and do not transfer to real-world performance. Popular methods of cooling athletes include ice vests, evaporative cooling vests, ice slurry/cold water ingestion, skin cooling, cold water immersion and mixed-method approaches (Racinais et al., 2021). Further, research is warranted to determine an effective cooling strategy in fencing. Due to a minimum rest period between fights of 10-15 minutes combining cooling interventions could be a more effective approach to alleviate accumulated heat load of fencing within the short recovery period that is available.

The Paralympic sport of wheelchair fencing shares similar physiological and thermoregulatory challenges as able-bodied fencing and has not been extensively researched. Wheelchair fencers also work at high levels with average $\dot{V}O_2$ ~73% $\dot{V}O_{2max}$ and average heart rate ~84% of maximum heart rate (Bernardi et al., 2010). The study by Bernardi et al. (2010) is the only study to use wheelchair athletes, with

Iglesias et al. (2019) using able-bodied participants when comparing standing to seated fencing. Furthermore, wheelchair fencers with spinal cord injury (SCI) may be at greater risk of heat imbalances in the body due to the protective clothing and compromised thermoregulatory responses to able-bodied participants. Wheelchair fencers are also required to wear an apron covering the lower body when competing which able-bodied fencers do not wear. Previous research with SCI participants has shown a greater heat storage in the lower body during exercise and in recovery, as well as decreased performance compared to able-bodied participants (Griggs, Havenith, Price, Mason, & Goosey-Tolfrey, 2017; Price & Campbell, 1999, 2003).

Aims

The aims of this thesis are:

1. Understand the physiological and movement demands of epée during simulated competition.

2. Compare the physiological and movement demands of epée between Poule and DE fights.

3. To be the first study to determine the movement demands of epée fencing using a tri-axial accelerometer.

4. Determine the thermoregulatory demands of epée fencing during simulated competition.

5. As a competition progresses DE fights are performed with a minimum rest period of 10 minutes between fights, therefore an aim of this thesis was to determine the thermoregulatory, cardiovascular, and perceptual responses across DE fights.

6. Assess the effects of external cooling (EXT; evaporative cooling vest) and mixed-method cooling (MIX; evaporative cooling vest and cold-water ingestion) interventions performed during the recovery period between DE fights on the physiological responses, cognitive function, and performance variables during epée fencing.

7. Apply an individualised approach (involving the world number 1 ranked category A and B fencers for epée) to determine the physiological and thermoregulatory responses to wheelchair epée during Poule and DE fights.
8. Determine physiological characteristics of wheelchair fencing athletes during incremental maximal oxygen uptake testing.

Chapter 2

2 Literature Review

This literature review will be split into three parts firstly discussing the physiological demands of the Olympic sport of fencing, with a specific focus on epée fencing. The second part will discuss how thermoregulation impacts fencing performance and potential benefits of cooling interventions to improve or maintain performance within fencing. Finally, the third part will discuss an individualised approach to the physiological and thermoregulatory demands of wheelchair fencing.

Part 1

2.1 Physiological Demands of Fencing

Fencing competitions last between 9-11 hours, comprise of 5-7 Poule fights (3-minute first to 5 points) and up to 8 DE fights (3x3-minute first to 15 points) and is characterised by repeated bouts of high intensity intermittent movements (Roi & Bianchedi, 2008; Turner et al., 2014). Fencers aim to maintain a certain distance from their opponent to avoid being hit and to determine when to initiate an attack to score points by moving up and down the 14m piste (Bottoms et al., 2013). Fencers have been reported to cover between 250-1000m during a fight (Roi & Bianchedi, 2008). It has been stated that fencing is heavily reliant on anaerobic power (in particular PCr) to perform attacking lunge and flèche movements to score points (Turner et al., 2014). Furthermore, a determinant of fencing performance is the ability to change direction (Turner et al., 2014). Therefore, speed of movement, acceleration and deceleration ability are important components of fencing performance (Turner et al., 2014) and the ability to repeatedly perform these high intensity movements in multiple fights will be important over a competition day. However, the aerobic system should not be ignored to allow for recovery of anaerobic energy stores and during the submaximal preparatory movements before initiating attacking movements during a fight (Bottoms et al., 2011). It has been shown that preparatory movements are a large part of a fencing fight (Bottoms et al., 2013; Wylde et al., 2013) with high intensity attacking movements representing <10% of a fencing fight (Bottoms et al., 2013; Wylde et al., 2013; Wylde & Yong, 2015). Furthermore, the different style of fencer may impact the predominant energy system used whereby attacking fencers will rely more on anaerobic energy systems and defensive fencers will rely more on aerobic energy systems. There are also differences between the weapons with epée having a greater sub-maximal component than foil and sabre with average actions lasting 2.5 seconds, 5 seconds and 15 seconds for sabre, foil and epée, respectively, with a range of <1 second to >60 seconds (Roi & Bianchedi, 2008). Therefore, epée could have a greater aerobic component than foil and sabre, which will have a greater PCr component than epée. In addition to the physical components of fencing performance, cognitive function is a key determinant of fencing in particular reacting to an opponent's movements (Balkó, Borysiuk, & Šimonek, 2017; Roi & Bianchedi, 2008) which is highlighted by the number of changes of direction in a fight 170-400 in epée and foil (Turner et al., 2014). Fencing is a tactical sport that requires high levels of concentration and focus to react to an opponent's movements and determine the best attacking approach to score points. There can also be different fencing styles adopted with some fencers being more attacking and some fencers being more defensive, which could change during a fight depending on the score. Therefore, it is important for a fencer to maintain cognitive function when competing. As a fencing competition progresses into later DE rounds (where the medals are won) and fatigue occurs there could be decreases in cognitive function and ability to repeatedly perform high intensity movements which could negatively affect performance.

Figure 2.1. The lunge attacking movement commencing from the on guard position (left to right).

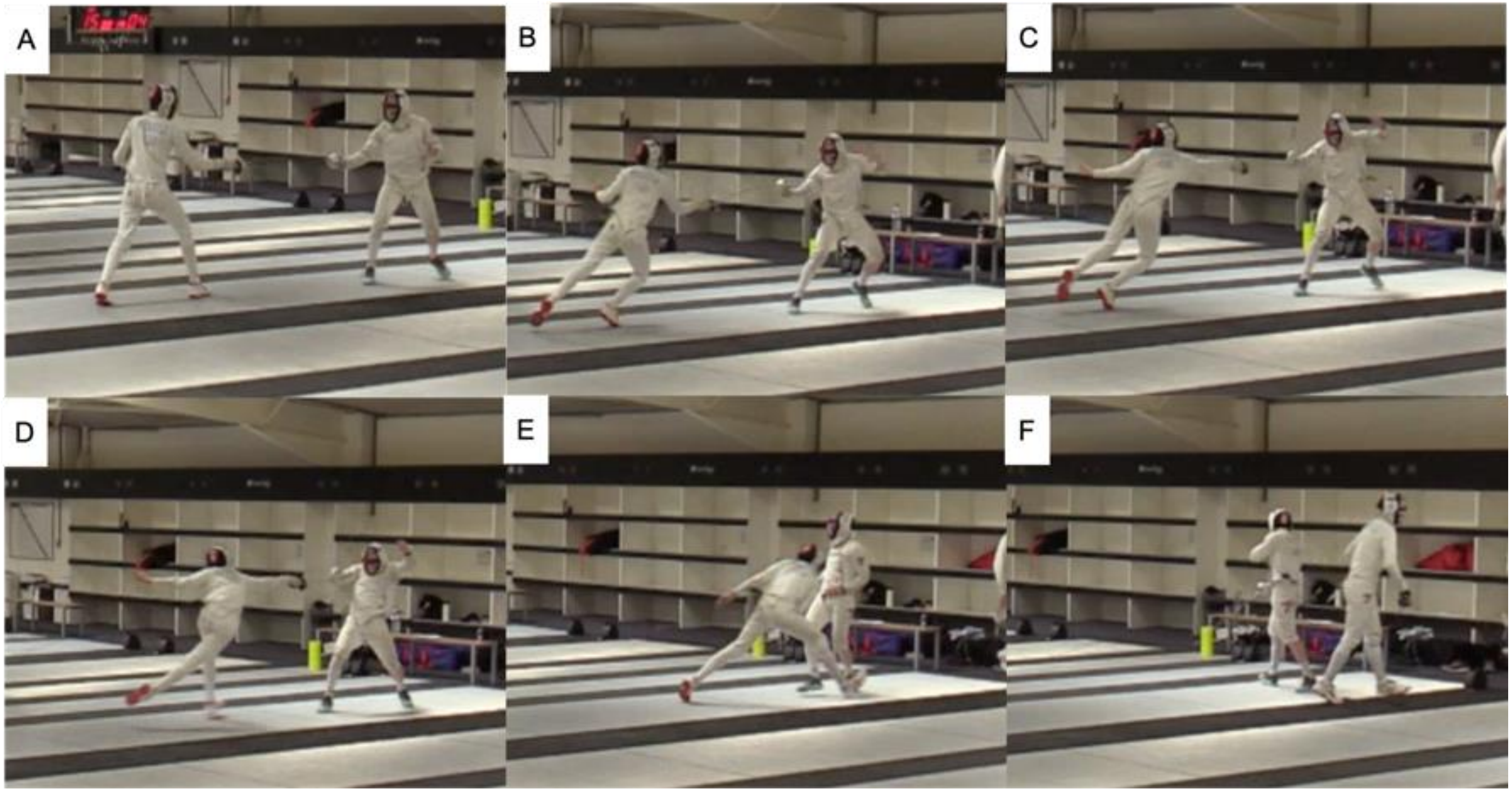


Figure 2.2. The fleche attacking movement which is initiated from either on guard (A), with the back leg driven forward over the front leg (B-D) with the body continuing forwards due to momentum generated (E-F). The hit should be achieved as the back foot lands with the arm extended (D). Fleche results in a halt in the fight and is often described as a "running attack" (Turner et al., 2014)

2.1.1 Work to Rest Ratio

Fencing is categorised by high intensity intermittent actions whereby a fencer will undertake multiple explosive actions to win points. This is highlighted through the work to rest ratios determined in previous research. Epée fencing tends to have a work to rest ratio of ~1:1-2:1 (Aquili et al., 2013; Bottoms et al., 2013; Turner et al., 2014). Foil and sabre tend to have greater rest periods than epée with work to rest ratios of ~1:1-1:3 and ~1:5-1:6 for foil and sabre, respectively, (Aquili et al., 2013). Furthermore, it has been shown that fencers will work on average for longer in epée (15 seconds), than in foil (5 seconds) and sabre (2.5 seconds) during a point (Aquili et al., 2013; Roi & Bianchedi, 2008; Turner et al., 2014). Therefore, there are distinct differences between the weapons with sabre being more explosive and epée having more of a submaximal component to performance. The system of priority could also influence the nature of each weapon whereby competing in foil and sabre engaging in the first attack could be vital for performance to score points over an opponent, whereas epée could be more tactical to outscore the opponent as there is no system of priority. Due to the greater work to rest ratios in epée than foil and sabre there could be a greater physiological demand placed on the body which could cause fatigue, especially in the later DE fights in a competition. This needs to be investigated so coaches, practitioners and fencers can gain a deeper understanding of the demands of fencing to inform training, recovery strategies and preparation for long competition days. Therefore, this thesis will be focussing on research in epée.

2.1.2 Heart Rate

Measuring HR is a simple and cost-effective method for measuring internal load of exercise performance. The measurement of HR during competition enables coaches and practitioners to plan training programmes to allow athletes to work at competition intensity during training to prepare for competition. Heart rate during fencing has been recorded in both simulated fencing (Bottoms et al., 2011, 2013; Iglesias et al., 2019; Li, Guo, So, & Yuan, 1999; Milia et al., 2013) and competition (Iglesias & Rodríguez, 1995; Wylde & Yong, 2015) as shown in Table 2.1. Fencing can produce high HR with most of the previous research showing average heart rate (HR_{av}) 75-100% of maximum heart rate (Table 2.1). Therefore, this suggests there could be a high cardiovascular strain when competing. Heart rate tends to be higher in DE fights compared to Poule fights this could be due to the longer duration fights causing a continual HR increase and the more competitive part of the competition, whereby if you lose you are knocked out, increasing catecholamine levels (Hoch et al., 1988).

There is a suggestion that simulated fencing tends to produce a lower HR response than competition as shown in Table 2.1, however there is limited competition data available. There is a lack of research determining the peak HR that can be achieved in fencing with no current research assessing peak competition HR. Peak HR measurements could: indicate the maximum cardiovascular strain experienced by a fencer when competing; inform training sessions to meet the maximal demands of performance; and inform recovery strategies. Furthermore, there are large standard deviations in the research for both average and maximum HR this could be due to different fencing styles employed e.g., offensive, and defensive styles and, also, reporting of absolute HR as opposed to relative percentage compared to maximum HR. Furthermore, previous fencing research has used participants of varying ages within the same study. Participants of different ages could impact the standard deviation as maximum HR tends to decline with age (Eskurza, Donato, Moreau, Seals, & Tanaka, 2002; Whyte, George, Shave, Middleton, & Nevill, 2008), therefore reporting relative percentages would be a better method of presenting HR data.

Table 2.1. Heart rate responses recorded during fencing (mean ± SD).

Authors	Weapon	Participant Sex	Simulated or Competition Fencing	Average Heart Rate (beats.min^{-1}) (% maximum HR if reported)	Peak Heart Rate (beats.min^{-1}) (% maximum HR if reported)
Bottoms et al. (2011)	Epée	Female	Simulated	DE: ~ 173 (87 ± 3%)	NS
Bottoms et al. (2013)	Epée	Male	Simulated	Poule: 155 ± 14 DE: 157 ± 14	Poule: 173 ± 15 DE: 179 ± 15
Iglesias & Rodriguez (1995)	Foil	Female	Competition	Poule and DE grouped: 173 ± 7	NS
Iglesias & Rodriguez (1995)	Epée	Male	Competition	Poule and DE grouped: 166 ± 8	NS
Iglesias et al. (2019)	Epée	Male	Simulated	Poule: 152 ± 22 DE: 164 ± 11	Poule: 170 ± 14 DE: 179 ± 8
Li et al. (1999)	Epée	Female	Simulated	Poule: 150 ± 7	Poule: 178 ± 7
Milia et al. (2013)	NS	Male	Simulated	DE: ~160-170	NS
Wylde & Yong (2015)	Foil	Female	Competition	Absolute HR NS (Poule: 93%, DE: 97%)	NS

HR = heart rate, NS = not stated, DE = Direct Elimination

2.1.3 Oxygen Consumption and Energy Expenditure

Understanding the $\dot{V}O_2$ responses and energy expenditure (EE) responses to fencing are important for coaches, practitioners, and athletes to determine the energy requirements of performance and to prepare appropriate nutrition strategies. Having appropriate nutritional strategies will ensure fencers are maintaining glycogen stores and maintaining hydration to maintain performance and avoid fatiguing early in a competition.

Due to the challenges of measuring expired gas in fencing due to the fencing mask there is limited research assessing the $\dot{V}O_2$ responses and energy expenditure (Bottoms et al., 2011; Iglesias & Rodríguez, 1999, 2000; Iglesias et al., 2019). During a national competition $\dot{V}O_2$ was estimated to be 54 ± 4 $ml.kg^{-1}.min^{-1}$ in male epée fencers and 40 ± 7 $ml.kg^{-1}.min^{-1}$ in female foil fencers with average $\dot{V}O_2$ 56-74% of $\dot{V}O_{2max}$ and peak oxygen consumption ($\dot{V}O_{2peak}$) during the fight recorded between 75-99% of $\dot{V}O_{2max}$ (Iglesias & Rodríguez, 1999, 2000). During simulated fencing research by Bottoms et al. (2011) showed similar relative $\dot{V}O_2$ responses during simulated epée in female athletes with average $\dot{V}O_2$ being ~75% of $\dot{V}O_{2max}$ (~35$ml.kg^{-1}min^{-1}$). However, during simulated epée fencing research by Iglesias et al. (2019) showed lower relative $\dot{V}O_2$ (44.2 ± 7.8 $ml.kg^{-1}.min^{-1}$) than earlier research by Iglesias and Rodríguez (1990, 2000). Poule fights were reported to have lower $\dot{V}O_2$ then DE fights (~39 $ml.kg^{-1}.min^{-1}$ vs. ~47 $ml.kg^{-1}.min^{-1}$) by Iglesias et al. (2019). However, $\dot{V}O_2$ responses have only been measured during simulated fencing not competition (Bottoms et al., 2011; Iglesias et al., 2019) or estimated using HR data (Iglesias & Rodríguez, 1999, 2000). Furthermore, simulated fencing research has only assessed the $\dot{V}O_2$ responses in non-competitive environments whereas there could be a greater energy demand during competitive fencing through increases in catecholamine release (Hoch et al., 1988; Viru et al., 2010).

Energy expenditure within fencing has previously been reported (Bottoms et al., 2011; Iglesias & Rodríguez, 1999, 2000; Iglesias et al., 2019; Milia et al., 2013). Iglesias and Rodríguez (1999, 2000) reported that international and national competition estimated EE were ~15.4 $kcal.min^{-1}$ and ~12.3 $kcal.min^{-1}$, respectively, with higher EE recorded in male than female fencers (~19.5 vs. ~10.7 $kcal.min^{-1}$). Similar EE for male epée fencers was recorded in simulated fencing for regional fencers of 17.5 ± 2.9 $kcal.min^{-1}$ for Poule and 19.3 ± 3.7 $kcal.min^{-1}$ for DE fights. However, lower EE (~11 $kcal.min^{-1}$) was determined in the studies by Bottoms et al. (2011) and Milia et al. (2013). However, in the study by Milia et al. (2013) it was not stated which weapon was used, therefore, it is difficult to draw conclusions from the data as if it was sabre or foil with shorter bouts this could explain these differences. Furthermore, the EE was only measured during simulated DE fights in the study by Bottoms et al. (2011) and Milia et al. (2013) which would not be representative of a true EE during competitive fencing. As highlighted above more research could be undertaken to assess the EE during competitive fencing.

2.1.4 Blood Lactate Concentration

To determine energy system contribution within fencing blood lactate concentration has been reported as shown in Table 2.2 (Bottoms et al., 2011; Iglesias & Rodríguez, 1995; Li et al., 1999; Milia et al., 2013; Turner et al., 2018). Relatively low blood lactate concentration has been reported, generally below a commonly used threshold of the onset of blood lactate accumulation (OBLA - <4.0 mmol.L^{-1}) with the exception of the study by Milia et al. (2013) whereby blood lactate concentration was ~7.0 mmol.L^{-1}. This could be due to only one DE fight being studied whereby fencers may have been more explosive due to knowing they only had to compete in one fight and as discussed earlier it was unclear what weapon was used. There have been conflicting reports in the literature regarding the energy system that is predominantly used in fencing. It has been stated that fencing may rely on alactic and glycolytic energy systems (Roi & Bianchedi, 2008; Turner et al., 2018, 2014) and that the aerobic system is not important (Turner et al., 2014). However, research by Bottoms et al. (2011) suggests fencers may also be reliant on aerobic energy sources, in particular, during epée which is characterised by longer working periods than foil and sabre. There is agreement that fencing does rely on the PCr energy system to provide explosive movements (Bottoms et al., 2011; Turner et al., 2014).

Interestingly, previous research has tended to group Poule and DE fights together and have not shown if there are any changes in energy system reliance over a competition. The only study whereby blood lactate concentration was determined across a competition was by Turner et al. (2018) and there was a decreasing blood lactate concentration from the last 8 to the final from 4.5 ± 1.5 mmol.L^{-1} to 3.2 ± 0.8 mmol.L^{-1} in sabre. As participants were knocked out during this study there were only two fencers left by the final stage compared to 5 in the last 8. Research study designs could incorporate a round-robin style of competition to simulate DE fights to determine the physiological demands of more participants reaching the final of a competition.

Due to the length of a fencing competition fencers may fatigue and become more reliant on aerobic energy sources to provide energy, especially in epée where the length of fights and work periods are longer than foil and sabre which have longer recovery periods to restore PCr stores. Therefore, more research needs to be conducted to establish whether there are changes in energy system reliance over a long competition. Understanding the energy requirements of fencing are important for coaches and practitioners to develop training programmes to target the correct energy systems to help athletes prepare appropriately for competition (Turner et al., 2018). Further, research should be undertaken across all weapons in fencing for both male and female athletes to fully understand the energy system reliance for the different types of fencing.

Table 2.2. Previous blood lactate concentration recordings during fencing.

Authors	Weapon	Participant Sex	Fight Type (Poule or DE)	Blood Lactate Concentration (mmol. L^{-1})
Bottoms et al. (2011)	Epée	Female	DE (Simulated)	~2.8
Iglesias & Rodríguez (1995)	Foil	Female	Poule and DE grouped	4.2
Iglesias & Rodríguez (1995)	Epée	Male	Poule and DE grouped	3.2
Li et al. (1999)	Epée	Female	Poule	3.2
Milia et al. (2013)	NS	Male and Female	DE	~7.0
Turner et al. (2018)	Sabre	Male	Poule	3.0
Turner et al. (2018)	Sabre	Male	DE	3.6

NS = not stated, DE = Direct Elimination

2.1.5 Perceptual Ratings of Perceived Exertion

Subjective ratings of an athlete's exertion are a good indicator as to how hard a performance was and are a simple measurement for coaches and practitioners to assess during training and competition. Ratings of perceived exertion (RPE) are often measured using the Borg 6-20 scale (Borg, 1998). There has been limited research within fencing assessing RPE of fencers (Bottoms et al., 2013; Turner et al., 2018). During simulated epée modest differentiated ratings of perceived exertion were recorded by Bottoms et al. (2013) for overall RPE (11 ± 2 for Poule and 13 ± 3 for DE), arms RPE (10 ± 3 for Poule and 13 ± 3 for DE), and legs RPE (10 ± 3 for Poule and 12 ± 3 for DE). Differentiated RPE could be useful to report in fencing as there could be local fatigue in the arms through sword movements and in the legs through repeated high intensity lunging movements during a fight (Turner et al., 2014). Competition research by Turner et al. (2018) in sabre showed similar average overall RPE for Poule (12 ± 2) and DE (14 ± 3) to Bottoms et al. (2013). When broken down by DE round there was an increase in RPE within the participants from the last 16 to the final (last 16 ~12, last 8 ~14, last 4 ~16 and final ~15). This may indicate as a competition progresses into the knockout rounds and opponents become tougher there may be an increased perception of effort from fencers. Furthermore, over a long competition participants may start to fatigue which could cause an increase in RPE. Research by Bottoms et al. (2013) also highlighted that local muscle fatigue from the arms and legs may impact performance and fatigue in fencing with similar ratings of exertion as recorded for overall RPE. This could be due to repeated arm movements and lunging movements which are the main movements involved in fencing (Bottoms et al., 2013). It was suggested by Bottoms et al. (2013) that fatigue does not affect the type of fencing movement but more likely the force and accuracy of movement. Furthermore, the sword arm could become fatigued due to the weight of the blade (epée: less than 770g, foil and sabre: less than 500g) with an outstretched arm when in on guard stance (as shown in Figure 2.2A) and forces required when deflecting an opponent's sword to defend an attack (parry). The legs are likely to become fatigued due to repeated lunging to attack an opponent (Turner et al., 2014), high intensity attacking movements (fleche), and retreating movements to avoid an attack. Fencers are also constantly moving forwards and backwards (bouncing) to maintain distance from their opponent and to initiate attacking and defensive movements which could cause additional fatigue in the legs. Future research in fencing could incorporate differentiated RPE to assess fencers' subjective perception on performance during competition and to complement objective physiological measurements.

2.1.6 Monitoring Movement Data

2.1.6.1 Methods for Monitoring Movement Data - Time-Motion Analysis vs. GPS/Accelerometer-Based Systems

There are different approaches to monitoring movement data of sporting performance. Two of the most common are time-motion analysis and Global Position System (GPS) or accelerometer-based systems. Time-motion analysis involves researchers videoing performance and then completing subjective post-competition notational analysis assessing movement data such as type, frequency and duration (Roberts, Trewartha, & Stokes, 2006). To ensure reliability of data collected researchers have to complete either intra or inter reliability which can be time consuming to re-analyse performance or get another researcher to analyse the same video which also requires clear operational definitions and can also be time consuming (Williams, 2012). From a practical perspective coaches and athletes do not have time to wait for time-motion analysis and often require immediate feedback. GPS uses satellites to send signals to the GPS device to calculate distance covered and can generate latitude, longitude and altitude information through connecting with a minimum of four satellites (Scott et al., 2016). They also calculate speeds and accelerations through the Doppler shift methods whereby the frequency of the satellite signal is analysed (Scott et al., 2016). GPS systems are, therefore, only suitable for outdoor sports due to the need for satellites. Whereas accelerometer-based systems use triaxial accelerometers, magnetometers, and gyroscopes (known as micro-electrical mechanical systems (MEMS)) to calculate movement data such as speed, acceleration, distance covered and training load. The majority of GPS systems now include MEMS within the device (Malone, Lovell, Varley, & Coutts, 2017). These systems provide practitioners with a lot of data and will record at 10-15Hz for GPS systems and 100Hz+ for accelerometer-based systems (Malone et al., 2017).

GPS/accelerometer-based systems provide detailed information on the external load of athletes (and internal load if physiological variables such as heart rate can also be measured), such as accelerations, speed, distance covered and can provide an overall training load score. Furthermore, sport science practitioners and coaches can use this information to design training programmes to improve athletes' fitness and attempt to match training demands to competition demands (Scott et al., 2016). The difference to time motion analysis is these systems can provide real-time data to coaches, athletes, and practitioners (Malone et al., 2017; Roell, Roecker, Gehring, Mahler, & Gollhofer, 2018). Due to modern technological advances, and time saving ability sport has moved away from time motion analysis to the use of GPS/accelerometer based systems to quantify the demands of sporting performance (Hoppe, Baumgart, Polglaze, & Freiwald, 2018; Scott et al., 2016).

There has been various research discussing the validity and reliability of the GPS/accelerometer-based systems for outdoor and indoor sport (Hoppe et al., 2018; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Malone et al., 2017; Roell et al., 2018; Scott et al., 2016). In the review by Scott et al. (2016) GPS units have been shown to be valid in measuring distances and speeds. They also stated that the units show good intraunit reliability, however interunit variability can differ so athletes should aim to wear the same unit for every training and competition. However, when devices have accelerometers built in there is very good intra and inter unit reliability shown suggesting devices can be interchanged and are also suitable for use indoors as well as outdoors (Scott et al., 2016). Furthermore, MEMS devices have been shown to accurately quantify accelerations and decelerations when compared to 3D motion analysis (Roell et al., 2018) and are therefore suitable for use in indoor sports.

2.1.6.2 Movement Data in Fencing

Within fencing there has been no previous research assessing the physiological demands using GPS/accelerometer-based systems. However, there has been previous research using time-motion analysis (Aquili et al., 2013; Bottoms et al., 2013; Wylde et al., 2013; Wylde & Yong, 2015), which gives some understanding to the movement demands of fencing performance. Research by Aquili et al (2013) and Bottoms et al. (2013) used time-motion analysis to determine work to rest ratios within fencing as described in chapter 2.1. Additionally, Bottoms et al. (2013) used the time motion analysis of simulated competition to create a simulated fencing protocol for epée. They also highlighted the importance of arm movement as well as leg movement within fencing training with similar RPE for arms and legs as overall RPE. Research by Wylde et al. (2013) and Wylde and Yong (2015) determined the different intensity of movements within foil fencing using time-motion analysis for well-trained and adolescent participants. They determined that ~8%, ~41% and ~51% of movements were high, moderate, and low intensity movements, respectively. However, due to the subjective nature of time-motion analysis (Roberts et al., 2006), there could be misinterpretation of movement types by researchers and also coaches and practitioners when prescribing training from the definitions. Furthermore, there is extremely limited data in the 3 fencing weapons for movement data.

Research should be undertaken within fencing to determine the external demands of fencing using GPS/accelerometer-based systems. It has been previously stated that speed of movement, and change of direction which consists of accelerations and decelerations are important determinants of fencing performance (Turner et al., 2014). Providing coaches and practitioners with speed, acceleration, deceleration, distance covered, and training load data could allow them to plan training programmes around the demands of competition. This would allow athletes to be better prepared for long competition days and give them an edge over their opponents. Additionally coupling the external demands of fencing with internal demands (such as HR, $\dot{V}O_2$, blood lactate concentration, and body temperature) would create a clearer picture of fencing performance. Furthermore, understanding the movement demands of fencing could allow for appropriate and effective recovery strategies to be designed to enable athletes to recover between fights and between competition days if competing in individual and team events.

2.1.7 Lab vs Field Based Testing

In sport science research there are two approaches to physiological testing that researchers can take: laboratory testing or field-based testing (Mendel & Cheatham, 2008). The advantages and disadvantages of both approaches are highlighted in Table 2.3. Within sport science the choice of testing is often determined by the validity, and reliability of equipment and testing protocols and access to participants as to whether they can come into the laboratory. Furthermore, laboratory testing is more suited to closed skill sports such as running, cycling and rowing due to appropriate equipment, whereas intermittent sports such as football, basketball and fencing are not suited and often require protocols to be designed that aim to mimic the sport demands (Bottoms et al., 2013; Mendel & Cheatham, 2008).

For the sport of fencing field-based testing may be a more appropriate method for understanding the physiological demands than laboratory testing. The laboratory-based protocol developed by Bottoms et al. (2013) was determined to be appropriate for epée however the authors did state that the physiological responses were still lower than simulated competition. Furthermore, it has been highlighted that there is a greater catecholamine response, motivation to perform and psychological stress response when participants compete in a competitive situation compared to a non-competitive or laboratory situation (Fernandez-Fernandez et al., 2015; Hoch et al., 1988; Viru et al., 2010). Fencing is a unique sport whereby traditional movements such as running, or cycling are not completed therefore testing using equipment such as treadmills and cycle ergometers in the laboratory would not be a valid measurement of fencing performance. As fencing is a whole-body sport, researchers need to ensure the upper body can be fatigued sufficiently which may be achieved better in the field fighting against an opponent. Furthermore, many sport science facilities are unlikely to contain the space to set up a fencing piste with scoring system, and have appropriate ceiling space to run physiological testing in a laboratory. As highlighted earlier in chapter 2.1 further research in fencing should consider testing athletes over a full competition schedule of Poule and DE fights in order to gain a true understanding of the physiological demands of fencing, previous research has tended to use less fights or cut out the Poule rounds (Bottoms et al., 2011; Iglesias et al., 2019; Li et al., 1999; Milia et al., 2013). However, due to research design, resources, time available for testing, low participant recruitment numbers, and fencers' schedules this may explain shorter fencing studies with less fights than a competition. Furthermore, cutting of Poule fights for intervention studies may be acceptable as there is usually ~60 minutes between Poule and DE fights so fencers may return to baseline levels for some physiological variables.

Table 2.3. Advantages and disadvantages of laboratory vs. field-based testing, table created from information from Mendel & Cheatham (2008).

Laboratory Testing	Field-Based Testing
Advantages	Advantages
Highly controlled testing	Ecological validity of field-based tests
Use standardised protocols	Less expensive than laboratory testing
Can produce good reliability of testing	More accessible for athletes
Can use equipment that cannot be easily used in the field e.g., online gas analysis, BodPod	Physiological testing takes place in athletes' natural training/competition environment
Environmental conditions can be standardised	Athletes may feel more comfortable in their own environment
Disadvantages	More likely to achieve true physiological responses
Lack of ecological validity	Disadvantages
Requires specialised personnel to run testing and equipment	More difficult to control testing due to environmental conditions – reliability may not be as high
Expensive	Some limitations on what equipment can be used
Facilities are not always accessible for athletes	Some field-testing protocols may still not be valid
Physiological responses are often lower than field testing	
May require athlete familiarisation sessions to protocols and equipment	
Requirement to simulate athlete training/competition conditions	

Part 2

2.2 Heat Balance

When competing fencers are required to wear full thick body protective clothing consisting of fencing mask, protective jacket, breeches, padded gloves, socks, shoes, plastron, and chest protector (for female athletes), with foil and sabre athletes wearing an additional electrical conductive jacket (International Fencing Federation, 2019). Moreover, fencing athletes may have potential issues with heat balance due to the multiple layers of protective clothing impeding heat loss and causing micro-climates raising body temperature (Pascoe, Bellingar, & McCluskey, 1994; Pascoe, Shanley, & Smith, 1994). It is, therefore, important to discuss thermoregulation.

Humans aim to maintain a core body temperature (T_{core}) between 36-37°C (Geneva, Cuzzo, Fazili, & Javaid, 2019; Obermeyer, Samra, & Mullainathan, 2017). To maintain heat balance, the internal heat production, through metabolic rate and external work done, must equal the rate of heat lost to the environment, through convection, radiation, conduction, evaporation, and heat storage. The conceptual heat balance equation (Parsons, 2003) shows this dynamic equilibrium.

$M-W\ (W.m^2) = C \pm R \pm K \pm E \pm S$

Whereby:

M = metabolic rate, W = external work done, C = convection, R = radiation, K = conduction, E = evaporation and S = heat storage

M-W represents the heat that is generated by the body. Convection is defined as the heat loss through moving air or liquid over a surface e.g., the skin (Wendt, Van Loon, & Van Marken Lichtenbelt, 2007). Radiation is the loss or gain of heat from infrared rays (Wendt et al., 2007) and the human body both emits and receives radiant heat, if the external temperature is greater than the body temperature the body will receive greater heat from radiation than it loses. Conduction is defined as the transfer of heat from one object to another through touch and can also occur within the body via a thermal gradient (Wendt et al., 2007). Evaporation is the heat loss through insensible water loss (ventilation and diffusion) and sweating (Wendt et al., 2007). Heat is transferred from the core to the surface of the skin (through sweating) and evaporates from the skin as water vapour due to vapour pressure differences between the skin and the air. Evaporative heat loss is influenced by the following factors: 1) ambient conditions (temperature and humidity), 2) convective currents around the body, and 3) the amount of skin surface exposed to the environment (Sawka & Wenger, 1988). Evaporative heat loss is the primary heat loss mechanism during exercise.

Figure 2.3 shows heat production and heat loss during exercise in active muscles, the transfer of heat from the core to the skin and heat exchange with the external environment (Powers & Howley, 2018). During exercise heat balance can be impeded by the environmental conditions (temperature and humidity), exercise intensity, and clothing layers that can impede heat loss (Brouns, 1991; Montain, Sawka, Cadarette, Quigley, & McKay, 1994; Nichols, 2014; Pascoe, Bellingar, et al., 1994; Pascoe, Shanley, et al., 1994; Sawka & Wenger, 1988). Excess heat production and an inability to dissipate heat effective causes an increase in cardiovascular strain which can have an impact on exercise performance and in the worst case scenario cause health problems and death if heat exhaustion or heat stroke develop (Howe & Boden, 2007; Nichols, 2014). Within fencing heat balance could be a potential issue due to the thick protective clothing that covers the whole body, which could impede heat loss through decreasing the evaporative and convective heat loss capacity. Furthermore, if fencing competitions or summer training are conducted in non-air-conditioned sports halls fencers may not be able to balance heat gain and loss effectively, which could then decrease performance and fatigue could occur.

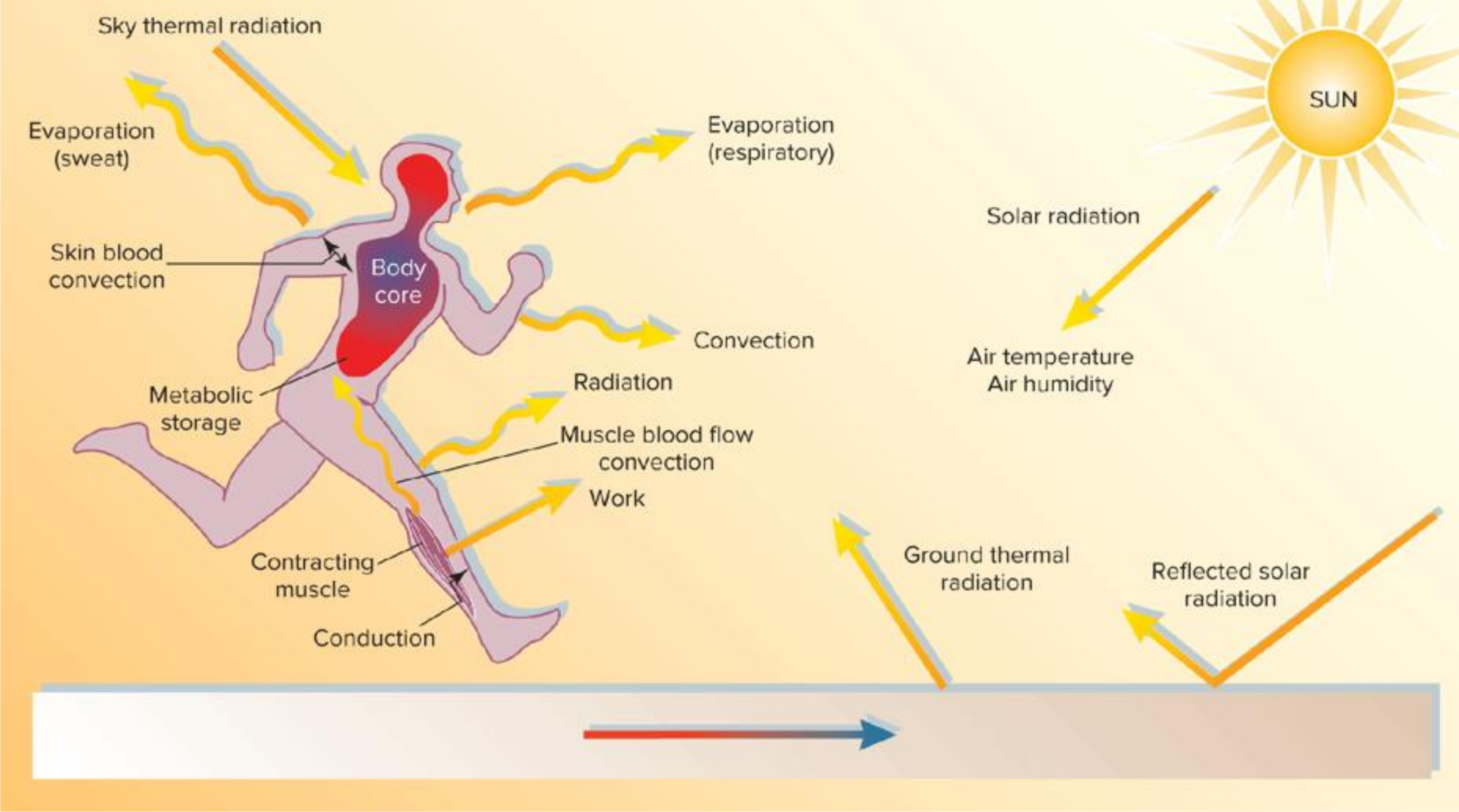


Figure 2.3. Heat production and heat loss within the body and external environment. Image taken from Powers & Howley (2018).

2.3 Thermoregulation and Exercise

The protective clothing worn by fencers could create a micro-climate between the skin and the clothing worn, that has a greater temperature than the ambient conditions. It has been shown in previous research that full body encapsulated protective clothing can create a micro-environment 6-10°C hotter than the ambient conditions (Bishop, Gu, & Clapp, 2000). Due to the full body protective clothing and the inability to dissipate heat through evaporation and convective mechanisms, the protective clothing worn in fencing could potentially create a hotter micro-climate than the ambient conditions and, therefore, be similar to exercising in hot conditions.

Traditionally, research has focussed on the decline of exercise performance (endurance, and intermittent sport) during high ambient temperatures and humidity which can range from 7-45% (M. R. Ely, Cheuvront, Roberts, & Montain, 2007; Galloway & Maughan, 1997; Marino et al., 2000; Maughan, Otani, & Watson, 2012; Mohr, Nybo, Grantham, & Racinais, 2012) with less research in sports which require protective clothing to be worn such as fencing. There could be a potential performance decline within these sports similar to exercise in the heat research due to the micro-climate created from the protective clothing which could increase core and skin temperature.

Exercise performance is affected when exercising in the heat due to the increased cardiovascular strain as the body attempts to maintain thermoregulation. Fatigue during exercise in the heat has been associated with high core temperature (T_{core}) ~39.5-40°C, hot mean skin temperature (T_{skin}) >35°C, and the strain on the cardiovascular system to pump blood to the working muscles as well as the skin to dissipate heat (de Korte, Bongers, Hopman, & Eijsvogels, 2021). When compared to exercising in temperate or cool conditions it has been determined that T_{core} is higher during exercise in the heat with T_{core} consistently greater than 39.5°C (de Korte et al., 2021; B. R. Ely et al., 2009; Galloway & Maughan, 1997; González-Alonso et al., 1999; Marino et al., 2000; Maughan et al., 2012; Mohr et al., 2012). However, it has been shown that athletes are able to finish races and also win medals with T_{core} well in excess of 39.5°C (B. R. Ely et al., 2009; Racinais et al., 2021, 2018). Therefore, this indicates fatigue due to high T_{core} is more complex. Researchers have discussed the role of hot T_{skin} (>35°C) in fatigue when exercising in the heat (B. R. Ely et al., 2010;

Sawka et al., 2012). High T_{skin} lowers the core to skin temperature gradient which increases skin blood flow requirements to dissipate heat (Sawka et al., 2012). Narrow core to skin temperature gradients (due to high T_{skin}) have been linked to increased cardiovascular strain when exercising in the heat due to an increase in heart rate and cardiac output to increase skin blood flow to dissipate heat, which has the knock-on effect of lowering blood flow to the working muscles which could cause fatigue (Cuddy, Hailes, & Ruby, 2014; Sawka et al., 2012). Therefore, T_{skin} may be more important than T_{core} with heat related fatigue. An increase in T_{core} relative to skin temperature would benefit cooling by increasing the core to skin temperature gradient and lower the skin blood flow requirements (Sawka et al., 2012). Research by Ely et al. (2010) showed that decrease in performance (~17%) could be associated with T_{skin} as during a time trial peak T_{core} was ~38.2°C, however T_{skin} was higher in the hot trial than the temperate trial (~36°C vs. ~31°C) and this caused narrower core to skin temperature gradients. Therefore, within fencing the protective clothing coupled with repeated high intensity exercise over a competition could potentially cause decreased performance and cardiovascular strain, due to increases in T_{core} and high T_{skin} which could cause a narrow core to skin temperature gradient. There has been no previous research that has reported T_{core} or T_{skin} in fencing.

There is also a subjective element to fatigue when exercising in the heat with greater RPE and thermal sensation recorded when exercising in the heat compared to temperate or cool conditions (B. R. Ely et al., 2010; Galloway & Maughan, 1997; Maughan et al., 2012; Périard et al., 2014). Therefore, if perception of effort and heat are greater when exercising this could lower the drive and motivation to continue exercising causing participants to fatigue (Marcora & Staiano, 2010; Marcora, Staiano, & Manning, 2009). It has been previously shown that human behaviour is driven by pleasure and displeasure of activity during exercise (Cabanac, 2006). Therefore, high RPE and thermal sensation could be driven by how unpleasurable the exercise is and when participants feel hot this feeling of displeasure could occur earlier during exercise forcing early fatigue during exercise (Cabanac, 2006; Marcora & Staiano, 2010; Marcora et al., 2009; Périard et al., 2014). Furthermore, it has been shown that skin temperature is a key factor in human behaviour in the heat (Schlader, Prange, Mickleborough, & Stager, 2009) and plays a role in determining thermal comfort. The afferent feedback from the skin to the hypothalamus of the environmental conditions could play a key role in determining exercise behaviour in the heat (Périard et al., 2014). The protective clothing and repeated high intensity exercise in fencing could cause decreased performance as a competition progresses through high RPE and thermal sensation that could cause displeasure during fencing which could be linked to high skin temperatures created from a micro-climate and an inability to dissipate heat.

Cognitive function has been shown to be affected by increases in body temperature with an inverted-U relationship (Schmit, Hausswirth, Le Meur, & Duffield, 2017). It has been suggested that when T_{core} rises above 38.5°C cognitive function declines (Gaoua, Racinais, Grantham, & El Massioui, 2011; Schmit et al., 2017). Despite high core temperatures being associated with improved reaction time it has been widely accepted there is a decrease in accuracy of cognitive tests (Ando et al., 2015; Bandelow et al., 2010; Gaoua, Grantham, Racinais, & El Massioui, 2012; Jiménez-Pavón et al., 2011; Lee et al., 2014; MacLeod, Cooper, Bandelow, Malcolm, & Sunderland, 2018; Simmons, Saxby, McGlone, & Jones, 2008). Furthermore, the decline in cognitive performance tends to occur in more complex tasks than simple tasks (Bandelow et al., 2010; Gaoua et al., 2012, 2011). There are inconsistencies within the literature as to whether T_{core} (Bandelow et al., 2010; Simmons et al., 2008) or T_{skin} (Gaoua et al., 2012) is the main driver for decreased cognitive function. Improvements in reaction time have also been linked to increased arousal due to exercise (MacLeod et al., 2018; Schmit et al., 2017) whereas decreased accuracy has been associated with central fatigue (Bandelow et al., 2010; Jiménez-Pavón et al., 2011; Schmit et al., 2017). This has important implications for fencing which has a high cognitive demand due to having to respond to an opponent’s potential explosive action quickly and select the appropriate visual information to defend or attack an opponent (Balkó et al., 2017; Roi & Bianchedi, 2008). Therefore, the protective clothing worn by fencers and the hot micro-climate created could increase T_{core} and T_{skin} to a level that has negative impacts on cognitive function. A fencer with decreased cognitive function could select the wrong information and make an incorrect decision which could concede points during a fight and cause them to be knocked out of the competition.

2.4 Thermoregulatory Demands of Fencing

There has been no previous research discussing the thermoregulatory demands of fencing. Fencing poses thermoregulatory challenges to the body. Firstly, fencing competitions can last between 9-11 hours (Roi & Bianchedi, 2008), therefore there will be multiple fights throughout a day with heat being produced by the active muscles, in the arms and legs, and stored by the body. Secondly, and most importantly, whilst competing fencers are covered head to toe in thick protective clothing which could pose challenges to thermoregulation. The protective clothing consists of a protective outer jacket made from cloth, undergarment consisting of a protective under-plastron (to protect the vital areas of the upper body), breeches, trousers, long socks, glove for the sword arm, protective chest guard (females only), and fencing mask, see Figure 2.4, additionally fencers wear sports apparel below this protective clothing. Jackets, plastrons, breeches and trousers are required to be made from cloth and be able to resist a pressure of 800 Newtons (International Fencing Federation, 2019). The mesh mask must be able to withstand a pressure of 12 kg with the bib of the mask being able to withstand 1600 Newtons (International Fencing Federation, 2019). Foil and Sabre athletes also are required to wear an additional conductive jacket, called a lame, due to the electric scoring system.

Due to potential rest periods between fights being around 10-15 minutes fencers often only remove the mask and glove between fights due to the time required to put on the protective clothing. Anecdotally, fencers have a fear of cooling down too much if they remove their protective clothing, which they believe could impact their power when performing if their muscles cool down too much. It is well documented that power and strength are reduced with colder muscle temperatures (Binkhorst, Hoofd, & Vissers, 1977; Davies & Young, 1983; De Ruiter & De Haan, 2001). However, during fencing evaporative and convective heat loss mechanisms will be affected due to the skin being covered and there will be an added insulative resistance from the thick protective clothing and other clothing layers. Therefore, heat loss post fight is important for fencers to lower T_{skin} and the associated cardiovascular strain in the recovery between fights. Fencers are, also, unlikely to become cold when removing protective clothing between fights due to the hot micro-climate created from protective clothing (Bishop et al., 2000) and could also warm up again before the subsequent fight. Furthermore, the use of a fencing mask may impede a valuable source of heat loss during exercise through the head. It has been shown the head can act as a heat sink and provide valuable heat loss especially as ambient temperature increases (Rasch, Samson, Cote, & Cabanac, 1991). Furthermore, the fencing mask could cause an increase in temperature around the face and influence thermal sensation and comfort due to local thermoreceptors (Flouris & Schlader, 2015; Gibson et al., 2020; Schlader, Simmons, Stannard, & Mündel, 2011) which could lower the drive to perform and impact fencing performance. The protective clothing coupled with the long competition day could impact the body’s ability to dissipate heat and cause an increase in thermal load through high core temperatures, skin temperatures, heat storage and perceptual responses (Pascoe, Bellingar, et al., 1994). This imbalance in heat gain and loss could cause a decrease in fencing performance and early development of fatigue especially in the latter DE rounds.

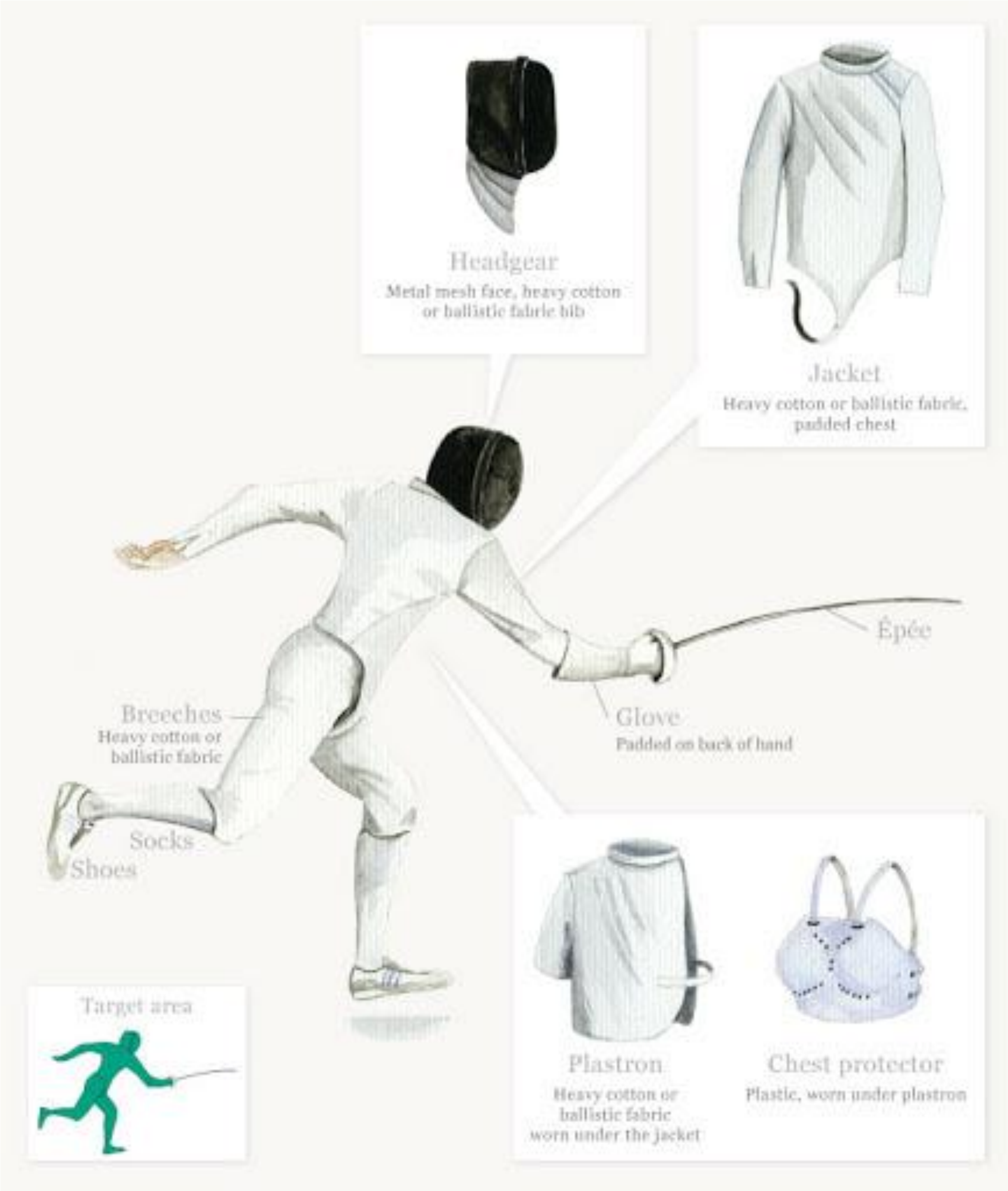


Figure 2.4. Epée fencing clothing requirements. Image taken from Cook, 2015

2.5 Thermoregulatory Demands of Protective Clothing Sports

Earlier in this literature review it was discussed that there is no previous research assessing the thermoregulatory demands of fencing. However, there has been previous research assessing sports with a similar protective clothing set up to fencing such as American football, ice hockey, and motor racing. These sports are similar in that they consist of athletes wearing helmets/face masks, and full body protective clothing. The section of the literature review will now focus on the thermoregulatory demand of these sports with a summary as to how the findings can be applied to fencing research.

2.5.1 American Football

American football poses the highest rated risk of athletes developing heat illness symptoms in the United States (Grundstein et al., 2012; Kerr, Casa, Marshall, & Comstock, 2013). In the study by Kerr et al. (2013) the risk of heat illness was 11.4 times greater for American football than all other sports combined It has been hypothesised that the influence of the environmental conditions during pre-season practice (high ambient temperatures and humidity), larger athletes (especially lineman) and protective clothing could all be causing these higher risks of developing heat illness (Davis, Baker, Barnes, Ungaro, & Stofan, 2016; Grundstein et al., 2012). The protective clothing, which covers 70% of the body in American football, can lower heat loss through convection, radiation and evaporation (Armstrong et al., 2010). American football shares similarities to fencing in terms of the intermittent nature, protective clothing covering the body and long competition periods.

Previous research in American football has highlighted an increased physiological strain and performance decrement when wearing protective clothing compared to non-protective clothing (Armstrong et al., 2010; Godek, Bartolozzi, Burkholder, Sugarman, & Dorshimer, 2006; Hitchcock, Millard-Stafford, Phillips, & Snow, 2007; McCullough & Kenney, 2003). The protective clothing worn within American football has been shown to cause a greater T_{core} (~0.5-2.0°C), RPE and energy cost than non-protective clothing (Armstrong et al., 2010; Hitchcock et al., 2007; McCullough & Kenney, 2003). Furthermore, as fatigue occurred at ~39.2°C, in Armstrong et al. (2010) there is a suggestion wearing protective clothing causes fatigue to occur at a lower T_{core} (Montain et al., 1994). Furthermore, Armstrong et al. (2010) showed there was an effect on performance of protective with a lower exercise time and less participants completing the exercise protocol (control – 7/10, partial protective clothing – 3/10 and full protective clothing 1/10).

2.5.2 Ice Hockey

Ice Hockey is an intermittent sport that combines layered protective clothing with cool ambient temperatures (Noonan et al., 2007). However, previous research has highlighted a thermal challenge for ice hockey athletes when competing due to the protective clothing and high intensity nature of the activity (Batchelder et al., 2010; Driscoll, McCarthy, Palmer, & Spriet, 2020; Noonan et al., 2007). It has been shown that there is a greater T_{skin} (34.1 ± 0.2°C vs. 28.8 ± 0.3°C) when wearing ice hockey protective vs. non-protective clothing (Noonan et al., 2007). Furthermore, wearing protective ice hockey clothing can raise T_{core} ~38.5°C with peak values 39.1°C (Batchelder et al., 2010; Driscoll et al., 2020). The greater T_{skin} and T_{core} with protective clothing could cause increased cardiovascular strain and increased levels of hypohydration through impeding heat loss mechanisms, increased heart rate, RPE and sweat losses (Batchelder et al., 2010; Driscoll et al., 2020; Noonan et al., 2007).

2.5.3 Motor Racing

Motor racing athletes are required to wear full body protective clothing similar to fencing. This includes a fire suit with up to 3 layers of thickness, fire resistant undergarments, boots and gloves, and a helmet with a balaclava (Potkanowicz & Mendel, 2013). This protective clothing can potentially lead to microenvironments that can impact on the driver's ability to dissipate heat, along with dehydration and hot environmental conditions inside the cockpit (Potkanowicz & Mendel, 2013). Peak T_{core} responses have been shown to be >38.5°C (Barthel et al., 2020; Brearley & Finn, 2007; Carlson et al., 2014; Turner & Richards, 2015) with values recorded as high as 39.7°C (Brearley & Finn, 2007). Furthermore, high T_{skin} >37.0°C have been recorded which has resulted in low core to skin temperatures 1.3 ± 0.3°C (Carlson et al., 2014). Low core to skin temperature gradients have been associated with increased cardiovascular strain through increased heart rate, skin blood flow, RPE and decreased stroke volume which decreases exercise performance as participants are unable to cope with and dissipate the excess heat within the body (Sawka et al., 2012) which will be exaggerated further with protective clothing.

2.5.4 Considerations for Fencing Research

There are similarities from previous research in American football, ice hockey and motor racing that can be applied to fencing. The full body protective clothing used with fencing presents similar issues to these sports with high T_{core}, and high T_{skin} leading to narrow core to skin temperature gradients. This could cause an increased cardiovascular strain through increased HR and cardiac output to increase blood flow to the skin to dissipate heat whilst maintaining muscle blood flow (Sawka et al., 2012). Furthermore, the protective clothing could impede evaporative and convective heat loss mechanisms causing heat imbalance in the body and creating hot micro-climates within the protective clothing layers that are hotter than ambient conditions. There could, also, be high ratings of perceived exertion, and thermal sensation or comfort which could impact upon the drive and motivation to perform and change fencer behaviour to adjust to the internal hot conditions (Périard et al., 2014) especially in latter stages of a competition against tougher opponents. It has also been shown in ice hockey which is competed in low ambient temperatures that there is an increased thermal demand linked to the protective clothing, high intensity exercise and increased dehydration (Batchelder et al., 2010; Noonan et al., 2007; Noonan & Stachenfeld, 2012). Fencing competition usually takes place in warmer ambient conditions and lasts a longer length of time than ice hockey so the thermoregulatory demand could be greater.

Assessing the thermoregulatory response over a fencing competition could be important to determine how exercising in fencing protective clothing can impact performance. Winners of a fencing competition could, therefore, not only have to be tactically/technically the best but also the athlete who can deal with the thermoregulatory and cardiovascular strain the best.

2.6 Methods of Measuring Thermoregulation

The following section of the literature review will discuss the different methods for measuring core and skin temperature during exercise. There are various methods for measuring core temperature during exercise (rectal (T_{re}), aural (T_{au}; through either tympanic or auditory canal measurements), oesophageal (T_{es}) or gastrointestinal (T_{gast}) which all have advantages, disadvantages, and different practicalities.

Traditional measurements of T_{skin} used wired systems whereas due to technological advances wireless systems have been created. It is important to discuss these different methods for measuring T_{core} and T_{skin} to determine the most appropriate methods that should be used within fencing research.

2.6.1 Core Temperature

Core body temperature is important to measure during exercise where heat balance could be an issue, as it has been previously shown earlier exercise fatigue and complications due to heat illness can occur at high T_{core} (Armstrong, Luca, & Hubbard, 1990; Cheuvront, Kenefick, Montain, & Sawka, 2010; González-Alonso et al., 1999). Furthermore, knowing an athlete's T_{core} during competition can enable coaches and practitioners to know what is physiologically comfortable and capable. As shown by Racinais et al. (2019, 2021) athletes can compete, win medals, and not show signs of heat illness with T_{core} >39.5°C which is often the diagnostic criteria for exertional heat stroke. Core temperature, also, allows practitioners to measure heat storage to be measured during exercise which can be used to develop appropriate cooling methods to improve performance. Core body temperature can be measured through different sites. The most commonly measurement sites used within exercise research are T_{re}, T_{au}, T_{es} or T_{gast}.

Rectal temperature involves inserting a temperature sensor (>100mm) beyond the anal sphincter to measure deep body temperature and is a commonly used method in the literature (Lim, Byrne, & Lee, 2008; Moran & Mendal, 2002). The measurement of T_{au} involves either placing a sensor on the auditory canal or on the tympanum in the ear. Tympanic temperature is measured through infrared sensors. Aural temperature reflects the temperature of the blood in the carotid artery supplying blood to the brain and the hypothalamus (Parsons, 2003), which is responsible for temperature regulation. Oesophageal temperature measurement requires a senor to be inserted through the nose into the oesophagus to the level of the heart (Moran & Mendal, 2002; Parsons, 2003). This measurement will reflect the internal blood temperature. Finally, T_{gast} involves the participant swallowing an ingestible telemetric temperature sensor to measure the temperature of the gastrointestinal (GI) environment. There are various advantages and disadvantages of each method which are discussed in Table 2.4. For field-based testing, especially fencing, the most appropriate method of T_{core}

measurement is T_{gast} measurement then T_{au}. Use of T_{core} pills to measure T_{gast} is easy to use, participants are unaware that temperature measurements are being made, and measurements are less effected by the external environment than T_{au} (Byrne & Lim, 2007; Lim et al., 2008). Rectal temperature and T_{es} are likely to cause too much discomfort to the participants which could impact upon the participants ability to perform during and willingness to take part in the research. Furthermore, due to the wired nature of these methods participants would have to wear a data logger in addition to other equipment.

Table 2.4. Advantages and disadvantages of core temperature measurement sites (Byrne & Lim, 2007; Lim et al., 2008; Moran & Mendal, 2002; Parsons, 2003).

Method of T_{core}	Advantages	Disadvantages
T_{re}	• Accurate • Most common site used in exercise research • Comfortable when inserted correctly •	• Delayed response time during rapid changes in T_{core} • Participants may dislike the concept of the measurement and can be discouraged from participating in research. • Potential spread of viral diseases if appropriate cleaning not undertaken • Not suitable for field-based exercise studies
T_{au}	• Reflects temperature of carotid artery • Easy site to access • Readily available and inexpensive equipment	• Can be uncomfortable • Measurements may be influenced by external environment
T_{es}	• Measures deep body temperature • Responds to rapid changes in T_{core} • Accurate	• Uncomfortable for participants • Difficult to insert the temperature sensor

		• Temperature is not the same along the length of the oesophagus • Consumption of food and drink may influence measurements • Not suitable for field-based exercise studies
T_{gast}	• Practical in exercise settings, especially field-based studies • Easy to use • Comfortable for the participants • Can measure continuous temperature • Participants unaware of measurements being taken • More commonly accepted in the literature	• Difficult to standardise location of the sensor in the GI tract • Has to be ingested hours before measurements required • Difficult to know transit time through the GI tract • Consumption of food and drink may influence measurements • Pills can be expensive and single use

T_{re} = rectal temperature, T_{au} = aural temperature, T_{es} = oesophageal temperature, T_{gast} = gastrointestinal temperature

2.6.2 Skin Temperature

As highlighted in chapter 2.3 high T_{skin} (>35°C) plays an important role in thermoregulation and decreased exercise performance when exercising in hot conditions (B. R. Ely et al., 2010; Sawka et al., 2012). High T_{skin} decreases the core to skin temperature gradient which increases cardiovascular strain as the body increases skin blood flow, HR and cardiac output in order to dissipate heat from the body (Sawka et al., 2012). This interaction between core and skin temperature is important to measure to ensure athletes do not fatigue early due to an inability to dissipate heat, do not develop symptoms of heat illness and to apply appropriate cooling interventions pre or during exercise. The full body protective clothing within fencing may cause an increase in T_{skin} and a decreased core to skin temperature gradient which could impact performance especially later in the DE rounds.

Mean skin temperature is often measured using the equations by Ramanathan (1964) and researchers often used wired skin thermistors or thermocouples to assess T_{skin} which limits thermoregulation research to more lab-based settings. Also wired skin thermistors or thermocouples may impede participant movement due to the wires getting in the way during exercise or detaching (Harper Smith, Crabtree, Bilzon, & Walsh, 2010). However, due to technological advances wireless skin thermistors and thermocouples are becoming more prevalent in applied sport science research to assess T_{skin} (Bongers, Eijsvogels, van Nes, Hopman, & Thijssen, 2015; Chalmers et al., 2019; James, Richardson, Watt, Gibson, & Maxwell, 2015; Lynch, Périard, Pluim, Brotherhood, & Jay, 2018). A popular wireless device is the Thermochron iButton and has been shown to have good validity for temperature measurement (Harper Smith et al., 2010; Hasselberg, McMahon, & Parker, 2013; McFarlin, Venable, Williams, & Jackson, 2015; van Marken Lichtenbelt et al., 2006). The iButtons have been reported to record a higher T_{skin} during exercise than wired thermistors (Harper Smith et al., 2010), this could be due to differences in heat exchange between the skin and external environment, the skin and the sensor, the vapour exchange with the environment, and the smaller surface area and possibility of detachment of the wired thermistors (Harper Smith et al., 2010). Furthermore, the iButton has been proposed as an inexpensive, easy to use and more practical method for use in field based testing (Harper Smith et al., 2010; Hasselberg et al., 2013; MacRae, Annaheim, Spengler, & Rossi, 2018; van Marken Lichtenbelt et al., 2006).

2.7 Effects of Cooling Methods on Performance

As shown in chapter 2.5 sports with thick protective clothing can have a decreased performance and increased cardiovascular strain through increased thermal load. To prevent the negative physiological and performance consequences establishing practical and effective cooling methods to cool athletes is needed. Cooling methods are a popular strategy during competition to attempt to gain a performance advantage, with 80% and 93% of athletes having planned pre-cooling and mid-cooling during the Doha World Championships 2019 endurance events, respectively, (Racinais et al., 2021). Cooling interventions aim to lower the thermoregulatory demand of exercise through lowering core and skin temperature, as well as having a potential cognitive impact through lower ratings of perceived exertion and thermal sensation (Tyler, Sunderland, & Cheung, 2015). Previous literature has shown that pre and per cooling methods are effective at alleviating the impact of heat stress and can improve performance (Bongers, Thijssen, Veltmeijer, Hopman, & Eijsvogels, 2015; Gibson et al., 2020; Tyler et al., 2015). The following section of the literature review will discuss different cooling methods, cooling method timing, and the impact of cooling on the thermoregulatory responses to exercise and performance, with a focus on cooling methods that are practical for fencing athletes.

2.7.1 Ice Vests

A popular and effective method of cooling athletes is wearing ice vests, with over 50% of athletes using this at the Doha World Championships 2019 (Racinais et al., 2021). This consists of athletes wearing a vest with pockets that can store ice packs which have been cooled in a freezer prior to competition. Due to the practicalities and extra weight added by the ice packs this method is often used as a pre-cooling technique or used during breaks such as half time. This could be an effective cooling method for fencing either as a pre-cooling and between fight method as they could remove their protective jacket and wear an ice vest to lower core and skin temperature. There has been numerous research studies assessing the effectiveness of ice vests on intermittent sports (Castle et al., 2006; Chaen, Onitsuka, & Hasegawa, 2019; Chan, Yang, Song, & Wong, 2017; Cheung & Robinson, 2004; Henderson et al., 2021; Keen, Miller, & Zuhl, 2017; Luomala et al., 2012; Taylor, Stevens, Thornton, Poulos, & Chrismas, 2019).

Research by Cheung & Robinson (2004) investigated the effects of pre-cooling using an ice vest circulating liquid at 5°C on intermittent sprints during submaximal cycling in temperate conditions 22°C and 40% humidity. During the pre-cooling condition there was a significantly lower T_{skin} (30.7 ± 2.3°C vs 32.5 ± 1.6°C) and peak heart rate (~4 beats.min^{-1}) than the control condition. The pre-cooling resulted in a lower T_{re} pre-exercise, however there was no significantly different T_{re} during exercise. Despite the thermoregulatory benefits of the pre-cooling intervention there was no difference in performance recorded as both peak and mean power output were similar during exercise (Cheung & Robinson, 2004). During the pre-cooling in this study participants wore the pre-cooling method for up to 75 minutes (or when T_{re} decreased by 0.5°C) which might not be feasible for athletes at a competition. Further, research by Castle et al (2006) when comparing different cooling conditions (control, ice vest, cold water immersion and ice packs on the upper legs (PACKS)) during intermittent cycling. The ice vest and PACKS conditions resulted in lower T_{re} than the control condition, there was a lower muscle temperature in the PACKS condition compared to control, however muscle temperature was similar in the ice vest and control conditions (Castle et al., 2006). There was also a lower T_{skin} compared to the control for the first 4 sprints in the ice vest and PACKS conditions. There was no difference in heart rate recorded. There was a significant performance difference whereby there was a greater total work done in both the ice vest and PACKS conditions and greater work done in each sprint in the PACKS condition than the control condition. Improvements in performance due to pre-cooling with ice vests has been shown for endurance exercise (Arngrïmsson, Petitt, Stueck, Jorgensen, & Cureton, 2004; Katica et al., 2018; Quod et al., 2008) with improvements in time trial performance. During time trial performance the physiological effects of pre-cooling of lower T_{skin}, T_{re} and thermal sensation tend to be present for the early part of exercise then the differences are not present in the latter portion of exercise (Arngrïmsson et al., 2004; Katica et al., 2018; Quod et al., 2008). Therefore, the early physiological benefits of cooling could improve performance due to a lower cardiovascular strain and perceptual responses to cooling.

Cooling with ice vests during breaks or during exercise (per-cooling) has also been studied (Chaen et al., 2019; Chan et al., 2017; Keen et al., 2017; Luomala et al., 2012). When using an ice vest during a 30 minute break between exercise bouts there was a lower T_{gast}, T_{skin}, core to skin temperature gradient and heat storage during the second exercise bout (Chan et al., 2017), there was also an average performance improvement of exercise time in the second bout of 99.5 ± 89.5%. This large range of performance improvement could indicate some participants have larger benefits from cooling than others. Similar performance improvements (21.5 ± 7.6%) were shown by Luomala et al. (2012) during cycling, in hot conditions (30°C), whereby an ice vest was worn after 30 minutes during exercise. There were no significant differences between the control and the ice vest trial in this study for thermoregulatory variables (T_{re}, and T_{skin}) or respiratory markers measured. However, the improvement in performance could have been associated with the lower thermal sensation and greater thermal comfort recorded in the first 30 minutes after cooling was applied, indicating a potential psychological benefit per-cooling (Luomala et al., 2012). Furthermore, research by Chaen et al. (2019) showed wearing an ice vest during a 15-minute half time break during an intermittent cycling protocol results in a greater power output being recorded in the second half compared to the control. There were no differences between the trials for T_{re}, however there were lower neck and T_{skin} recorded during the cooling period and the first 15 minutes of the second half. Similarly, to the study by Luomala et al. (2012) there was a greater thermal comfort and lower thermal sensation recorded during the second half in the cooling trial. However, during moderate exercise research by Keen et al. (2017) showed there were no differences between per-cooling and control when placing ice packs on the legs and arms in American football athletes during exercise for various thermoregulatory and physiological variables. There were no differences for T_{re}, heart rate or $\dot{V}O_2$ recorded. There were also no differences determined for perceptual responses of thermal sensation, thirst, or RPE between trials. However, there was no performance measurement in the study by Keen et al. (2017). Furthermore, cooling the upper and lower limbs may be less effective than cooling the torso as seen in the previous studies mentioned.

Research by Taylor et al. (2019) and Henderson et al. (2021) showed the beneficial effects of wearing an ice vest during an intermittent warm-up for rugby sevens athletes. In the ice vest trials there was a lower increase in T_{gast} during the warm-up compared to the control in hot conditions. Further, there were perceptual benefits recorded with lower thermal sensation, thermal comfort and RPE in the ice vest trials (Taylor et al., 2019), however these differences for thermal sensation and thermal comfort were not determined in the study by Henderson et al. (2021). The pre-cooling did not affect any warm-up physical parameters highlighting no negative impact on warm-up performance, which can be a worry for coaches and athletes when implementing pre-cooling interventions (Taylor et al., 2019).

Overall, there seems to be a benefit to high intensity performance when wearing ice vests whether they are used as a pre-cooling or per-cooling method. The majority of the physiological and perceptual benefits tend to be in the early parts of exercise post cooling with no differences in physiological or perceptual responses at the end of exercise. There is a suggestion of an improved performance due to a perceptual rating of thermal sensation and comfort which may allow the participants to be more motivated to perform and therefore lower the effects of the physical strain during exercise. Ice vests could be an effective method for cooling in fencing athletes, however ice vest use would depend on access to freezers at competition to keep the ice packs frozen when they were not being used. With fencing competitions lasting 9-11 hours the lack of access to freezers may limit the practicality of ice vests within fencing. Fencers would be more likely to use ice vests in the knockout DE rounds due to longer fights and fighting tougher opponents causing increased thermal load.

2.7.2 Cooling Vests

Another method for cooling athletes that is similar to ice vests is the using of cooling vests or evaporative cooling vests (ECV). They are similar in that they cover the participants torso and are often cooled by submerging the vest in water. This then helps the athlete to dissipate heat through increasing evaporative heat loss mechanisms. The ECV are more practical than ice vests as they are not needed to be stored in ice like the ice packs do for ice vests and can be repeatedly cooled by submerging in water. This could be more practical for fencing athletes competing in a sports hall environment and may not have access to freezers, and they will always have access to a tap to activate the cooling properties of the vest. However, there is limited research into their use and effectiveness during exercise due to being a relatively new technology (Eijsvogels, Bongers, Veltmeijer, Moen, & Hopman, 2014), and potentially not having an as aggressive cooling effect as other methods (Bongers et al., 2017).

During cycling time to exhaustion it has been shown that pre-cooling with ECV produced a greater time to exhaustion than control (Bogerd, Perret, Bogerd, Rossi, & Daanen, 2010). In comparison to an ice vest time to exhaustion was decreased in the ECV trial. There were no differences for T_{re} between trials with similar values recorded at exhaustion, however, there were lower T_{skin} recorded at the end of pre-cooling in the ECV trial and ice vest trial which resulted in lower T_{skin} during the early stages of exercise. During sub-maximal exercise in participants with SCI there was no exercise performance difference between ECV and control trials (Bongers, Eijsvogels, et al., 2015). However, there were similar physiological effects recorded to the study by Bogerd et al. (2010), whereby there was a lower T_{skin}, and greater core to skin temperature gradient. Furthermore, in the study by Bongers et al. (2015) there was a lower thermal sensation recorded in the ECV trial compared to the control trial, highlighting a potential perceptual benefit of this cooling method. Similar physiological and performance measurements were determined in able-bodied athletes (Eijsvogels et al., 2014) in temperate conditions (25°C, 55% humidity) for a 5km time trial. There were no improvements in 5km time trial performance between conditions (20:46 mins vs 20:54 mins) in this study. Physiologically, there were no differences in core temperature between trials, however there were lower T_{skin} recorded during the early stages of exercise, and a greater core to skin temperature gradient (Eijsvogels et al., 2014). Moreover, participants had greater levels of thermal comfort during the cooling trial than the control trial.

Overall, there is a benefit physiologically and perceptually of ECV for participants, however there are mixed results for the impact on exercise performance as highlighted above. The ECV are a more practical and easier to use method for cooling than ice vests as they do not require freezers to keep the ice packs cold over a long competition day and can be repeatedly cooled by submerging in water.

2.7.3 Ice Slurry and Cold-Water Ingestion

Ice slurry and cold-water ingestion are easy and practical methods for reducing the thermal strain of exercise performance (Lee, Shirreffs, & Maughan, 2008). These methods are similar in terms of their delivery whereby participants ingest cold fluids. Ice slurry ingestion requires participants to consume a beverage consisting of ice and water or drinking cordial at a temperature below 0°C, whereas cold water ingestion requires participants to ingest a cold-water beverage ~1-5°C. Cold-water ingestion is a more popular choice by athletes during exercise than ice slurry ingestion (~60% vs. ~11%, respectively, of athletes using these during competition (Racinais et al., 2021)), however ice slurry was used by ~20% of athletes pre-race (Racinais et al., 2021). There has been extensive research into the effects of cold water and ice slurry ingestion on endurance and intermittent exercise performance and the physiological responses to exercise as described in Table 2.5.

There is generally a benefit to performance of either ice slurry or cold-water ingestion with 75% of research articles in Table 2.5 showing an improvement in performance. The performance improvement was clear in endurance exercise, in particular time trial performance, however there is limited evidence within intermittent sports as to the benefit of these interventions (Aldous et al., 2019; Gerrett, Jackson, Yates, & Thomas, 2017; Naito, Haramura, Muraishi, Yamazaki, & Takahashi, 2020; Naito et al., 2018; Zimmermann & Landers, 2015). Only one of the studies (Naito et al., 2020) showed an improvement in intermittent performance of 4% greater work done, with research by Aldous et al. (2019), Gerrett et al. (2017), and Zimmermann & Landers (2015) showing no performance difference, and Naito et al. (2018) not measuring performance. However, these studies are often completed using protocols to simulate intermittent sport movement data (such as speed and distance) in the laboratory but does not factor in tactical or technical aspects of performance e.g., points or goals scored which are often true indications of successful performance in intermittent sports such as football, fencing or tennis. Therefore, there is a need for more applied field-based research assessing if these interventions are beneficial for intermittent sports, especially as major competitions often take place in the summer months e.g., Olympic Games, and World Cups.

Table 2.5. Previous cold-water and ice slurry ingestion research

Authors	Ice Slurry or Cold-Water Ingestion and volume ingested	Control Condition (volume given the same as ice slurry or cold water unless stated)	Intervention Timing	Environmental Conditions (Temperature °C, relative humidity)	Exercise	Physiological Effects compared to control	Performance Improvement compared to control
Aldous et al., 2019	Ice slurry (Pre 7.5 g.kg^{-1} body mass, half time 3.75 g.kg^{-1})	Room temperature water (21°C)	Pre-match and half time	30.7 ± 0.3 °C, 50.9 ± 4.2%	2 x 45-minute intermittent sprint with 15-minute half time	Lower TS, T_{re} and T_{skin} in 1st half vs. control. No 2nd half differences	No difference in physical parameters measured
Burdon, Hoon, Johnson, Chapman, & O'Connor, 2013	Ice slurry (3.5 g.kg^{-1} body mass)	Water (37°C)	Every 15 minutes during exercise	32°C, 40%	90 minutes SS followed by TT – endurance	Lower T_{gast} T_{skin}, heat storage in SS, greater heat storage in TT, lower HR, lower RPE and thermal comfort in SS. No differences in TT for $T_{gast,}T_{skin,}$ or HR.	10.5 ± 7.9% improvement in TT performance, greater power output recorded
Byrne, Owen,	Cold-water ingestion -	Water (37°C)	Pre-exercise	32°C, 60%	30-minute TT – endurance	Lower T_{re} pre-exercise and during TT, lower pre thermal	Greater TT distance covered 2.8 ± 2.4%,

Cosnefroy, & Lee, 2011	2°C (3 x 300ml aliquots)					comfort, no difference for T_{skin}, HR, blood lactate concentration, RPE or thermal comfort during exercise	and power output recorded
Gerrett et al., 2017	Ice slurry (7.5 g.kg^{-1} body mass)	Water (23.4 ± 0.9°C)	Pre-exercise	30.9 ± 0.9°C, 41.1 ± 4.0%	31-minute self-paced intermittent protocol	Lower T_{gast}, lower TS until 15 minutes into exercise, no difference in T_{skin}, blood lactate concentration, HR, and RPE	No difference in speed or distance covered in intermittent protocol
Ihsan, Landers, Brearley, & Peeling, 2010	Ice slurry (6.8 g.kg^{-1} body mass)	Water (26.8 ± 1.3°C)	Pre-exercise	30°C, 75%	40km TT – endurance	Lower T_{re} pre-exercise, and 100 KJ of TT, afterwards no difference in T_{re}, no difference for T_{skin}, lower TS pre-exercise and 200 KJ of TT, no differences in HR, RPE or blood lactate concentration	6.5% improvement in TT performance 6.9% greater mean power output
James, Richardson, Watt, Gibson, & Maxwell, 2015	Ice slurry (7.5 g.kg^{-1} body mass)	No intervention	Pre-exercise	31.9 ± 1.0°C, 61 ± 9%	Incremental exercise – endurance	Lower T_{re} pre-exercise, TS during exercise, no difference for $\dot{V}O_{2max}$, HR, T_{re}, T_{skin}, and RPE during exercise	Improved running speed at 2 and 3.5 mmol/L blood lactate concentration, 2.4%

							increased running time at $\dot{V}O_{2max}$
Lamarche et al., 2015	Cold-water ingestion – 1.5°C (4 x 3.2ml.kg^{-1} body mass aliquots)	Water (50°C)	5 minutes pre-exercise, 15, 30, 45 minutes during exercise	25°C, 25%	75 minutes at 50% $\dot{V}O_{2peak}$ – endurance	No difference in heat storage, T_{re}, and T_{skin} between hot and cold drinks. Lower evaporative heat loss in cold drink trial. Greater heat load in hot drink due to heat of ingested fluid.	N/A
Lee et al., 2013	Cold-water ingestion - 4°C (2 x 400 ml aliquots during each rest period)	Water (28°C)	During rest between exercise bouts	32°C, 62%	2 x 45 minutes SS with 15 minutes rest at 5.5km.h^{-1} (7.5% gradient) – repeated bouts of endurance exercise	Lower T_{re} in second exercise bout and in second recovery period. Greater T_{skin} decrease during first recovery period, no T_{skin} difference during exercise. Lower HR in second exercise bout and recovery period. No difference in RPE or TS during exercise. Lower TS in second recovery period.	N/A
Lee, Shirreffs, &	Cold-water ingestion - 4°C (3 x	Water (37°C)	Pre-exercise	35 ± 0.2°C, 60 ± 1%	TTE at 66 ± 2% $\dot{V}O_{2max}$ – endurance	Lower T_{re} -20 minutes pre-exercise to 45 minutes during exercise, similar T_{re} at	23 ± 6% greater TTE in cold drink trial

Maughan, 2008	300ml aliquots pre-exercise, 100ml every 10 minutes during exercise)		and during exercise			exhaustion. Lower T_{skin} from 20 minutes onwards during exercise. Lower HR 0-35 minutes during exercise, similar HR at exhaustion. Lower TS and RPE during exercise, and lower TS in rest period. Similar TS and RPE at exhaustion	
Morris, Bain, Cramer, & Jay, 2014	Cold-water ingestion – 1.5°C (3.2 $ml.kg^{-1}$ body mass)	Water (37°C and 50°C)	Pre-exercise (5 minutes), and during exercise (15, 30 and 45 minutes)	23.7 ± 1.3°C, 32 ± 10%	75 minutes SS at 50% $\dot{V}O_{2max}$ - endurance	Lower mean and local (forehead, back and arm) sweat rates. No difference in T_{re}, T_{au}, or T_{skin} during exercise	N/A
Mündel, King, Collacott, & Jones, 2006	Cold-water ingestion - 4°C	Water (19.4± 0.7°C)	Pre-exercise ($8ml.kg^{-1}$) and ad libitum during exercise	33.9 ± 0.2°C, 27.9 ± 0.7%	TTE at 65% $\dot{W}_{max}$ – endurance	Lower HR during exercise. Tendency for lower T_{re} at fatigue. Similar T_{skin}, heat storage, $\dot{V}O_2$, RPE, and sweat rate. Greater drink rate during exercise.	11 ± 5% greater TTE

Naito & Ogaki, 2017	Ice slurry -0.5°C and cold-water ingestion - 4°C (1.25 g.kg^{-1} body mass pre-exercise and 2.0 g.kg^{-1} body mass during exercise)	No control – comparison of ice vs water	Pre exercise and 15-, 30- and 45-minutes during exercise	35°C, 30%	TTE at 60% $\dot{V}O_{2max}$ - endurance	Lower T_{re} and T_{skin} up to 30 minutes of exercise in ice compared to water, no difference in T_{re} and T_{skin} at exhaustion. No difference in heat storage. Lower TS pre-exercise in ice compared to water. No difference in RPE, HR, and $\dot{V}O_2$ throughout	~18% greater TTE in ice compared to water
Naito et al., 2020	Ice slurry (1.25 g.kg^{-1} body mass during breaks and 7.5 g.kg^{-1} body mass at half time (	Water (36.5°C)	During breaks between repeated sprints at half time.	36.5 ± 0.5°C, 50 ± 3%	2 x 30 sets of 1-minute repeated sprints (5 seconds maximal pedalling, 25 seconds active recovery, 30 seconds rest) with 1 minute of rest every 5 sets for cooling and 10 minutes half time between sets - intermittent	Lower sweat rate. Lower T_{re} and T_{skin} in second 30 set exercise block. No difference in HR during exercise. Lower TS at half time but no differences in TS during exercise. Lower RPE at final 5 sets of exercise only.	No difference for peak or mean power output. ~4% greater work done.

Naito et al., 2018	Ice slurry and cold-water ingestion - 4°C (1.25 g.kg^{-1} body mass)	No control ice and water compared	During breaks between simulated tennis games and sets	36.5 ± 0.5°C, 50 ± 3%	Repeated sprint tennis protocol (4 sets consisting of 8 games consisting of 6 points which were 1 minute 36 secs in length, with 90 second rest between odd numbered games and 120 seconds rest between sets) – intermittent	Sweat loss lower in ice than water. Change in T_{re} lower in ice than water (no report of absolute values), and lower forehead temperature in ice than water. No difference in T_{skin}. Lower HR from set 2-4 in ice than water. Lower thermal comfort in set 3 and 4 in ice than water. No difference for RPE or TS.	N/A
Riera, Trong, Sinnapah, & Hue, 2014	Ice slurry and cold-water ingestion - 3°C (190ml)	Water (23°C)	Pre-exercise and every 5km during TT	30.7 ± 0.8°C, 78 ± 0.03%	20km TT – endurance	No difference in T_{gast}, tendency for lesser ΔT_{gast} in ice slurry. No difference in HR.	No difference for water and control during TT. Ice quicker TT than control.
Stanley, Leveritt, & Peake, 2010	Ice slurry	Water (18.4 ± 0.5°C)	Recovery between exercise bouts (5 minutes – 400 ml, 15,	33.7 ± 0.8°C, 60.3 ± 2.0%	75 minutes at 58 ± 6 peak power output, then 50 minutes rest for cooling then TT based upon athlete's	No difference in T_{re} at end of TT, but lower T_{re} at the end of recovery period after cooling. No difference in HR. Lower TS during recovery period.	1.9% improvement in TT performance (non-significant) – 6/10 participants quicker in TT. Similar

			25 and 35 minutes – 200ml)		peak power output – endurance	No difference in blood lactate concentration.	power output between trials
Stevens, Dascombe, Boyko, Sculley, & Callister, 2013	Ice slurry (10g.kg^{-1} body mass)	Water (30°C)	During cycle leg of triathlon (17-45 minutes)	32-34°C, 20-30%	10km TT run of triathlon (standardised swim and cycle legs) – endurance	Lower T_{gast} from 47 minute of cycle to end of 10km run. No difference for HR, RPE and blood lactate concentration. Greater $\dot{V}O_2$ in final km of run. Lower TS at 5-6 and 9-10km of TT	2.5% improvement in TT performance
Takeshima, Onitsuka, Xinyan, & Hasegawa, 2017	Ice slurry (7.5 g.kg^{-1} body mass)	No intervention	Either pre or post warm-up	30°C, 80%	TTE at 55% peak power output – endurance	Lower T_{re} in post-warm-up cooling trial during exercise than control and pre-warm-up cooling trial. Similar T_{re} at exhaustion. Lower T_{skin} up to 40 minutes of TTE in post-warm-up cooling than control and 5 minutes than pre-warm-up cooling trial. Similar T_{skin} at exhaustion. No difference in HR, RPE or TS during exercise.	Greater TTE in pre-warm-up (9%) and post-warm-up (~16%) than control. 6% greater TTE in post-warm-up than pre-warm-up.

Zimmermann & Landers, 2015	Ice slurry (6.8 $g.kg^{-1}$ body mass)	Water (25°C)	Pre-exercise	33.1 ± 0.1°C, 60.3 ± 1.5%	2 x 36-minute repeated sprint protocol with 6-minute recovery between blocks – intermittent	Lower T_{re} throughout exercise. No difference in HR or RPE. Lower TS at the start and 18 minutes of second exercise block.	No difference in peak power output or total work done.

SS = steady state, TT = time trial, TTE = time to exhaustion, HR = heart rate, T_{re} = rectal temperature, T_{gast} = gastrointestinal temperature, T_{au} = aural temperature, T_{skin} = mean skin temperature, RPE = rating of perceived exertion, TS = thermal sensation, $\dot{V}O_{2max}$ = maximal oxygen consumption

Within the studies highlighted in Table 2.5 assessing the effects of ice slurry or cold-water ingestion there are mixed physiological responses that occur during these interventions. When compared to the control trial there is often a lower core body temperature, particularly in the early stages of exercise. This lower core body temperature occurs across all exercise modalities of steady state endurance (Burdon et al., 2013; Lee et al., 2008, 2013; Mündel et al., 2006; Naito & Ogaki, 2017; Takeshima et al., 2017), maximal endurance (Byrne et al., 2011; Ihsan et al., 2010; Stevens et al., 2013), and intermittent exercise (Aldous et al., 2019; Gerrett et al., 2017; Naito et al., 2020, 2018; Zimmermann & Landers, 2015) protocols. Despite this there are no differences for core body temperature at exhaustion as shown in Table 2.5, which could be expected for participants to fatigue at a similar core body temperature during exercise. Furthermore, there is some evidence that ice slurry or cold-water ingestion is beneficial for lowering T_{skin} (Aldous et al., 2019; Burdon et al., 2013; Lee et al., 2008; Naito et al., 2020; Naito & Ogaki, 2017; Takeshima et al., 2017), however, not all studies have shown a lower T_{skin} (Byrne et al., 2011; Gerrett et al., 2017; Ihsan et al., 2010; Lee et al., 2013; Mündel et al., 2006; Naito et al., 2018; Takeshima et al., 2017). It is unclear why some studies determine a difference for T_{skin} and others do not, it could be due to multiple factors such as: environmental conditions, participant training level, exercise modality and intensity or timing of the cooling intervention. Most studies have shown there is no effect of ice slurry or cold-water ingestion on heart rate, oxygen consumption, heat storage and blood lactate concentration as shown in Table 2.5.

In addition to the physiological effects of ice slurry or cold-water ingestion there appears to be a perceptual benefit to the participants through lower thermal sensation and lower thermal comfort when compared to control conditions, as highlighted in Table 2.5. This is apparent across different exercise modalities: steady state endurance (Lee et al., 2008; Naito & Ogaki, 2017; Stanley et al., 2010), maximal endurance (Byrne et al., 2011; Ihsan et al., 2010; James et al., 2015; Stevens et al., 2013) and intermittent exercise (Gerrett et al., 2017; Naito et al., 2018; Zimmermann & Landers, 2015). Interestingly, there seems to be no differences on RPE recorded between ice slurry or cold-water ingestion compared to control conditions.

There have been potential mechanisms highlighted in the literature as to how ice slurry and cold-water ingestion work. One such mechanism is cooling the body through these methods creates a heat sink in the body lowering core temperature (Burdon et al., 2013; Lee et al., 2008; Mündel et al., 2006; Riera et al., 2014), this therefore allows for a greater heat storage capacity during exercise (Ihsan et al., 2010; James et al., 2015; Lee et al., 2008; Naito & Ogaki, 2017). Furthermore, it has been hypothesised that improvements in performance could be due to glycogen sparing through a lower rise in core temperature allowing the muscles to work for longer in the cooling trials (Ihsan et al., 2010). Skin temperature could also play a role into the effectiveness of these cooling interventions whereby a lower T_{skin} could allow for a greater blood flow to the working muscles (James et al., 2015; Naito et al., 2020; Takeshima et al., 2017). Finally, the impact of these cooling interventions could be perceptual whereby a lower thermal sensation or thermal comfort could maintain motivation and drive to perform and also delay central fatigue (Burdon et al., 2013; Byrne et al., 2011; Ihsan et al., 2010; Mündel et al., 2006; Naito et al., 2020; Stanley et al., 2010; Stevens et al., 2013). There has also been perceptual benefits of cooling linked to oral and gut thermoreceptors that send messages to the brain indicating a beneficial subjective feeling of cooling to maintain drive to perform (Byrne et al., 2011; Stevens et al., 2013; Takeshima et al., 2017).

Due to a potential lack of freezer at competition ice slurry may not be a suitable method of cooling for fencers, however there would be access to cold water indicating cold-water ingestion may be a more appropriate cooling strategy for fencers. The physiological effects of cold-water ingestion vary within the literature Table 2.5. There has been a lower T_{core} reported compared to the control in some studies (Byrne et al., 2011; Lee et al., 2008, 2013; Mündel et al., 2006), but not others (Lamarche et al., 2015; Morris et al., 2014; Riera et al., 2014). Differences may be attributable to the volume of fluid given with research showing a positive impact on T_{core} having a greater fluid volume (aliquots of 300-400ml (Byrne et al., 2011; Lee et al., 2008, 2013) or 8ml.kg^{-1} body mass (Mündel et al., 2006) compared to aliquots of 190ml (Riera et al., 2014) or 3.2 ml.kg^{-1} body mass (Lamarche et al., 2015; Morris et al., 2014)). The effects on T_{skin} are unclear with cold-water ingestion with only Lee et al. (2008, 2013) determining a lower T_{skin} (~0.3-0.7°C) and greater rate of T_{skin} decrease (cold water: 0.05°C.min^{-1} vs. control: 0.03°C.min^{-1}), whereas there were no differences in T_{skin}

determined by Lamarche et al. (2015), Morris et al. (2014), Byrne et al. (2011), and Mündel et al. (2006). There is also a perceptual benefit of cold-water ingestion with a lower thermal sensation during exercise (Byrne et al., 2011; Lee et al., 2008). Furthermore, there is an improved performance in time trials and time to exhaustion ~3-23% with cold water ingestion (Byrne et al., 2011; Lee et al., 2008; Mündel et al., 2006).

2.7.4 Skin Cooling

Skin cooling is often a popular method of cooling athletes, particularly during breaks in play in intermittent sports such as tennis. Skin cooling methodologies vary in the literature and involve either iced towels placed on parts of the body (Lynch et al., 2018; Schranner et al., 2017), electric fans (Lynch et al., 2018; Schranner et al., 2017), spraying water onto the skin usually the face or limbs (Griggs, Havenith, Price, Paulson, & Goosey-Tolfrey, 2015; Lynch et al., 2018; Schranner et al., 2017; Stevens, Kittel, et al., 2017), or cooling certain limbs usually the forearms (Hedge et al., 2021; Nakamura, Muraishi, Hasegawa, Yasumatsu, & Takahashi, 2020).

Research by Schranner et al. (2017) and Lynch et al. (2018) compared different skin cooling methodologies within intermittent simulated tennis performance. The most effective skin cooling methods noted were ice towels placed on the neck and upper legs (ICE) and electric fans with skin wetting (FAN_{wet}). There were lower T_{re}, T_{skin}, RPE and thermal sensation post cooling recorded across the intermittent protocols for both ICE and FAN_{wet} compared to the control trial. This highlights both the physiological and perceptual effects of skin cooling for the participants. There were no performance measurements recorded in the study by Schranner et al. (2017) and Lynch et al. (2018) to see the performance impact of cooling, however in the study by Schranner et al. (2017) there were more participants that completed the intermittent protocol in the FAN_{wet} and ICE compared to the control (7 vs. 5 vs. 1, respectively) which could indicate a performance improvement in terms of time to exhaustion of skin cooling. Further, research by Griggs et al. (2015) showed spraying water over the face, torso, and arms (in addition to ice vest pre-cooling) in wheelchair rugby athletes lowered the thermal strain during an intermittent sprint protocol. There were lower changes in T_{gast} and T_{skin} reported in the water spray trial than the control and lower T_{skin} than the ice vest only trial. However, there were no differences between the trials for any performance, perceptual or other physiological parameters. Skin cooling (face spray) has been shown to be as effective as cold water immersion for improvement in running time trial performance (Stevens, Kittel, et al., 2017) despite no differences for T_{re} or T_{skin} compared to the control condition and greater T_{re} and T_{skin} than cold water immersion. There was a lower thermal sensation and forehead temperature reported in both the cooling conditions compared to the control. This could suggest there is a perceptual benefit of skin cooling and due to a greater density of thermal afferents on the face this may have impacted the improved performance (Stevens, Kittel, et al., 2017).

Forearm skin cooling has also been shown to be an effective method for lowering the thermal strain of exercise in the heat (Hedge et al., 2021; Nakamura et al., 2020). There were lower core temperatures (~0.4°C), heart rate, thermal sensation and greater thermal comfort recorded in the forearm cooling compared to control conditions in both studies. During the intervention period the forearm cooling lowered the T_{skin} (~35.5°C to ~33.5°C) in the study by Nakamura et al. (2020), although they did not report T_{skin} measurements during exercise, so it is unclear whether this effect of lower T_{skin} lasted during exercise and was linked to improved performance. Mean skin temperature was not presented in the study by Hedge et al. (2020). The forearm cooling was also associated with increased performance variables through lower cadence to produce a similar power output (Hedge et al., 2021) and increased cycling time to exhaustion (Nakamura et al., 2020) compared to control conditions (9.4 ± 2.9 mins vs. 5.8 ± 1.3 mins). The methods of forearm cooling used in these studies may not be appropriate to real world sports performance as the study by Hedge et al. (2020) used a device attached to the handlebars of the bike with constant cold water pumped into the device which would not transfer well to fencing performance due to a lack of facilities for this device. The methods in the study by Nakamura was more practical using cold water (10°C) and adding ice to maintain the temperature, however this would require athletes to ensure there were appropriate freezer facilities at a competition and could take time to get the appropriate water temperature which they may not have between fights. Additionally cooling the forearms could potentially impact dexterity and fine motor skills (Maley et al., 2018) which could therefore impact fencing performance due to the use of these muscles in a fight.

Skin cooling has various physiological and perceptual benefits during exercise and can be conducted in short periods of time e.g., breaks in play, half time or between fights. The beneficial effects can be dependent on the areas cooled with larger benefits when more of the body is cooled. The practicalities of requiring freezers to keep ice in might limit some of these methods to be used in fencing particularly over a long competition day. Furthermore, overcooling the forearms could be counter-productive in fencing if there are detriments to dexterity. Additionally, cooling regions such as the legs could be impractical for fencers by having to remove all their fencing equipment between fights and could lower muscle temperature which could decrease power (De Ruiter & De Haan, 2001; Gibson et al., 2020), which is important for certain fencing movements such as lunges and fleches (Turner et al., 2014).

2.7.5 Mixed-Method Approaches

To maximise the benefits of cooling to improve exercise performance researchers have combined some of the cooling methods highlighted above together. Mixed-method cooling approaches can take different approaches by combining internal and external cooling methods (Aldous et al., 2019; Hasegawa, Takatori, Komura, & Yamasaki, 2006; Nakamura et al., 2020; Stevens, Bennett, et al., 2017) or by combining different external methods together to cool different areas of the body (Cotter, Sleivert, Roberts, & Febbraio, 2001; Duffield, Green, Castle, & Maxwell, 2010; Duffield, Steinbacher, & Fairchild, 2009; Duffield & Marino, 2007; James et al., 2015; Maroni, Dawson, Landers, Naylor, & Wallman, 2020; Minett, Duffield, Marino, & Portus, 2011, 2012; Quod et al., 2008). Table 2.6 shows the different methods that have been used for mixed-method cooling.

Overall, mixed-method approaches have a performance improvement as shown in Table 2.6 for both endurance and intermittent sports, this is often associated with a lower core temperature, skin temperature and perceptual ratings of thermal sensation and comfort. Some studies have also shown additional physiological benefits with mixed-method cooling with lower HR, RPE, blood lactate concentration and RPE (Cotter et al., 2001; Hasegawa et al., 2006; Minett et al., 2011, 2012), however these differences are not always present in the research as shown in Table 2.6.

Most mixed-method cooling interventions tend to use impractical methods for the sport of fencing such as whole-body or limb cold water immersion (CWI) or reliance on carrying numerous ice packs to cool the different parts of the body, which would have to be kept in a freezer to keep them cold. Furthermore, with fencing competitions lasting all day the pre-cooling effects of methods such as CWI would not be present by the knockout DE rounds which ultimately decided the medal positions. Therefore, more research is required to discover more practical cooling interventions that can be used in applied settings. It is interesting to note researchers have mainly combined external cooling interventions as a mixed-method approach, however combining internal and external cooling interventions may be easier to achieve using cold-water ingestion as the internal method. Ice vests and evaporative cooling vests are often overlooked in the research as the external method of cooling. As highlighted by Racinais et al. (2021) cold-water ingestion and ice vests are popular methods of cooling chosen by athletes.

Table 2.6. Mixed-method cooling approaches used in previous research.

Authors	Internal-external or combined external	Mixed-Method Cooling Intervention	Performance improvement with mixed-method	Physiological responses with mixed-method during exercise
Aldous et al. (2019)	Internal-external	Ice packs on the legs + ice slurry ingestion	↑ Distance covered and high-speed distance covered	↓ ΔT_{re}, T_{skin}, TS
Cotter et al. (2001)	Combined external	Ice vest + cold air + leg cooling	↑ Power output – 16%	↓ ΔT_{re}, T_{skin}, RPE (SS), TS (SS), Thermal Comfort (SS), HR (SS)
Duffield et al. (2010)	Combined external	CWI + ice packs on the legs	↑ Power output in last 10 minutes, total distance covered – 8%	↓ T_{re}, T_{skin}, TS during first 15 minutes of exercise
Duffield et al. (2009)	Combined external	Cooling vests + ice towels on head/neck + ice packs on legs	↑ Distance covered	↓ T_{gast}
Duffield & Marino (2007)	Combined external	CWI + ice vest	No difference (ES of 0.8 for hard run distance covered)	↓ T_{gast} (up to 40 minutes of exercise), T_{skin} (up to 10 minutes of exercise), thermal comfort at breaks
Hasegawa et al. (2006)	Internal-external	CWI + water ingestion (14-16°C)	↑ Exercise time	↓ T_{re} (SS), T_{skin} (SS), HR (SS), blood lactate concentration (SS), sweat loss, TS, RPE

James et al. (2015)	Combined external	Ice towels on head/neck + forearm immersion + ice vest + cooling shorts	No difference	↓ T_{skin}, TS
Maroni et al. (2020)	Combined external	Forearm cooling using a glove + ice vest	No difference	↓ T_{gast}, TS
Minett et al. (2012)	Combined external	Ice towels on head/neck + forearm immersion + ice vest + ice packs on legs	↓ Sprint time, ↑ hard run distance and total distance covered	↓ T_{gast}, T_{skin}, HR, TS
Minett et al. (2011)	Combined external	Ice towels on head/neck + forearm immersion + ice vest + ice packs on legs	↑ Hard run distance and total distance covered	↓ $T_{gast,}$ $T_{skin,}$ HR, TS, RPE
Nakamura et al. (2020)	Internal-external	Ice slurry ingestion + forearm immersion	No statistical difference however mean TTE ↑ ~44% compared to control	No differences reported (exercise values of HR, T_{skin}, TS not reported but were all lower after pre-cooling)
Quod et al. (2008)	Combined external	CWI + ice vest	↑ TT performance - 3.8%	↓ T_{re}, TS (SS)
Stevens et al. (2017)	Internal-external	CWI + ice slurry – pre-exercise, or face spray + mouth rinse – during exercise, or CWI + ice slurry + face spray + mouth rinse	↓ TT time	↓ ΔT_{re}, $T_{skin,}$ TS

CWI = cold water immersion, T_{re} = rectal temperature, T_{gast} = gastrointestinal temperature, T_{skin} = mean skin temperature, TS = thermal sensation, TT = time trial, TTE = time to exhaustion, SS = steady state only, ES = effect size, ↓ = lower, ↑ = increased/improved

2.8 Timing of Cooling Interventions

Within the research highlighted above for the different methods of cooling athletes there are different timing options available to athletes and practitioners. Pre-cooling methods involve athletes using cooling methods prior to exercise and per-cooling methods involve athletes using cooling methods during exercise (Bongers, Thijssen, et al., 2015). As highlighted in this literature and in the review by Bongers et al. (2015) pre-cooling and per-cooling using the methods described in chapter 2.7 are both effective at delaying the rise in core temperature and can improve exercise performance, in particular endurance exercise.

Intermittent sports pose an additional challenge with performing cooling interventions than endurance sports due to often having to compete against an opponent e.g., fencing, taekwondo, and tennis or are involved in game activity e.g., football, netball, and rugby, therefore, per-cooling is often not an option for these athletes. Due to the length of intermittent sports and day long competitions as seen in fencing or taekwondo pre-cooling methods could also not be useful for these athletes as the effects often disappear after ~25-30 minutes of exercise (Bongers, Thijssen, et al., 2015; Duffield et al., 2010; Ihsan et al., 2010; Naito & Ogaki, 2017). However, intermittent sports have breaks between bouts of exercise such as half time in football or breaks between fights in fencing, this presents an opportunity for cooling interventions to take place to improve or maintain performance.

Previous research has highlighted the physiological benefits of cooling during breaks in play during intermittent exercise (Aldous et al., 2019; Chaen et al., 2019; Chalmers et al., 2019; Lee et al., 2013; Lynch et al., 2018; Price, Boyd, & Goosey-Tolfrey, 2009; Schranner et al., 2017). Cooling during breaks has been shown to decrease T_{re}, T_{skin}, HR, heat storage and perceptual ratings of thermal sensation and thermal comfort (Chalmers et al., 2019; Lee et al., 2013; Lynch et al., 2018; Price et al., 2009; Schranner et al., 2017). However, lower T_{skin} (Aldous et al., 2019; Chalmers et al., 2019; Lee et al., 2013), heart rate (Chaen et al., 2019; Lynch et al., 2018), and perceptual ratings (Aldous et al., 2019; Lee et al., 2013) are not always determined. It is unclear with the previous research as to the performance benefits of cooling during breaks despite the lower heat and cardiovascular strain. Research by Chaen et al. (2019) showed an increase in mean power output and participants exercised for longer in the study by Schranner et al. (2017), however, there was no difference in second half performance during the study by Aldous et al. (2019) and there were no performance variables measured in research by Chalmers et al. (2019), Lynch et al. (2018), Lee et al. (2013), and Price et al. (2009). Therefore, more research is required to understand if there are benefits to performance. Furthermore, most of the research tends to focus on cooling during a single break in play (half time) as the research is focussed on popular team sports such as football or rugby. Further research, therefore, could focus on cooling interventions to improve performance in sports with multiple breaks between exercise bouts or competitions that last multiple hours such as fencing or taekwondo, especially as these athletes tend to wear thick protective clothing when competing which increases cardiovascular and heat strain when exercising as described in chapter 2.5.

Part 3

2.9 Wheelchair Fencing

The Paralympic sport of wheelchair fencing provides a good medal opportunity for athletes with 16 events scheduled at the 2020 Tokyo Paralympic games across the three weapons (epée, foil, and sabre) for individual and team events. Paralympic fencing consists of two categories: category A and B with differences between categories determined by a participant’s trunk control (International Wheelchair and Amputee Sports Federation, 2020b). Wheelchair fencing is a unique sport and requires athletes to compete in a static wheelchair and rely on trunk lunging movements to evade opponents and score points. With the growth of Paralympic sport, it is important to understand the physiological demands of these sports to aide athletes and coaches in training and preparing for competition. It has been highlighted by wheelchair fencing coaches that the ability to perform repeated high intensity lunges and sustain this over a competition are important for performance (Villiere et al., 2021), in addition to speed of movement, flexibility, agility, motor control, trunk strength, and fencing arm strength and power (Villiere et al., 2021).

There has only been two previous research studies that have attempted to quantify the physiological profile of wheelchair fencing (Bernardi et al., 2010; Iglesias et al., 2019). Bernardi et al. (2010) determined peak oxygen consumption ($\dot{V}O_{2peak}$) using arm crank ergometry to be 2.4 ± 0.7 $L.min^{-1}$ and peak heart rate to be 182 ± 5 for a group of 6 category A and B fencers. Furthermore, peak blood lactate concentration during the field test was 4.7 ± 1.4 $mmol.L^{-1}$ indicating wheelchair fencers using anaerobic energy sources. The wheelchair fencers used in this study had a similar fitness level to wheelchair tennis ($\dot{V}O_{2peak}$: 2.3 ± 0.3 $L.min^{-1}$) and wheelchair basketball players ($\dot{V}O_{2peak}$: 2.7 ± 0.5 $L.min^{-1}$) but were lower than Nordic sit skiers (3.3 ± 0.3 $L.min^{-1}$) and wheelchair racing athletes (3.1 ± 0.3 $L.min^{-1}$). During a simulated field-based test, 3 x 3 minutes bouts with 1 minute rest between bouts, Bernardi et al. (2010) reported that wheelchair fencers compete at high levels of $\%\dot{V}O_{2peak}$ (mean $\dot{V}O_2$: 73 ± 3 $\%\dot{V}O_{2peak}$, peak $\dot{V}O_2$: 92 ± 11 $\%\dot{V}O_{2peak}$) and heart rate (mean HR: 84 ± 5%, peak HR: 95 ± 8%). Similarly, research by Iglesias et al. (2019) showed similar absolute mean (1.9 ± 0.5 $L.min^{-1}$ and peak (2.5 ± 0.7 $L.min^{-1}$) $\dot{V}O_2$ responses during wheelchair fencing in able-bodied athletes, however mean and peak heart rate recorded was lower than in the study by Bernardi et al. (2010). Energy expenditure during wheelchair fencing was also determined to be 10.0 ± 2.5 $kcal.min^{-1}$ and 11.7 ± 3.2 $kcal.min^{-1}$ in 5- and 15-point fights, respectively. Differences between the studies could be the use of able-bodied athletes in the study by Iglesias et al. (2019). They might not have used as much trunk movement compared to accustomed wheelchair fencers which has been shown to be the predominant muscles used by wheelchair fencers (Borysiuk, Nowicki, Piechota, & Błaszczyszyn, 2020). Further, the protocol in the study by Bernardi et al. (2010) required longer fencing time whereas Iglesias et al. (2019) competed in first to 5 or 15 points as per a regulation wheelchair fencing fight.

As highlighted in chapter 2.5 in able-bodied sport protective clothing can add extra physiological strain to athletes. Wheelchair fencers have to wear mandatory protective clothing (International Wheelchair and Amputee Sports Federation, 2020a) similar to able-bodied fencing, however in wheelchair epée fencers have to wear an additional apron covering the lower body that could add additional thermal load.

It has been shown that athletes with spinal cord injury (SCI) have a compromised thermoregulatory response compared to able bodied athletes (Griggs, Havenith, Price, et al., 2017; Price, 2006; Price & Campbell, 1997, 1999, 2003; Price & Goosey-Tolfrey, 2008; Pritchett, 2011). There has been shown to be a greater heat storage in participants with SCI in particular in the lower body with increases in thigh and calf temperatures (Price & Campbell, 1997; Price & Goosey-Tolfrey, 2008; Pritchett, 2011). Furthermore, during recovery from exercise Price & Campbell (1999) participants with SCI continued to store heat whereas able bodied participants demonstrated heat loss. Research by Griggs et al. (2017) showed that participants with SCI covered less distance and had a slower push speed but had a greater thermal load than non-SCI participants. This was most likely due to the large area of insensate skin in subjects with SCI reducing the body's ability to dissipate heat which could cause continual core and skin temperature increases (Griggs, Havenith, Price, et al., 2017). Additionally, it was shown that participants with SCI perceived the thermal load to be similar to athletes without SCI, therefore participants with SCI may be unable to accurately perceive thermal strain.

There has been no research assessing the thermoregulatory demands of wheelchair fencing. Therefore, considering the compromised thermoregulation of participants with SCI and the protective clothing covering the whole-body research should be undertaken in wheelchair fencing. The physiological demands of wheelchair fencing are not well understood as there has only been one study using wheelchair athletes (Bernardi et al., 2010) so future research should add to this. The study by Bernardi et al. (2010) also grouped different category fencers together, due to the limited number of wheelchair fencers and potential differences in function between participants an individualised approach may be a more suitable methodology when reporting data (Halperin, 2018).

2.10 Overall Thesis Aims

The overall aim of this thesis is to develop a further understanding of the physiological, movement and thermoregulatory demands of epée fencing, and to determine if there are benefits of cooling on physiological responses, cognitive function, and performance variables during epée fencing. This thesis will focus on research in epée fencing due to epée having a greater work to rest ratio than foil and sabre as highlighted in chapter 2.1.1, therefore, epée fencers may be under greater physiological and thermoregulatory strain which needs investigating. Finally, the researcher had better access to epée athletes as participants for the research studies in this thesis.

Chapter 3

3 General Method

Several studies in this thesis used similar methods. To avoid repetition, methods used in more than one of the following experimental chapters (chapters 4-8) are described in this section and will only be described in short in the experimental chapters.

3.1 Participant Recruitment

Participants for chapter 4 and 5 were recruited individually through support staff at British Fencing and were all competing at a national standard based upon the last 12 months of competition. For chapter 7 participants were club standard and recruited from two fencing clubs, and all competed in fencing competitions for a minimum of two years. Participants for chapter 8 were recruited through the head coach of British Disability Fencing Association. All participants recruited were epée fencers. Participant characteristics for each study are presented in each chapter. All testing was performed in the participants International Fencing Federation approved fencing equipment (International Fencing Federation, 2019).

3.2 Ethics, Consent and Preliminary Questionnaires

All studies were approved by University of Hertfordshire’s Health Science Engineering & Technology Ethics committee. Before testing all participants provided informed written consent and completed a separate departmental health screen and previous and current training background in epée.

The following ethics protocol numbers were used in this thesis:

aLMS/PGR/UH/02960(2)

LMS/PGR/UH/03566

aLMS/PGR/UH/03617(2)

3.3 Body Mass and Stature

Body mass was measured to the nearest 0.1kg using electronic weighing scales (Seca Clara 803, Birmingham, UK). Participants wore minimal clothing for all measurements and were instructed to stand on the scales barefoot facing forwards (Winter, Jones, Davison, Bromley, & Mercer, 2007). Stature was measured to the nearest 0.1cm using a portable stadiometer (Seca 213, Birmingham, UK). The participants were measured barefoot, requested to take an inhalation of breath and instructed to have the head in the Frankfort Plane (Winter et al., 2007).

3.4 Ambient Environmental Conditions

The ambient environmental conditions were measured using a wet bulb globe temperature (WBGT) monitor (HT30, Extech Instruments, Nashua, NH, USA), which recorded WBGT, black bulb temperature, ambient temperature, and humidity. The conditions were measured during each round of fights by placing the device next to the middle of one of the fencing pistes at the chest level of the researcher.

3.5 Epée Fencing Competition Format

For chapter 4 and 5 participants were required to attend a fencing competition at the Leon Paul Fencing Centre with a format of Poule rounds and Direct Elimination (DE) rounds. The Poule rounds involved participants competing in seven 3-minute bouts or first to 5 points fights. Following the Poule rounds participants were seeded leading into the DE rounds (3 x 3-minute bouts or first to 15 points fight) based upon the results of the Poule. During fencing a bout is classified as up to 3 minutes of actual fighting time, and a fight is classified as the total time from start to end including any rest periods or stoppages between points. When a point is scored in fencing the time is immediately stopped and resumed upon the referee’s command to start fencing to allow a full 3 minutes of fencing time in each bout. The seeding after the Poule rounds allowed the top seed to have a more beneficial route to the final round as would occur at competition. Instead of conventional competition knockout rounds within the DE the DE was adapted to a format that was similar to a round-robin, whereby instead of being knocked out as in a normal competition the fencers all fought each other as if reaching the final (Figure 3.1). This allowed a more complete data collection for the eight participants during each competition and was used to replicate participants reaching a final of a standard fencing competition. Participants were instructed to prepare as they would for competition. Between the end of Poule 7 and start of DE 1 there was a break of 1 hour 25 minutes for chapter 4 and 1 hour 35 minutes for chapter 5 which is standard at competition.

For the purposes of this unique competition format the winner was determined on fights won, and in the event of a tie points difference, and then points scored. A staggered monetary incentive (as Amazon vouchers) was given for all placings within the competition, as well as a trophy for the winner, to ensure the fencers gave maximal effort. The following monetary prizes as Amazon gift vouchers were awarded: 1st £120, 2nd £80, 3rd £60, 4th £40, 5th £30, 6th £20, 7th £15 and 8th £10.

Round of 128 (DE 1)
1v8, 4v5 | 3v6, 2v7

Round of 64 (DE 2)
2v8, 4v6 | 3v5, 1v7

Round of 32 (DE 3)
4v7, 3v8 | 1v6, 2v5

Round of 16 (DE 4)
4v8, 1v5 | 2v6, 3v7

Round of 8 (DE 5)
6v7, 5v8 | 1v4, 2v3

Semi Final Round (DE 6)
6v8, 1v3 | 2v4, 7v5

Final Round (DE 7)
5v6, 7v8 | 1v2, 3v4

Figure 3.1. Direct Elimination Round Robin Structure. Number indicates seeding from Poule rounds.

3.6 Blood Lactate Analysis

3.6.1 Biosen C-Line

For chapter 4 and 5 blood lactate concentration was measured by taking a small 10µl capillary blood sample from a fingertip on the non-sword arm. The fingertip was wiped with a 70% isopropyl alcohol swab, and then punctured using a sterile single use lancet (Accu-Chek Safe T Pro Plus Lancet, Accu-Chek, Roche, Basel, Switzerland). The first drops of blood were wiped away, and the sample was collected in a sodium heparised capillary tube. The sample was then placed into a microcentrifuge tube containing a haemolysing solution and mixed to ensure all the blood had exited the capillary tube ready for analysis. Blood lactate concentration was then measured in duplicate using the Biosen C-Line lactate analyser which was calibrated following manufacturer instructions using 12.0 mmol.L^{-1} calibration standard (Biosen C-Line, Ekf Diagnostics, Cardiff, UK). Samples were collected within 3 minutes of the fight finishing. The Biosen-C line has been reported to have a coefficient of variation of <1.5% (Ekf Diagnostics, 2021).

3.6.2 Lactate Pro

For chapters 7 and 8 blood lactate concentration was measured using a portable blood lactate analyser (Lactate Pro 2, Arkray Global Business Inc., Kyoto, Japan). A fingertip was wiped with a 70% isopropyl alcohol swab as noted above, and then punctured using a sterile single use lancet (Accu-Chek Safe T Pro Plus Lancet, Accu-Chek, Roche, Basel, Switzerland). The first drops of blood were wiped away and a 0.3µl capillary blood sample was collected on a test strip. Exercise samples were collected within 3 minutes of the fight finishing.

Reliability testing was undertaken to compare blood lactate concentration between Lactate Pro 2 and Biosen C-Line (Appendix A). In brief, there was a significant Pearson correlation coefficient ($r = 0.980$, $p < 0.05$) determined for blood lactate concentration between Lactate Pro 2 and Biosen C-Line, as shown in Figure A.1. Excellent ICC was also reported between Lactate Pro 2 and Biosen C-Line (0.988 (0.330)).

3.7 Core Temperature Measurements

3.7.1 Core Temperature Pill

Upon arrival to testing the 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. This allowed the pill to enter the digestive tract for accurate gastrointestinal temperature (T_{gast}) measurements (Notley, Meade, & Kenny, 2021). During chapter 7 core temperature pills were consumed ~60 minutes prior to testing commencing. This was due to logistical issues with the testing taking place at club training sessions and issues with some of the core temperature pills not turning on immediately when removed from the magnet. However, there were no significant differences ($F_{(2,10)} = 0.161$, $p = 0.854$, $\eta^2 = 0.031$) determined for pre-warm-up T_{gast} in chapter 7 (CON: 37.10 ± 0.40°C, EXT: 36.99 ± 0.68°C, MIX: 36.89 ± 0.76°C) indicating the core temperature pills could have been in a similar position within the body during the testing.

The CorTemp pill is accurate to within ± 0.1°C and transmits a signal via magnetic flux to the data recorder. The data recorder (HQ Inc., Palmetto, FL, USA) was held 2-3 cm behind the participants back (and thus fencing jacket) for all measurements as per the manufacturer instructions (Figure 3.4). Pre-fight T_{gast} readings <36.0°C and post-fight T_{gast} readings <36.5°C were excluded due to being considered outside what would be seen as normal human physiological range (Geneva et al., 2019). Nine fights in chapter 4 and two fights in chapter 5 were excluded for analysis due to being outside these ranges. In-house Intraclass Correlations (ICC) reliability (Cicchetti, 1994; Shrout & Fleiss, 1979) 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.

Standard Error of Measurement (SEM) was calculated as follows for all reliability calculations:

$$\text{SEM} = \text{SD} * \sqrt{(1-\text{ICC})}$$

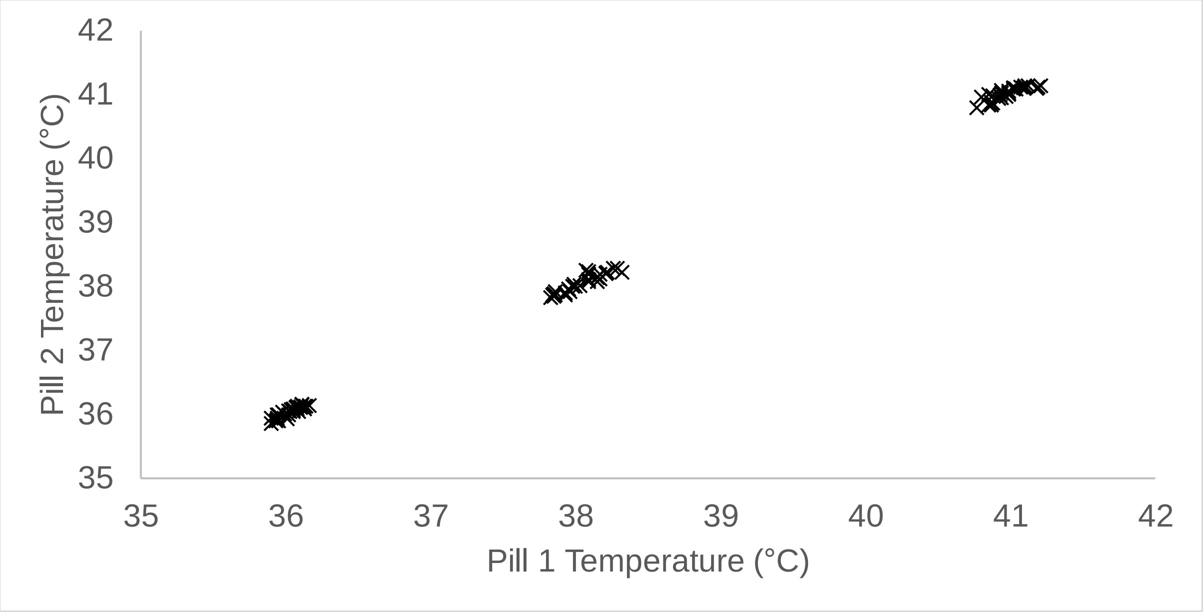
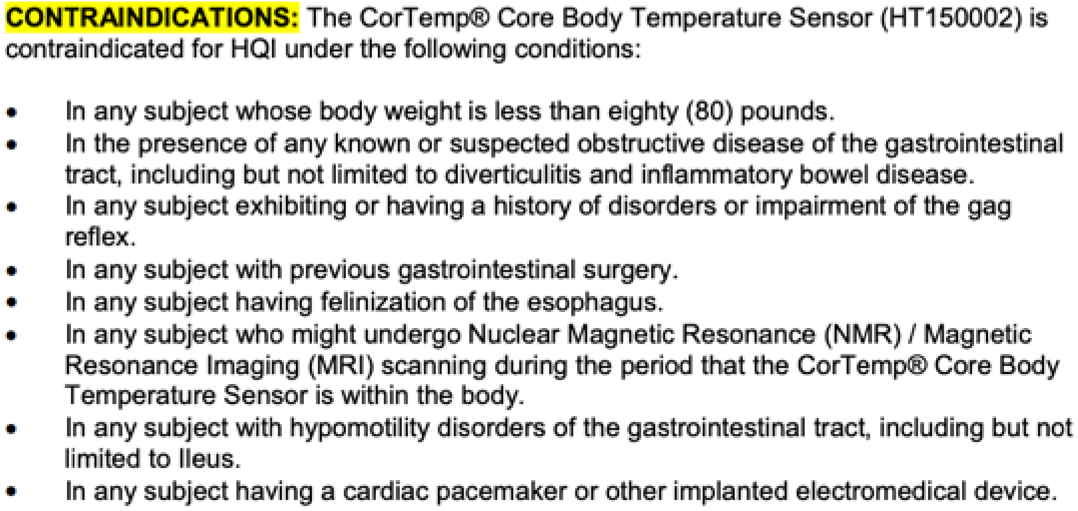


Figure 3.2. Comparison of water bath temperature (°C) between two core temperature pills at 36°C, 38°C and 41°C.

Participants were excluded from taking a CorTemp pill if they met any of the contraindications outlined by the manufacturer (Figure 3.3). One participant in chapter 5 had a contraindication (gastrointestinal disorder) so had core temperature measured aurally.



CONTRAINDICATIONS: The CorTemp® Core Body Temperature Sensor (HT150002) is contraindicated for HQI under the following conditions:

- In any subject whose body weight is less than eighty (80) pounds.
- In the presence of any known or suspected obstructive disease of the gastrointestinal tract, including but not limited to diverticulitis and inflammatory bowel disease.
- In any subject exhibiting or having a history of disorders or impairment of the gag reflex.
- In any subject with previous gastrointestinal surgery.
- In any subject having felinization of the esophagus.
- In any subject who might undergo Nuclear Magnetic Resonance (NMR) / Magnetic Resonance Imaging (MRI) scanning during the period that the CorTemp® Core Body Temperature Sensor is within the body.
- In any subject with hypomotility disorders of the gastrointestinal tract, including but not limited to Ileus.
- In any subject having a cardiac pacemaker or other implanted electromedical device.

Figure 3.3. Contraindications of the CorTemp pill. Image taken from the CorTemp pill manual (HQInc., 2021).

Figure 3.4. Core Temperature Measurement Position during Testing

3.7.2 Aural Temperature Measurement

For the participant in chapter 5 that reported contraindications for the CorTemp pill use and during chapter 7 aural temperature (T_{au}) was also measured to assess internal body temperature. Aural temperature was measured using an infrared ear thermometer by inserting the thermometer into the auditory canal (Braun Thermocscan 6013, Braun, Kronberg, Germany (chapter 5); or Braun Thermoscan 7 IRT6520, Braun, Kronberg, Germany (chapter 7)). In-house reliability at rest of the Braun infrared thermometers showed excellent ICC (SEM) of 0.853 (0.064) (Cicchetti, 1994; Shrout & Fleiss, 1979) by measuring T_{au} of the right ear every 5 minutes over 2 hours.

3.8 Skin Temperature Measurements

Wireless skin thermochrons (iButtons DS1992L, Maxim Integrated Products Inc., San Jose, CA, USA, resolution 0.0625°C) were attached using zinc oxide strapping tape (Tiger Tapes, Physique Management Company Ltd, London, U.K.) to the participants on the following sites: biceps (midway between acromion process and olecranon process on the biceps muscle), chest (midway between the axillary and the nipple), thigh (midway between inguinal crease of the hip and patella), calf (largest circumference of the muscle belly), and inside the top of the fencing mask to enable mean skin temperature (T_{skin}) to be measured. Prior to placing the thermochrons on the participants they were programmed using a USB computer interface (DS1402D-DR8 Blue Dot Receptor; DS9490R 1-Wire to USB Adaptor, Maxim Integrated Products Inc., San Jose, CA, USA). Each thermochron's real-time clock was time synchronised 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 as follows:

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

(Ramanathan, 1964)

In house reliability using a water bath showed excellent reliability (Cicchetti, 1994; Shrout & Fleiss, 1979) 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, (mean ICC ± SD). 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.

3.9 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). The heart rate was recorded at 1Hz, and movement data were recorded using a tri-axial accelerometer, gyroscope and digital compass-based system recording at 200Hz. In house validity and reliability data showed coefficient of variation of 5-6% for forward movement and 10-12% for backwards movement distance (Appendix B). Data was recorded via Bluetooth using the Polar Team Pro software on a tablet (iPad 5th Generation, Apple Inc., Cupertino, CA, USA). All participant characteristic information was entered into the software prior to testing and each participant was then given a unique numbered device. This allowed data to be collected simultaneously from all participants at the same time without a need for them to wear heart rate monitor watches. Maximum heart rate was determined in the software based upon the participant's age predicted maximum heart rate (HR_{APM}) and was calculated as 220-age. Absolute heart rate recorded in beats.min^{-1} and relative heart rate recorded as a percentage of HR_{APM} were recorded during the testing.

3.10 Training Load

Training load (measured in arbitrary units (AU)) was calculated using the Polar Team Pro 2 algorithms within the software. There was an attempt to obtain the algorithm from Polar, however they would not disclose the calculation. The algorithm calculates training load by using the participant's anthropometry, heart rate dynamics during exercise, mechanical impact of the exercise, and energy expenditure (Nissila & Kinnunen, 2008), training load per minute (AU.min^{-1}) was also calculated. The training load calculation reflects the non-fat energetic cost of exercise, with fat being seen as an infinite energy source (Nissila & Kinnunen, 2008). Carbohydrate stores and protein via gluconeogenesis are seen as finite stores that need to be recovered (Nissila & Kinnunen, 2008).

3.11 Work to Rest Ratio

To determine work to rest ratio each Poule and DE fight were recorded at 50Hz using a fixed camcorder (Sony CX450 Handycam, Sony Europe B.V. Weybridge, U.K.) upon a tripod with the full fencing piste, referee and scoring system in view. A two-button code window of "work" and "rest" was created using performance analysis software (Sportscode Elite version 10, Hudl, Lincoln, Nebraska, USA). An exclusive link was created between the two buttons so when "work" was pressed "rest" was deactivated and vice versa. “Work” was determined as time by hand signals (bringing the hands together) from the referee when announcing “fence” until a point was scored through lights on the scoring system indicating which fencer had won a point. “Rest” was determined as time between a point being scored as indicated by lights on the scoring system and referee’s hand signals when announcing “fence”. Mandatory one minute rest time during DE fights after a three-minute bout was not included with rest time calculations when competing so as to not skew work to rest ratios. Work to rest ratio was calculated by dividing the total time working (seconds) by total time resting (seconds).

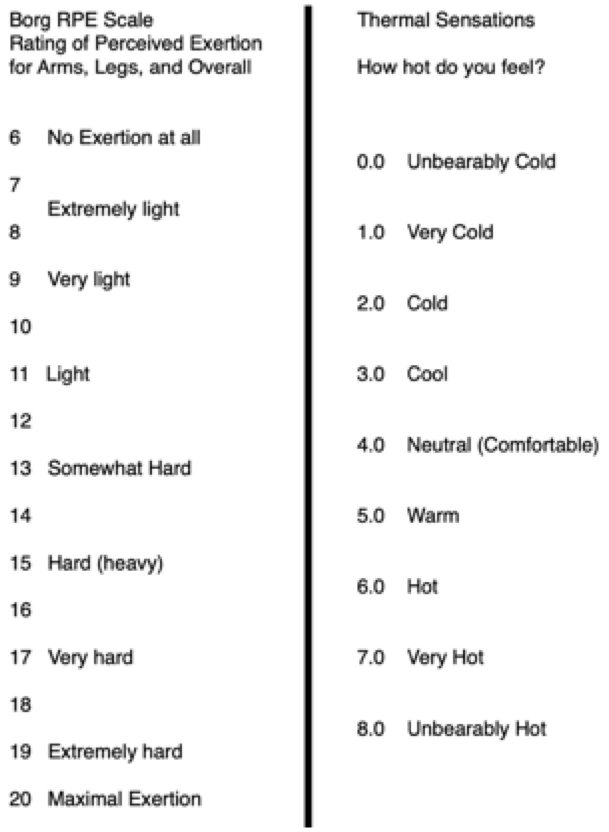
All work to rest ratios for Poule and DE fights were analysed by the same researcher. Intra-observer reliability was conducted for the researcher for 10 able-bodied Poule fights whereby the researcher analysed each fight on three occasions. Mean coefficient of variation was calculated by dividing the standard deviation by the mean and was determined as good (1.90 ± 0.99%) for the analysed Poule fights.

3.12 Ratings of Perceived Exertion

Differentiated Ratings of Perceived Exertion (RPE) were recorded using the Borg 6-20 category scale as shown in Figure 3.5 (Borg, 1982, 1998). Participants subjectively rated exertion for their arms (RPE_A), legs (RPE_L) and overall (RPE_O) perceptions which have been used previously in fencing (Bottoms et al., 2013). Participants were familiarised on how to use the differentiated RPE to ensure accurate readings.

3.13 Thermal Sensation

Subjective ratings of thermal sensation were recorded using a 9 point category scale as shown in Figure 3.5 (Young, Sawka, Epstein, Decristofano, & Pandolf, 1987). Participants were familiarised on how to use the thermal sensation scale to ensure accurate readings.



Borg RPE Scale
Rating of Perceived Exertion
for Arms, Legs, and Overall

6	No Exertion at all
7	
	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat Hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal Exertion

Thermal Sensations

How hot do you feel?

0.0	Unbearably Cold
1.0	Very Cold
2.0	Cold
3.0	Cool
4.0	Neutral (Comfortable)
5.0	Warm
6.0	Hot
7.0	Very Hot
8.0	Unbearably Hot

Figure 3.5. RPE and Thermal Sensations scale used in this thesis

3.14 Statistical Analysis

Data in all chapters are presented as mean ± standard deviation (SD) with 95% confidence intervals (95% CI), unless stated otherwise. Data for all chapters were analysed 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. Specific statistical analysis for the variable collected are described in each chapter.

For Paired-Students t-test analysis effect sizes (ES) were calculated for statistically significant differences using Cohen’s d (Cohen, 1988) 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) (Hopkins, Marshall, Batterham, & Hanin, 2009).

For analysis of variance (ANOVA) analysis partial eta squared (η^2) effect sizes (Cohen, 1988) were calculated for within and between group differences and considered to be small (η^2 0.10 – 0.24), moderate (η^2 0.25 – 0.39) and large (η^2 >0.40) (Cohen, 1988).

Significant Pearson’s correlation coefficients were determined to be small ($r = 0.10$-0.29), moderate ($r = 0.30$-0.49) or large ($r > 0.50$) (Cohen, 1988).

Chapter 4

4 Study 1 – Physiological Demands of Epée Fencing During Competition

This chapter has been published in a slightly modified form in the *International Journal of Performance Analysis in Sport*: Oates, L., Campbell, I., Price, M., Muniz-Pumares, D., Iglesias, X., Bottoms, L. (2019). The physiological demands of elite epée fencers during competition, *International Journal of Performance Analysis in Sport*, 19(1), 76-89 (https://doi.org/10.1080/24748668.2018.1563858)
Accepted: December 2018.

This chapter has also been presented in a slightly modified format at:

The *STEM for BRITAIN: Biological and Biomedical Science Exhibition:* Oates, L., Campbell, I., Price, M., Muniz-Pumares, D., Iglesias, X., Bottoms, L. (2018). Physiological Demands of Epée Fencing.

The *University of Hertfordshire Life & Medical Sciences Annual Conference*: Oates, L., Campbell, I., Price, M., Muniz-Pumares, D., Iglesias, X., Bottoms, L. (2019). Physiological demands of elite epée fencers during competition.

The *24th Annual Congress of the European College of Sport Science:* Oates, L., Campbell, I., Price, M., Muniz-Pumares, D., Iglesias, X., Bottoms, L. (2019). Physiological Demands of Epée Fencing Performance. *24th Annual Congress of the European College of Sport Science,* 635 Accepted March 2019.

4.1 Abstract

The aim of this study was to determine the physiological demands of epée fencing performance. Eight well-trained male epée fencers competed in a competition consisting of 7 Poule and 7 DE fights. Gastrointestinal temperature, HR, movement data, training load, and differentiated RPE were collected for all Poule and DE fights. Expired gas, and EE were measured using breath-by-breath gas analysis during selected fights, along with blood lactate concentration. Maximal HR and RPE were greater in DE than Poule fights. There was a tendency for greater increases in Tgast in DE compared to Poule fights (p = 0.052). Blood lactate concentration decreased during the competition from Poule to DE suggesting reliance on phosphocreatine and aerobic energy sources during epée. High oxygen consumption (~50 ml.kg-1.min-1) and EE (~13 kcal.min-1) were recorded in both Poule and DE. Participants covered 3 times more distance in DE than Poule fights, but there were no significant differences in distance covered per minute. There was a greater training load per minute (~3.9 vs. ~3.5 AU), peak speed and percentage of zone 2 accelerations in DE than Poule fights. This is the first study to show an increased physiological strain, with high aerobic and anaerobic demands, as fencing competition progressed from Poule to DE. Additionally, there was a considerable energy demand exhibited during epée competition. Movement demands of epée were also assessed for the first-time using a tri-axial accelerometer-based system showing a large physical demand of performance.

4.2 Introduction

Understanding of the demands of a sport is becoming an important aspect for coaches and athletes. The majority of research regarding the physiological demands of sport tends to be more focused within team based and well-funded sports such as football, tennis, rugby and cycling (Cunniffe, Proctor, Baker, & Davies, 2009; Dempsey, Gibson, Sykes, Pryjmachuk, & Turner, 2018; Drust, Atkinson, & Reilly, 2007; Fernandez-Fernandez, Sanz-Rivas, & Mendez-Villanueva, 2009; Gomes, Coutts, Viveiros, & Aoki, 2011; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005; Santalla, Earnest, Marroyo, & Lucía, 2012). However, there is little research reporting the physiological demands of the Olympic sport of fencing (sabre, foil, or epée).

As described in chapter 2.1 epée fencing is reliant on both PCr and aerobic energy systems with work to rest ratio ~1:1. However, there is limited research reporting the physiological demands within male epée fencing during competition. Previous research within epée has utilised simulated fights in a laboratory setting (Bottoms et al., 2011, 2013; Iglesias & Rodríguez, 2000). One study conducted during epée competition (Iglesias & Rodríguez, 1995) showed male epée fencers achieved an average heart rate of 166 ± 8 beats.min^{-1}, with blood lactate concentration post fight averaging 3.2 ± 0.7 mmol.L^{-1} during competition. Oxygen consumption was estimated (from incremental HR and $\dot{V}O_2$ data) to be 54 ± 4 ml.kg^{-1}.min^{-1}, with estimated energy expenditure to be 15.4 kcal.min^{-1} in international competition compared to 12.3 kcal.min^{-1} in a national competition (Iglesias & Rodríguez, 1999, 2000). Research by Bottoms et al. (2011) showed female epée athletes achieved average HR of ~89% of maximal heart rate, with modest $\dot{V}O_2$ responses with average values of ~35 ml.kg^{-1}.min^{-1} being recorded during simulated fencing. Furthermore, blood lactate concentrations were determined to be relatively low ~2.8 mmol.L^{-1} again indicating an importance of the phosphocreatine energy system. During a simulated competition Bottoms et al. (2013) showed relatively low heart rate responses of between 150-170 beats.min^{-1} during both Poule and DE fights for male epée fencers. In addition, there were modest RPE values reported during the simulated competition with RPE being greater in the DE compared to the Poule rounds (13 vs. 10, respectively). However, as these were simulated fencing fights and not actual competition the physiological response is likely to lower due to potential lack of motivation from the fencers to compete and also due to lower catecholamine release (Hoch et al., 1988).

Movement data within fencing research has traditionally used time motion analysis as described in chapter 2.1.6.2 with ~8%, 41% and 51% of movements classified as high, moderate and low intensity, respectively, (Wylde et al., 2013; Wylde & Yong, 2015). However, values have only been reported in foil. There could be differences between foil and epée with potentially more time in moderate or low intensity than high intensity movements during epée due to the more tactical nature, longer point duration and no right of way rule in epée. In recent years the analysis of movement data within sport science has evolved due to technological advances and is now commonly undertaken using GPS/accelerometer based systems (Hoppe et al., 2018; Scott et al., 2016). There has been no research reporting the movement demands of epée fencing using these systems. Using this method is more advantageous as: it is less time consuming to analyse, a larger range of variables are available, it allows external and internal training loads to be determined, and can be more accurate than time motion (Roberts et al., 2006; Roell et al., 2018; Scott et al., 2016). Furthermore, movement data added with other physiological variables, such as HR, $\dot{V}O_2$ and blood lactate concentration, would give a greater understanding of the physiological demands of fencing and could be used to inform training and strength and conditioning programmes.

Therefore, the aims of this study were to determine the physiological and movement demands of epée fencing during simulated competition and compare how the physiological demands change between Poule and DE fights. These data will be essential for coaches, practitioners, and athletes to understand the demands of epée fencing to prescribe training sessions and prepare for competition.

4.3 Methods

4.3.1 Participants

Eight male well-trained epée fencers (ranked within the top 35 in the United Kingdom at the time of testing) volunteered to take part in this study. All fencers competed at a national or international standard, had previous epée training history, and trained regularly in epée. Thus the population represented a typical fencing cohort at a national competition (Table 4.1).

Table 4.1. Participant Characteristics (mean ± SD).

Variable	Mean ± SD
Age (years)	24.0 ± 9.2
Stature (cm)	178.9 ± 2.8
Body Mass (kg)	72.4 ± 4.8
Fencing (Hours per Week)	6.9 ± 3.0
Strength and Conditioning (Hours per Week)	3.5 ± 1.7
Previous Fencing Experience (years)	10.9 ± 6.5

4.3.2 Procedures

Participants competed in a fencing competition as described in chapter 3.5. Questionnaires, body mass and stature were recorded as described in chapters 3.2 and 3.3. Body mass was recorded pre Poule.

Environmental conditions were recorded as described in chapter 3.4. Over the competition duration average WBGT was 16.4 ± 0.7 C, black bulb temperature was 19.4 ± 0.4°C, ambient temperature was 19.5 ± 0.5°C and humidity was 63.4 ± 4.9%.

During the competition various physiological measures were taken pre, during and post each Poule and DE fight, Figure 4.1. Expired gas was also collected during selected Poule and DE fights. Each participant had expired gas measured during two Poule and two DE fights due to only having two gas analysers available.

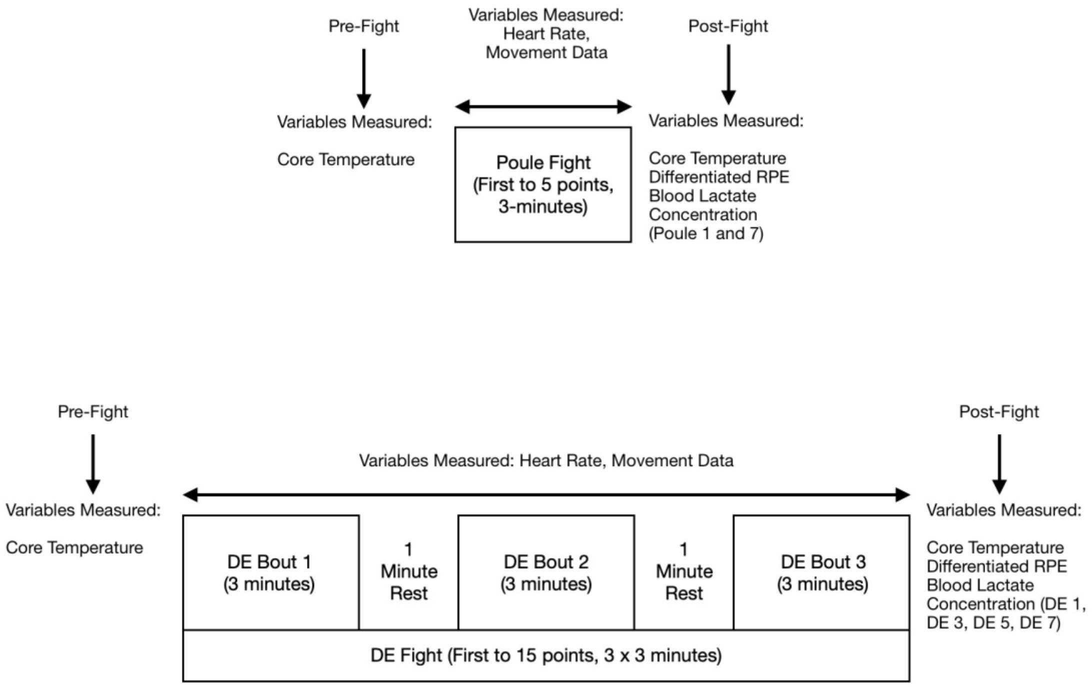


Figure 4.1. Schematic diagram of a Poule and DE fight. See general methods for specific measurement information (chapter 3).

4.3.3 Gastrointestinal Temperature Measurements

Gastrointestinal temperature was measured as described in chapter 3.7.1. None of the participants had any contraindications to the CorTemp pills (chapter 3.7.1). During the competition T_{gast} (°C) was measured pre and post each Poule and DE fight.

4.3.4 Heart Rate Monitoring and Movement Data

Heart rate and movement data were recorded as described in chapter 3.9. Absolute heart rate (beats.min^{-1}) and relative heart rate (% HR_{APM}) for average heart rate (HR_{av}), and maximum heart rate (HR_{max}) were recorded for all Poule and DE fights. Additionally, time spent above 80% HR_{APM}, and time in heart rate zones were analysed for all Poule and DE fights. The following heart rate zones were utilised: Zone 1 – 50-59% HR_{APM}, Zone 2 – 60-69% HR_{APM}, Zone 3 – 70-79% HR_{APM}, Zone 4 – 80-89% HR_{APM}, Zone 5 - >90% HR_{APM}.

Distance covered (m), distance covered per minute ($m.min^{-1}$), peak speed ($m.s^{-1}$), average speed ($m.s^{-1}$), and number and percentage of accelerations and decelerations in three acceleration/deceleration zones were analysed. Accelerations and decelerations were split into the following zones: Zone 1 – accelerations 0.50 to 0.99 $m.s^{-2}$ and decelerations -0.50 to -0.99 $m.s^{-2}$; Zone 2 – accelerations 1.00 to 1.99 $m.s^{-2}$ and decelerations -1.00 to -1.99 $m.s^{-2}$, Zone 3 – accelerations > 2.00 $m.s^{-2}$ and decelerations > - 2.00 $m.s^{-2}$.

4.3.5 Training Load

Training load (AU) and training load per minute ($AU.min^{-1}$) were determined as described in chapter 3.10.

4.3.6 Blood Lactate Concentration

Blood lactate analysis was undertaken as described in chapter 3.6.1. Capillary blood samples were collected at baseline, post Poule 1, post Poule 7, post DE after every other round i.e. DE1, DE3, DE5, and DE7 (Figure 4.1). Capillary blood samples at baseline were collected after a minimum of 10 minutes rest. Post fight capillary blood samples were collected within 3 minutes of the fight terminating.

4.3.7 Ratings of Perceived Exertion

Differentiated ratings of perceived exertion (RPE_A, RPE_L, and RPE_O) were recorded as described in chapter 3.12. Differentiated RPE was collected immediately post fight for all Poule and DE fights (Figure 4.1).

4.3.8 Gas Analysis

Expired gas was collected and analysed during two fights in both the Poule and DE rounds for each participant using a portable breath-by-breath gas analysis system (Cosmed K4b2, Cosmed, Rome, Italy). The Cosmed gas analysis system was calibrated by a four-step calibration procedure as highlighted by the manufacturer. Initially a room air calibration procedure was carried out. Secondly, a reference gas calibration was carried out using factory measured gas concentrations of 5% carbon dioxide, 17% oxygen, and Nitrogen for balance. The gas cylinder valve was opened to a pressure of 44-73 psi (3-5 bars) then placed onto the calibration unit. Following gas calibration, a gas delay calibration was completed involving breathing through the face mask at a constant rate with the optoelectronic reader connected to the sample line. Finally, the turbine calibration was completed with the optoelectronic reader, and turbine being connected to a 3-litre volume calibration syringe (Hans Rudolph, Shawnee, Kansas State, USA).

Participants were required to wear a face mask underneath their fencing mask for expired gas to be collected. The participant's opponent during the fight also had expired gases analysed so as not to disadvantage each participant during the fight. Expired gas data was averaged over 5-second periods of time during the fight to calculate: average and maximum $\dot{V}O_2$, respiratory exchange ratio (RER), and energy expenditure (EE) during each fight were calculated using principles of indirect calorimetry (Elia & Livesey, 1992). Due to a technical issue with one of the gas analysers being damaged during one of the DE fights, thirteen fights during the DE were analysed from seven participants. For RER there was an issue with the volume of carbon dioxide produced ($\dot{V}CO_2$) recordings in 4 Poule fights so results are presented for 11 Poule fights and 14 DE fights.

4.3.9 Statistical Analysis

Data are presented and analysed as described in chapter 3.14. Paired-Students t-test analyses were undertaken to compare HR_{av}, HR_{max}, percentage of time spent in heart rate zones, RPE_O, RPE_A, RPE_L, distance covered, distance covered per minute, peak speed, average speed, training load, training load per minute and percentages of accelerations in acceleration zones between all Poule and DE fights. Paired students t-test analyses were also undertaken for Poule and DE fights where gas analysis was collected for average $\dot{V}O_2$ during the fight, maximum $\dot{V}O_2$ achieved during the fight, and EE.

A one-way repeated measures analysis of variance (ANOVA) was undertaken to compare the blood lactate response across the competition. A two-way repeated measures ANOVA (fight x time) was also undertaken to compare core temperature responses between Poule and DE fights and within each fight comparing pre to post fight.

Effect sizes were calculated as described in chapter 3.14.

4.4 Results

4.4.1 Physiological Demands

There were significantly greater absolute HR_{max} ($t_{(55)} = -5.809$, $p < 0.001$), relative HR_{max} ($t_{(55)} = -5.859$, $p < 0.001$), RPE_O ($t_{(53)} = -8.114$, $p < 0.001$), RPE_A ($t_{(53)} = -5.968$, $p < 0.001$), and RPE_L ($t_{(53)} = -5.767$, $p < 0.001$) in the DE compared to the Poule fights (Table 4.2). Differences for absolute and relative HR_{max} were small and moderate, respectively. Differences for RPE_O, RPE_A, and RPE_L were large, moderate, and moderate, respectively. There were no significant differences for absolute HR_{av} ($t_{(55)} = -1.506$, $p = 0.138$) or relative HR_{av} ($t_{(55)} = -1.405$, $p = 0.166$) between Poule and DE fights, as shown in Table 4.2.

Table 4.2. Physiological responses of Epée fencing for Poule and DE fights (mean ± SD (95% CI)).

Variable	Poule	DE	*P* value	ES
HR_{av} (beats.min^{-1})	168 ± 12 (161, 175)	169 ± 14 (161, 176)	0.138	0.08
HR_{av} (% HR_{APM})	86.3 ± 6.6 (82.7, 90.0)	86.5 ± 6.3 (83.0, 90.0)	0.166	0.03
HR_{max} (beats.min^{-1})	180 ± 11 (174, 187)	187 ± 13 (180, 194)*	< 0.001	0.58
HR_{max} (% HR_{APM})	92.4 ± 6.1 (89.0, 95.8)	96.0 ± 5.3 (93.1, 98.9)*	< 0.001	0.63
RPE_O	11 ± 3 (10, 13)	15 ± 3 (14, 17)*	< 0.001	1.33
RPE_A	10 ± 2 (9, 12)	12 ± 2 (11, 14)*	< 0.001	1.00
RPE_L	11 ± 3 (9, 13)	14 ± 3 (12, 15)*	< 0.001	1.00

HR_{av} = Average Heart Rate during fight, HR_{max} = Maximum Heart Rate, HR_{APM} = Age Predicted Maximum Heart Rate, RPE = Rating of Perceived Exertion, DE = Direct Elimination, ES = Effect Size, * significant difference to Poule ($p < 0.001$).

The participants spent 82.2 ± 14.0% and 76.4 ± 26.9% of the fight time above 80% HR_{max} for DE and Poule, respectively. There were no significant differences ($p > 0.05$, ES range = 0.05-0.33) shown between time spent in the different heart rate zones between Poule and DE fights (Figure 4.2).

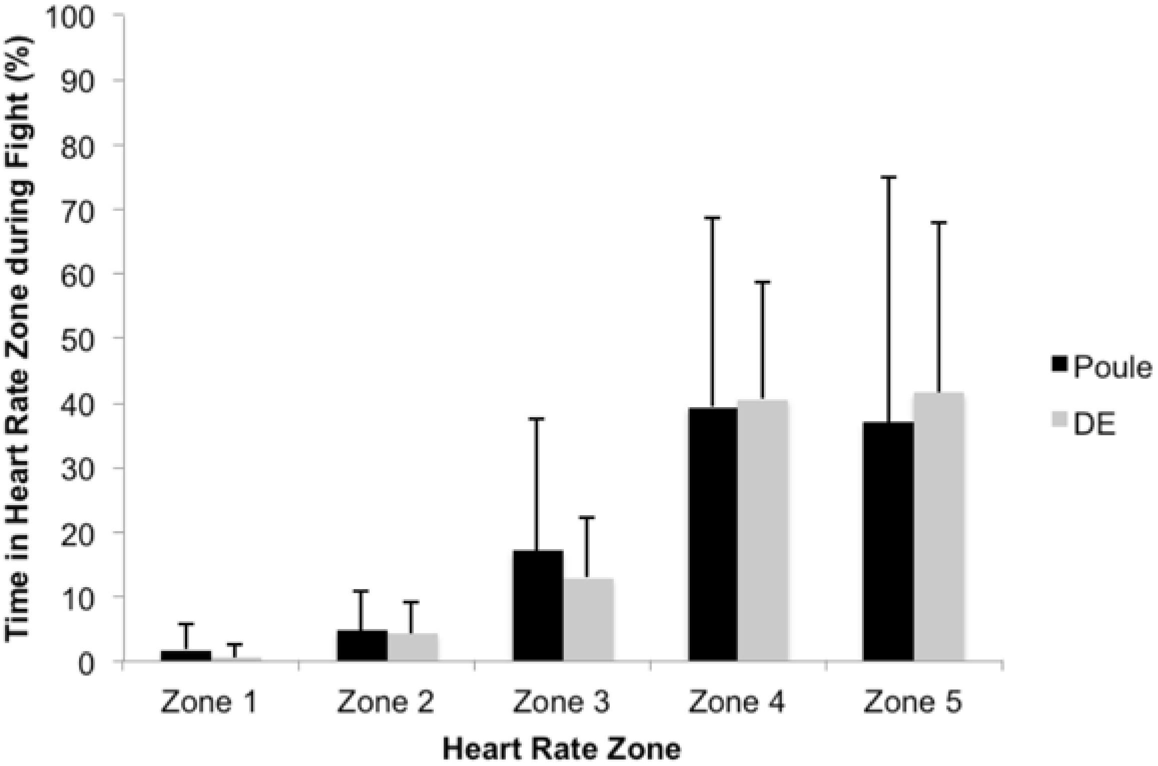


Figure 4.2. Time spent (%) in heart rate zones during Poule and DE fights (mean ± SD).

DE = Direct Elimination. Zone 1 = 50-59% HR_{APM}, zone 2 = 60-69% HR_{APM}, zone 3 = 70-79% HR_{APM}, zone 4 = 80-89% and HR_{APM}, zone 5 = 90-100% HR_{APM}.

There was a significant main effect for time for T_{gast} ($F_{(1,46)} = 73.8$, $p < 0.001$, $\eta^2 = 0.68$), revealing that T_{gast} increased from pre-fight to post-fight (37.65°C vs. 38.06°C, respectively). A significant main effect for fight type ($F_{(1,46)} = 32.97$, $p < 0.001$, $\eta^2 = 0.86$) was also observed between Poule and DE, whereby T_{gast} was greater in all DE compared to all Poule fights 38.11°C vs. 37.59°C, respectively. Although no significant interaction was observed between time and fight for T_{gast}, it did approach significance ($F_{(1,46)} = 3.978$, $p = 0.052$, $\eta^2 = 0.08$) with a tendency for a greater T_{gast} increase pre to post fight in DE compared to Poule fights (Figure 4.3) 0.49°C vs. 0.31°C average increase, respectively.

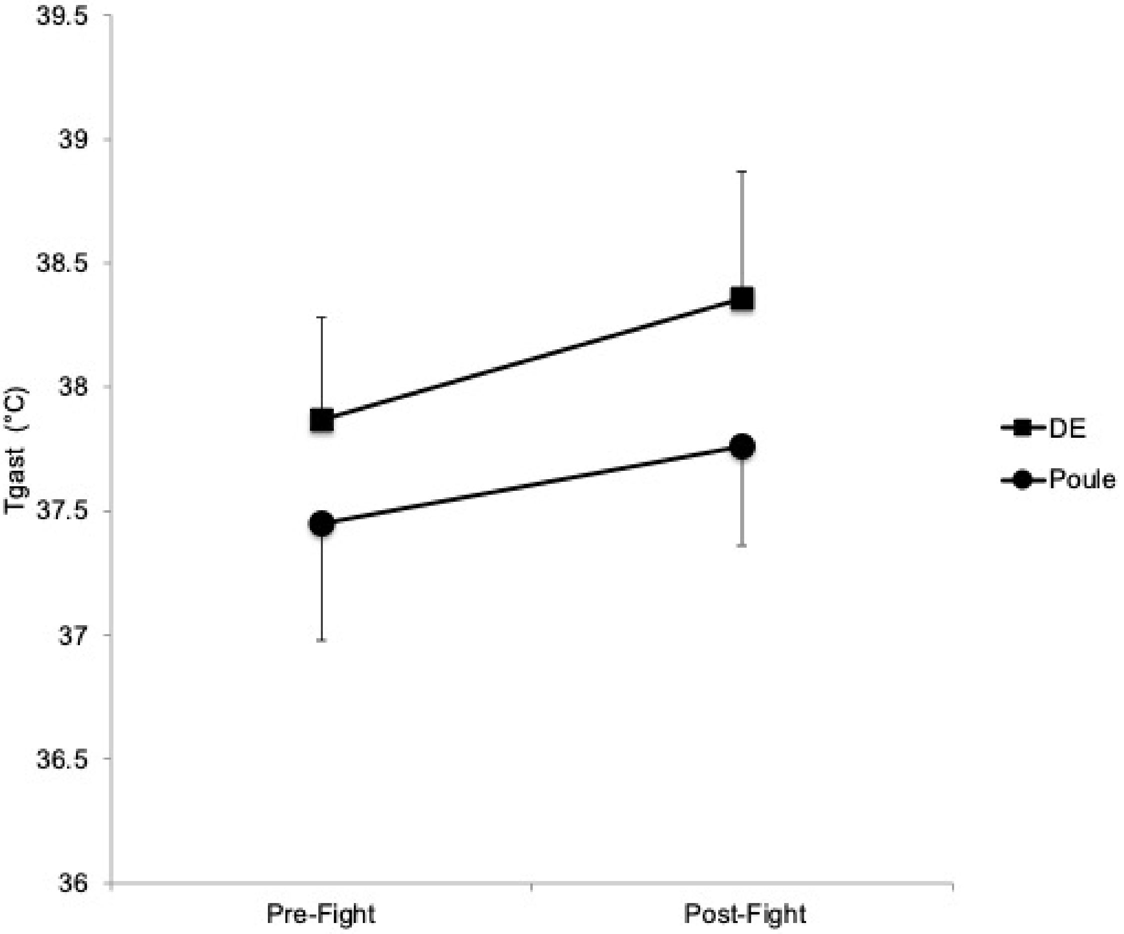


Figure 4.3. Gastrointestinal temperature (°C) response in Poule compared to DE (mean ± SD). Circles = Poule and Squares = DE.

T_{gast} = Gastrointestinal Temperature, DE = Direct Elimination.

A significant difference ($F_{(5,35)} = 6.9$, $p < 0.001$, $\eta^2 = 0.50$) was observed for blood lactate concentration responses during the competition. Post-hoc analysis showed that blood lactate concentration was greater in Poule 1 in comparison to Baseline ($p = 0.005$*),* Poule 7 ($p = 0.020$), DE 5 ($p = 0.038$) and DE7 ($p = 0.038$) as demonstrated by Figure 4.4. Thus, there was a decrease in blood lactate concentration as the competition progressed from Poule rounds to DE rounds from ~4.5mmol.L^{-1} (Poule 1) to ~2.0mmol.L^{-1} (DE 7).

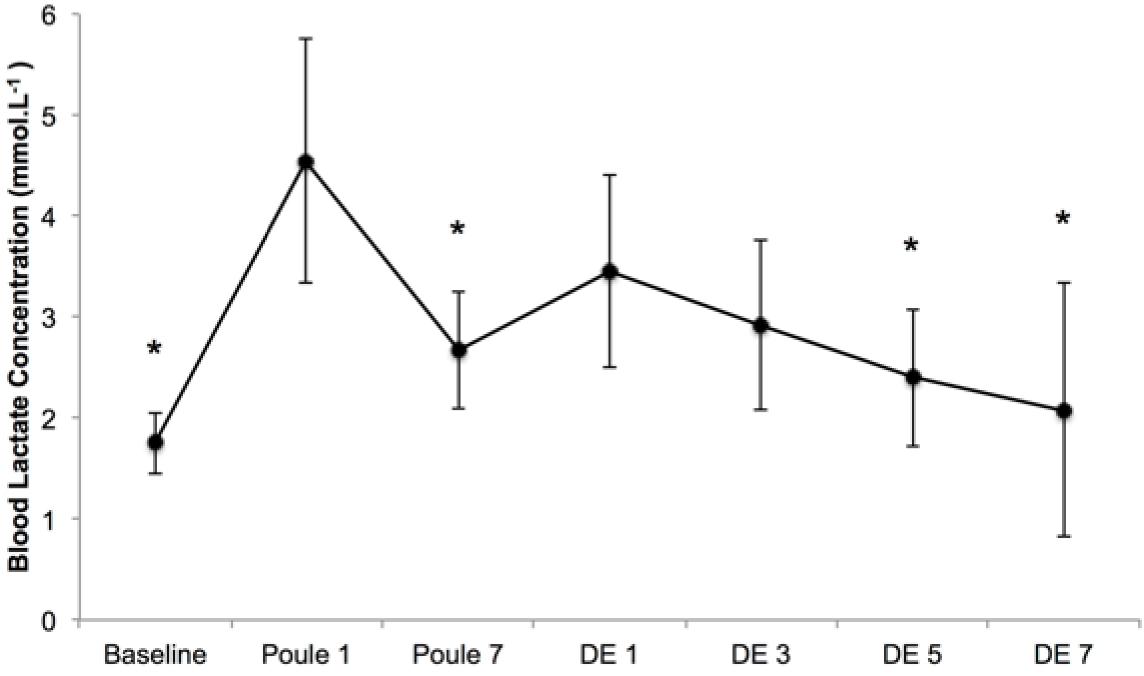


Figure 4.4. Blood lactate concentration (mmol.L^{-1}) during Epée fencing during Poule and DE fights (mean ± SD).

DE = Direct Elimination. * significant difference to Poule 1 ($p < 0.05$).

Mean $\dot{V}O_2$ was similar between Poule and DE fights (37.0 ± 4.5 ml.kg^{-1}.min^{-1} (34.3, 39.7) vs. 37.3 ± 6.4 ml.kg^{-1}.min^{-1} (33.4, 41.1); $t_{(12)} = -0.147$, $p = 0.885$, ES = 0.05). Maximum $\dot{V}O_2$ recorded was similar between Poule and DE fights (49.1 ± 6.1 ml.kg^{-1}.min^{-1} (45.5, 52.8) vs. 51.2 ± 9.3 ml.kg^{-1}.min^{-1} (45.6, 56.8); $t_{(12)} = -0.852$, $p = 0.411$, ES = 0.27). Furthermore, EE was also similar between Poule and DE fights (12.7 ± 1.7 kcal.min^{-1} (11.6, 13.7) vs. 12.8 ± 2.4 kcal.min^{-1} (11.3, 14.2); $t_{(12)} = -0.268$, $p = 0.793$, ES = 0.05). Average RER for Poule fights was 0.87 ± 0.07 and for DE fights was 0.91 ± 0.05.

4.4.2 Movement Data

Movement data is shown in Table 4.3. Average DE fight and effective fight duration was significantly greater than Poule fight duration ($t_{(27)} = -11.403$, $p < 0.001$) with a very large ES. Furthermore, participants covered 3 times as much distance in DE in contrast to Poule fights ($t_{(55)} = -16.446$, $p < 0.001$, ES = 2.81), however there was no significant difference between Poule and DE for distance covered per minute ($t_{(55)}$ = 1.874, p = 0.066, ES = -0.21). Participants achieved a greater peak speed in the DE when compared to the Poule ($t_{(55)}$ = -4.844, p < 0.001); however, average speed was lower in the DE when compared to the Poule fights ($t_{(55)}$ = 5.846, p < 0.001). Based on effect sizes differences in peak and average speed were both moderate. Training load ($t_{(7)}$ = -13.180, p < 0.001) and training load per minute ($t_{(55)}$ = -3.456, p = 0.001) were significantly greater in DE when compared to Poule fights with a very large and small difference determined, respectively. There were a significantly greater percentage of accelerations occurring in zone 2 ($t_{(55)}$ = -2.874, p = 0.006) which coincided with a significantly lower percentage of accelerations occurring within zone 1 ($t_{(55)}$ = 2.742, p = 0.008) between DE and Poule fights. There were no significant differences ($t_{(55)}$ = -0.145, p = 0.885) for percentage of accelerations in zone 3 between DE and Poule fights.

Table 4.3. Movement data of epée fencing for Poule and DE fights (mean ± SD (95%CI)).

Variable	Poule	DE	*P value*	ES
Fight Duration (min)	3:45 ± 1:44 (3:04, 4:26)	13:11 ± 3:15 (11:55, 14:26)*	< 0.001	3.62
Effective Fight Duration (min)	3:45 ± 1.44 (3:04, 4:26)	11:40 ± 2:45 (10:55, 12:23)	< 0.001	3.44
Distance Covered (m)	283 ± 93 (231, 335)	833 ± 261 (688, 977)*	< 0.001	2.81
Distance covered per minute ($m.min^{-1}$)	78 ± 15 (74, 82)	75 ± 13 (71, 78)	0.066	-0.21
Peak Speed ($m.s^{-1}$)	3.4 ± 0.7 (3.2, 3.6)	3.9 ± 0.8 (3.7, 4.2)*	< 0.001	0.67
Average Speed ($m.s^{-1}$)	1.3 ± 0.2 (1.2, 1.4)	1.1 ± 0.2 (1.1, 1.2)*	< 0.001	-1.00
Zone 1 Accelerations (%)	53.88 ± 9.29 (51.40, 56.37)	50.43 ± 8.80 (48.07, 52.78)*	0.008	-0.38
Zone 2 Accelerations (%)	41.90 ± 9.01 (39.49, 44.31)	45.29 ± 8.80 (42.93, 47.65)*	0.006	0.38

Zone 3 Accelerations (%)	4.21 ± 3.26 (3.34, 5.09)	4.28 ± 1.90 (3.78, 4.79)	0.885	0.03
Training Load (AU)	93 ± 30 (68, 119)	319 ± 54 (274, 364)*	< 0.001	5.17
Training Load per minute (AU.min^{-1})	3.5 ± 0.9 (3.2, 3.8)	3.9 ± 0.7 (3.7, 4.1)*	0.001	0.50

DE = Direct Elimination, * significant difference to Poule ($p < 0.05$)

4.5 Discussion

The aims of this study were to determine the physiological and movement demands of epée fencing during competition and compare how the physiological demands change between Poule and DE fights. Secondly, this is the first study to determine the movement demands of epée fencing using a tri-axial accelerometer-based system. This study showed DE fights were more physiologically demanding than Poule fights as reflected in the movement patterns. Despite similar distance covered per minute there was a greater peak speed, training load per minute, and shift from zone 1 to zone 2 accelerations in DE than Poule fights. This was in line with physiological and perceptual responses as there was also an greater HR_{max}, RPE_{O}, RPE_{A}, RPE_{L} and T_{gast} in DE than Poule fights. This study highlighted the importance of the alactic and aerobic energy systems due to relatively low blood lactate concentration recorded which decreased from Poule 1 to DE 7. The T_{gast} response may indicate the protective clothing creates a hot micro-climate due to T_{gast} >38.5°C in DE fights.

4.5.1 Physiological and Perceptual Demands

When compared to research by Bottoms et al. (2013), during simulated competition in male epée fencers, HR_{max} and HR_{av} were greater in this study in Poule fights (HR_{max}: 92.4% vs. 89.0% HR_{APM}, and HR_{av}: 86.3% vs. 79.4% HR_{APM}). During DE fights in this study HR_{av} was ~169 beats.min-1 (86.5% HR_{APM}) which is similar to HR_{av} recorded by Iglesias and Rodriguez (1995), in national level male epée fencers (~166 beats.min^{-1}) and Bottoms et al. (2011) in female epée fencers (87% HR_{APM}). However, HR_{av} was lower in research by Bottoms et al. (2013; 82% HR_{APM}). Maximum heart rate during DE fights in this study was shown to be greater (96.0% vs. 91.7% HR_{APM}) than those recorded previously (Bottoms et al., 2013). The higher heart rates exhibited in this study could be due to the non-competitive nature of simulated fights of the previous studies causing a decreased heart rate response. Therefore, it could be beneficial to compare the results in this study to an actual competition to see if similar heart rates are determined. Additionally, there could have been a decreased catecholamine release causing a lower HR response in the simulated fights compared to competition (Hoch et al., 1988). Furthermore, research has shown an increased sympatho-adrenal system activation, with an increase in cortisol, during competitive versus non-competitive performances in tennis and running (Fernandez-Fernandez et al., 2015; Viru et al., 2010).

The participants spent the majority of the fight within heart rate zones 4 and 5 for both Poule (76.4%) and DE (82.2%). The percentage of time spent above 80% HR_{APM} in this study was greater than those determined within international and national competition for elite male foil fencers in Poule (76.4% vs. 68.0%) and DE (82.2% vs. 74.0%) fights (Turner et al., 2017). This suggests epée is exhibiting a high cardiovascular strain and is producing a greater physiological demand than other fencing weapons (foil and sabre). This could also be due to longer work to rest ratio in epée when compared to the other weapons (Aquili et al., 2013).

Core temperature showed an increase from pre-fight to post-fight as well as between Poule and DE fights. There was a tendency for a greater increase in T_{gast} pre-fight to post-fight in the DE ($p = 0.052$) compared to the Poule (0.49°C vs. 0.31°C, respectively). Additionally, in DE fights 53% of T_{gast} recorded were above 38.5°C with some T_{gast} recordings greater than 39°C. Epée fencing despite being relative short in duration (~13 minutes for a DE fight) can contribute to potential cardiovascular and heat stress through a raised T_{gast}. This raised T_{gast} could be associated with the increased HR_{max} achieved during DE, as well as the increased time above 80% HR_{max}. The increased heat production could cause an increase in heart rate to distribute blood flow to the skin to dissipate heat from the core.

In addition to a greater increase in T_{gast}, participants had a mean starting T_{gast} ~0.42°C higher in the DE compared to the Poule. This could, therefore, indicate the participants struggled to reduce T_{gast} to baseline levels between fights. The added influence of protective equipment and layers worn by the fencers could impact upon their ability to dissipate heat effectively, especially evaporative heat loss mechanisms (Gavin, 2003; Pascoe, Shanley, et al., 1994). Similar core temperature responses have been reported in other protective clothing sports such as American Football (Armstrong et al., 2010), ice hockey (Batchelder et al., 2010; Driscoll et al., 2020), and motor racing (Barthel et al., 2020; Carlson et al., 2014). Further research is needed to assess the thermoregulatory demands of fencing and if there is an impact on performance as seen in other sports with protective clothing. Furthermore, the use of helmets within certain sports reduces a vital surface area for heat dissipation: the head (Pascoe, Bellingar, et al., 1994). The head has been shown to provide significant heat loss during exercise, with heat loss increasing as workload and ambient temperature increase (Rasch et al., 1991). Skin temperature and mask temperature should be examined, in addition to T_{gast}, to determine if this impacts upon thermoregulation during fencing and if there is a hot micro-climate due to the protective clothing.

Ratings of perceived exertion were greater in the DE when compared to the Poule fights for RPE overall (15 vs. 11), arms (12 vs. 10), and legs (13 vs. 11), with larger increases in RPE_O than RPE_A and RPE_L. Thereby showing an increased perceptual strain as the competition progressed into DE fights. Bottoms et al. (2013), during simulated fencing performance in male fencers (n = 7), showed a similar trend with RPE being significantly greater for RPE_O (13 vs. 11), RPE_A (12 vs. 10), and RPE_L (13 vs. 10) for DE fights in comparison to Poule fights. The increased perceptual strain as the competition progresses from Poule to DE could be linked to the increased cardiovascular strain as highlighted in this study by a greater HR_{max}, T_{gast}, and percentage of time spent above 80% HR_{max} (82% vs. 76%). Increased mental fatigue as the competition progressed into later DE could also cause an increase in RPE which has been previously shown in cycling (Marcora & Staiano, 2010; Marcora et al., 2009).

Blood lactate concentration in this study tended to show a decrease from Poule 1 to DE 7. Blood lactate concentration peaked after Poule 1 (~4.54 $mmol.L^{-1}$), with lower blood lactate concentration after Poule 7 (~2.67 $mmol.L^{-1}$). Furthermore, blood lactate concentration was lower in DE 5 (~2.40 $mmol.L^{-1}$) and DE 7 (~2.08 $mmol.L^{-1}$) when compared to Poule 1. Similar blood lactate concentrations have been reported in fencing (Bottoms et al., 2011; Iglesias & Rodríguez, 1995). Iglesias and Rodriguez

(1995) recorded mean blood lactate concentration during international epée competition in national level male fencers to be ~3.7 mmol.L^{-1}; and Bottoms et al. (2011) during simulated epée DE fights determined blood lactate concentration to be ~2.8 mmol.L^{-1} within female national level fencers. This is the first study within epée showing blood lactate concentration changes over a competition. The results from this study and previous research highlights the importance of the alactic energy systems during fencing (Bottoms et al., 2011; Turner et al., 2014). Furthermore, peak speed in this study was greater but average speed was lower in DE than Poule which may indicate evidence of alactic ATP resynthesis for high intensity movements. However, it cannot be ignored that fencers could also be heavily reliant on energy to being derived from aerobic sources as a competition progresses from Poule to DE (Bottoms et al., 2011). This could be explained by the lower blood lactate concentration, greater peak speeds, and lower average speeds determined in the DE fights. It is evident that repeated numbers of high intensity actions during repeated cycling exercise causes an increase in energy to be supplied from aerobic sources especially if there is insufficient recovery time (Bogdanis, Nevill, Boobis, & Lakomy, 1996; Gaitanos, Williams, Boobis, & Brooks, 1993). Therefore, fencers may benefit from improving aerobic fitness to replenish PCr stores and to provide energy in latter stages of a competition. Previous research has determined VO$_{2max}$ in men's epée to be ~50-60 ml.kg^{-1}.min^{-1} (Roi & Bianchedi, 2008).

Maximum and mean oxygen consumption recorded during the competition was similar between the Poule and DE fights (maximum: 49.1 vs. 51.2 ml.kg^{-1}.min^{-1}, mean: 37.0 vs. 37.3 ml.kg^{-1}.min^{-1} Poule vs. DE, respectively). Comparable $\dot{V}O_2$ responses (~54 ml.kg^{-1}.min^{-1}) have been reported in the literature (Bottoms et al., 2011; Iglesias & Rodríguez, 1999). Mean $\dot{V}O_2$ values recorded in female epée athletes by Bottoms et al. (2011) were shown to be ~35 ml.kg^{-1}.min^{-1} (~75% $\dot{V}O_{2peak}$). Overall results from the current study and previous studies suggest that fencers must possess a high level of aerobic fitness to deal with the demands of competition.

Within the current study EE was shown to be ~12.7 kcal.min^{-1} and ~12.8 kcal.min^{-1} for Poule and DE fights, respectively, which is similar to those previously reported of ~12.0 kcal.min^{-1} in national level female and male fencers (Bottoms et al., 2011; Iglesias & Rodríguez, 1999). Determining the energy cost of fencing is important, as despite being relatively short, high EE values are apparent. Using EE values obtained in this study and the average fight times for Poule and DE it could be estimated that average EE of reaching the final of a competition could be ~1500 kcal.min^{-1} (not considering energy expended during rest periods between fights). The RER results indicated fencers were predominately reliant on carbohydrate during Poule and DE fights with ~230g of carbohydrates used across 7 Poule and 7 DE fights calculated using non-protein RER reference tables (McArdle, Katch, & Katch, 2006, p. 192). Therefore, it could be important to ensure adequate carbohydrate intake for fencing athletes to meet the energy requirements of performance due to the long nature of the whole fencing competition.

4.5.2 Movement Data

The mean distance covered during Poule and DE during this study was ~280m and ~830m which is similar to that reported previously in the fencing literature (Roi & Bianchedi, 2008). However, there was a wide range of distance covered with participants covering 120-670m and 435-1652m in Poule and DE fights, respectively. There were no significant differences between Poule and DE fights for distance covered per minute. However, there were relatively large standard deviations evident. This shows the varying nature of epée fencing performance whereby the demand placed upon the body could be largely determined by the individual fight i.e., attacking vs. defensive opponent. Within Poule fights the predominate energy system could be determined by distance covered with greater reliance on anaerobic glycolysis with greater distance covered as shown by Figure 4.5A. However, there was no relationship for DE fights between blood lactate concentration and distance covered possibly due to longer fight durations and an increased reliance on aerobic energy as shown by Figure 4.4 and Figure 4.5B.

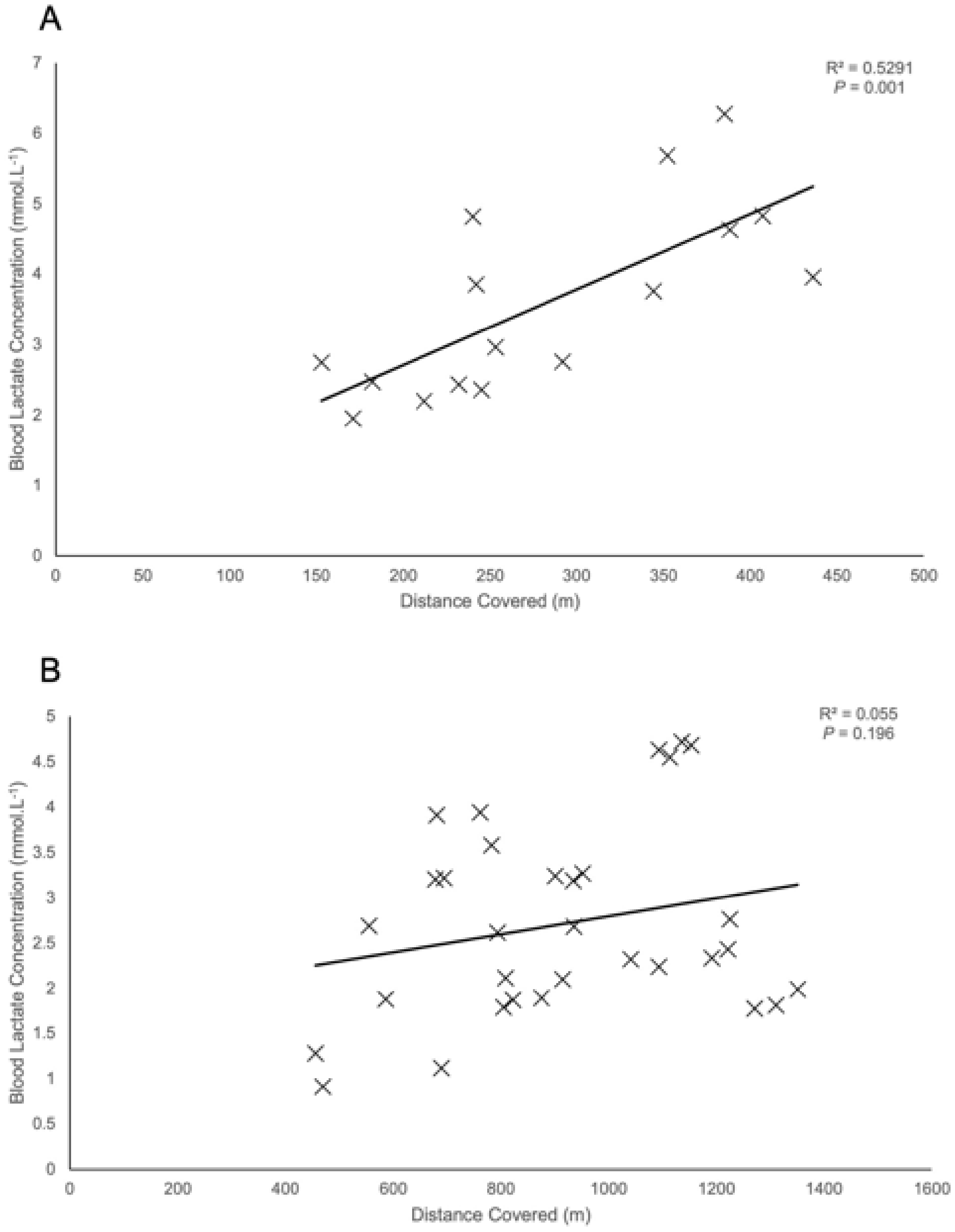


Figure 4.5. Relationship between distance covered (m) and blood lactate concentration (mmol.L^{-1}) for Poule (A) and DE (B) fights.

There were no significant differences for accelerations in zone 3 between DE and Poule fights. However, there was a greater percentage of accelerations occurring in zone 2 with a lower percentage of accelerations in zone 1 during DE fights in comparison to Poule fights. There was also a greater peak speed achieved in the DE than Poule fights. This could indicate a tactical shift within the DE fights whereby the fencers are initiating more high intensity attacks (through more lunge (chapter 2.1 Figure 2.1) or fleche (chapter 2.1 Figure 2.2) attacks) to score points, especially when losing a fight. Furthermore, there were higher training loads per minute determined for

DE than Poule fights. The greater percentage of zone 2 accelerations, peak speed, and training load per minute could have caused the greater physiological demand in DE fights than Poule fights as shown through greater T_{gast}, HR_{max}, and time spent above 80% HR_{max}. Understanding the movement demands (lunge and fleche movements) of epée can ensure coaches and athletes maximise their training and recovery to be prepared for competition. Practitioners and coaches should attempt to achieve similar total acceleration numbers in zones 1, 2 and 3 in training that are exhibited during competition to mirror the demands of competition.

4.5.3 Conclusions

This study showed that there is an increased physiological strain observed as an epée competition progresses from Poule to DE rounds. This is exhibited through increased HR_{max}, greater RPE_{O}, RPE_{A}, RPE_{L} and a tendency for a greater increase in T_{gast} in the DE compared to the Poule, as a result of increases in movement data (peak speed, zone 2 accelerations and training load per minute) and fight duration. Additionally, participants spent ~80% of a fight above 80% HR_{APM}. There seems to be an increasing demand on the alactic and aerobic energy system as a competition progresses as blood lactate concentration decreased from Poule 1 to DE 7, despite increased intensity of movements as shown by greater peak speeds achieved and a shift in zone 1 to zone 2 accelerations in DE fights. This study also suggests the protective clothing likely creates a hot micro-climate and increased cardiovascular and heat stress through T_{gast} >38.5°C in DE fights, however the full thermoregulatory demand of fencing and impact of the protective clothing are not known and need to be investigated. Therefore, skin temperature, mask temperature and perceptions of heat should be determined during fencing. Energy expended during the competition was also shown to be high, with a predominance of carbohydrate used as a fuel, highlighting the importance of ensuring appropriate carbohydrate intake to meet the energy requirements of competition. This is the first study to assess movement data of epée fencing using a tri-axial accelerometer athlete tracking system to quantify the movement demands of epée (distance covered, training load, speed of movement and accelerations) and how these impact on the increased cardiovascular strain of DE fights compared to Poule fights. More research should be conducted on the demands of fencing competition to confirm the results of this study.

This chapter presented the physiological responses to epée fencing, as highlighted above with T_{gast} >38.5°C in DE fights the full thermoregulatory demands of epée need to be investigated and this will be the focus of chapter 5.

Chapter 5

5 Study 2 – Thermoregulatory Demands of Epée Fencing During Competition

This chapter has also been presented in a slightly modified format at *BASES Conference 2019:* Oates, L., Campbell, I., Price, M., Bottoms, L. (2019). Thermoregulatory demands of epée fencing performance during competition. *Journal of Sports Sciences,* 37 (sup1), 54, (https://doi.org/10.1080/02640414.2019.1671688)

5.1 Abstract

Fencing athletes are required to wear full body protective clothing when competing. This could cause cardiovascular strain particularly as a competition progresses into DE rounds. Therefore, the aim of this study was to determine the thermoregulatory responses of epée fencing across different phases of competition (Poule and DE). Seven well-trained epée fencers competed in a simulated competition comprising of seven Poule and seven DE fights. Gastrointestinal temperature, T_{skin}, T_{mask}, core to skin temperature gradient, HR, thermal sensation, differentiated RPE, and movement data were collected for all fights. There was a moderate thermoregulatory demand during Poule rounds shown by post fight T_{gast} (~38.0°C), T_{skin} (~34.5°C), and thermal sensation ratings. There was a greater thermoregulatory demand during DE rounds shown by T_{gast} (>38.0°C pre and >38.5°C post fight), T_{skin} >35.0°C, narrow core to skin temperature gradients, thermal sensation ratings (~7.0), increases in T_{mask} across DE rounds (~1.1°C), and RPE. There was a significant ($p < 0.001$) increase in T_{skin} in both Poule and DE during the recovery between fights. Furthermore, there was a potential performance impact through significantly ($p < 0.05$) decreased distance covered and distance covered per minute from DE 1 to DE 7 possibly due to thermoregulatory demands of epée. This is the first study showing the thermoregulatory responses of epée fencing with high T_{skin}, RPE and thermal sensation recorded. High T_{mask} and T_{skin} could indicate a hot micro-climate due to the protective clothing. Finally, increased T_{skin} during recovery between fights highlights fencers may benefit from cooling, particularly DE rounds.

5.2 Introduction

As discussed in chapter 2.4 fencing athletes are required to wear extensive whole-body protective equipment when competing, which could create a hot micro-climate. The whole-body protective equipment could increase body temperature, cardiovascular strain and negatively impact fencing performance. There has been no previous research reporting the thermoregulatory demands of fencing. In chapter 4 it was shown epée fencers T_{gast} reach ~38.5°C during DE fights with some athletes reaching a T_{gast} >39°C. As discussed in chapter 2.5 research in other sports, with protective clothing requirements, has suggested that protective layers worn by athletes can hinder performance due to increased cardiovascular strain and increased chances of heat stress occurring through rises in T_{core} and T_{skin} and an inability to dissipate heat from the body. Furthermore, the fencing mask may also cause an increase in face temperature which has been shown to negatively influence thermal sensation and comfort (Flouris & Schlader, 2015; Schlader et al., 2011) and, therefore, could impact performance through changes in behaviour due to feeling hot. The fencing mask could also impede a vital source of heat loss from the head (Rasch et al., 1991). Therefore, fencing clothing may pose challenges to heat loss from the body and perception of heat. This is especially the case during longer and high pressure DE fights, as observed in other sports with thick protective clothing such as American football, and motor sport (Armstrong et al., 2010; Brearley & Finn, 2007; Carlson et al., 2014; Davis et al., 2016).

It has also been proposed that hot skin temperatures (>35°C) impairs aerobic performance due to an increase in skin blood flow requirements (Cheuvront et al., 2010; Sawka et al., 2012; Tatterson, Hahn, Martin, & Febbraio, 2000), and thus producing a reduced thermal gradient between core and skin temperature (Sawka et al., 2012). This increased skin blood flow causes an increase in heart rate to maintain cardiac output due to reduced cardiac filling (Sawka et al., 2012). There is also an association between hot skin and reductions in cerebral blood flow and therefore cerebral oxygen delivery (Nybo, Møller, Volianitis, Nielsen, & Secher, 2002; Nybo & Nielsen, 2001; Rasmussen et al., 2010). However, skin temperature has not been reported in fencing during or between fights. Although fencers have short recovery times between fights (minimum 10 minutes in DE fights), it has been previously shown that it can take up to 90 minutes for body temperature to return to baseline post exercise (Kenny & McGinn, 2017). Therefore, if fencers do not remove protective clothing between fights this may further impede heat loss in the recovery period resulting in increased body temperature which could accumulate with subsequent fights and negatively impact performance.

An increase in skin and core temperature has also been shown to decrease skill based performance (Sunderland & Nevill, 2005) and cognitive performance (Hancock & Vasmatzidis, 2003; Simmons et al., 2008). It has been proposed by Hancock and Vasmatzidis (2003) that tasks with higher cognitive complexity are impacted to a greater extent by heat stress. During fencing athletes must perform multiple complex tasks to win points for example reacting to opponent’s movements, sword movements and attacks, decision making when to attack or defend whilst maintaining appropriate distance between their opponent to not be exposed, all whilst wearing a protective mask that can impede field of view.

The added influence of dehydration through high sweat rates when exercising in the heat or wearing protective clothing adds further cardiovascular stress through decreases in blood volume, cardiac output and stroke volume, increased heat storage and heart rate (González-Alonso, Crandall, & Johnson, 2008; González-Alonso, Mora-Rodriguez, & Coyle, 2000; González-Alonso et al., 1999). Previous research by Bottoms et al. (2013) reported sweat losses of ~3 litres during a simulated epée competition (~4% body mass). It has been previously reported than >2% body mass could cause decreases in cognitive, technical, and physical performance (L. B. Baker, Dougherty, Chow, & Kenney, 2007; Cheuvront & Kenefick, 2014; Nuccio, Barnes, Carter, & Baker, 2017). Therefore, sweat losses during epée could contribute to such decreases in performance.

The aims of this chapter were to investigate the thermoregulatory demands of epée fencing during competition, across Poule and DE rounds. The DE accounts for a large component of a competition (especially if an athlete reaches the final) and is performed with a minimum resting period of 10 minutes between fights, therefore, it is important to determine whether there are any differences in thermoregulatory, cardiovascular, and perceptual responses between DE fights as fencers’ fatigue.

5.3 Methods

5.3.1 Participants

Seven male well-trained epée fencers volunteered to take part in this study. All fencers competed at a club or international level (ranked within the top 65 in the United Kingdom at the time of testing), had previous epée training history and trained regularly in epée. This represented a typical fencing cohort at a national competition (Table 5.1).

Table 5.1. Participant Characteristics (mean ± 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

5.3.2 Procedures

Participants competed in a fencing competition as described in chapter 3.5 with 7 Poule and 7 DE fights in a round-robin style with the Poule seeding the DE fights. 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.

Preliminary questionnaires, body mass and stature were recorded as described in chapters 3.2 and 3.3. Body mass was recorded pre and post both Poule and DE to assess sweat loss. Participants were instructed to towel dry before body mass measurements and wear minimal clothing.

Environmental conditions were recorded as described in chapter 3.4. Throughout the competition average WBGT was 21.5 ± 1.3°C, and humidity was 49.8 ± 4.7%.

During the competition various measurements were taken pre, during and post each Poule and DE fight (Figure 5.1).

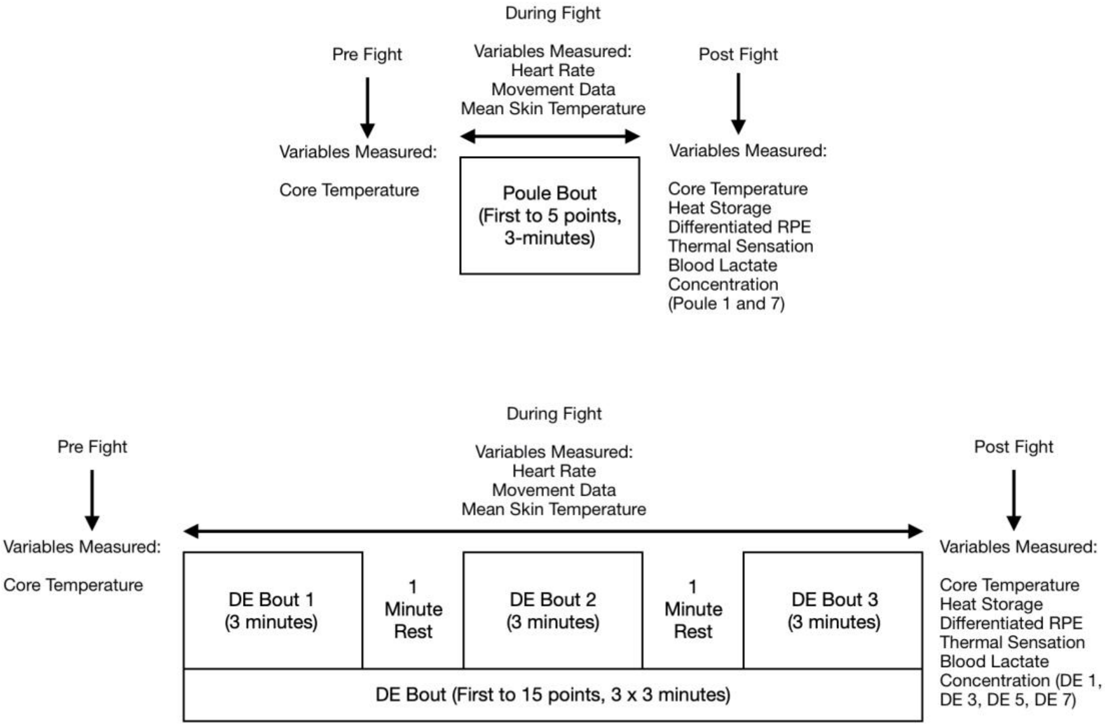


Figure 5.1. Variable measurement pre, during, and post fight for each Poule and DE fight during the simulated competition.

5.3.3 Gastrointestinal Temperature Measurements

Gastrointestinal temperature was measured as described in chapter 3.7.1. One of the participants had a contraindication (gastrointestinal disorder) to the CorTemp pills so had T_{au} measured as described in chapter 3.7.2. During the competition T_{gast} (°C) was measured pre and post each Poule and DE fight. Difference between T_{gast} pre and post fight was calculated for all Poule and DE fights.

5.3.4 Skin Temperature Measurements

Skin temperatures were measured and T_{skin} calculated as described in chapter 3.8. Mean skin temperature was calculated for the following time points Poule: first and last minute, of each fight, average for each fight, and 5th minute of recovery between fights; DE: first and last minute of each fight, average for each fight, 5th minute of recovery and 10th minute of recovery between fights.

5.3.5 Mask Temperature Measurements

Fencing mask temperature (T_{mask}) was determined by placing an iButton thermochron (as described in chapter 3.8) inside the top of the mask so it did not disturb the vision of the participants. The iButton was programmed as described in chapter 3.8. Mask temperature was measured during the first minute, last minute and average for all Poule and DE fights. The change in T_{mask} for each Poule and DE fight was calculated by subtracting the first minute temperature from the last minute temperature in each fight.

5.3.6 Heat Storage

Heat storage was calculated for each Poule and DE fight using the following equation (Havenith, Inoue, Luttikholt, & Kenney, 1995):

Heat Storage ($J.g^{-1}$) = $(0.8.\Delta\ T_{gast} + 0.2.\Delta\ T_{skin}).C_b$

Where C_b is the specific heat of body tissues (= 3.49 $J.g^{-1}.°C^{-1}$).

5.3.7 Core to Skin Temperature Gradient

Core to skin temperature gradient was calculated by subtracting T_{skin} during the last minute of the fight from post fight T_{gast} for all Poule and DE fights.

5.3.8 Heart Rate Monitoring and Movement Data

Heart rate and movement data were recorded as described in chapter 3.9. Both absolute heart rate ($beats.min^{-1}$) and relative heart rate (% HR_{APM}) average heart rate (HR_{av}), and maximum heart rate (HR_{max}) were recorded for all Poule and DE fights. Distance covered (m), and distance covered per minute ($m.min^{-1}$) during each Poule and DE fight were recorded.

5.3.9 Training Load

Training load (AU) and training load per minute (AU.min^{-1}) were determined as described in chapter 3.10.

5.3.10 Work to Rest Ratio

Work to rest ratio was determined for all Poule and DE fights as described in chapter 3.11.

5.3.11 Blood Lactate Concentration

Capillary blood samples for blood lactate concentration determination were collected and analysed as described in chapter 3.6.1. Capillary blood samples were collected at baseline, post Poule 1, post Poule 7, post DE after every other round i.e., DE 1, DE 3, DE 5, and DE 7 (Figure 5.1). Capillary blood samples at baseline were collected after a minimum of 10 minutes rest. Post fight capillary blood samples were collected within 3 minutes of the fight terminating.

5.3.12 Blood Glucose Concentration

Capillary blood samples for blood glucose concentration determination were collected as described in chapter 3.6.1. Blood glucose concentration was then measured in duplicate using the Biosen C-Line lactate analyser which was calibrated following manufacturer instructions using 12.0 mmol.L^{-1} calibration standard (Biosen C-Line, Ekf Diagnostics, Cardiff, UK). Capillary blood samples were collected at baseline, post Poule 1, post Poule 7, post DE after every other round i.e., DE 1, DE 3, DE 5, and DE 7. Capillary blood samples at baseline were collected after a minimum of 10 minutes rest. Post fight capillary blood samples were collected within 3 minutes of the fight finishing.

5.3.13 Ratings of Perceived Exertion

Differentiated ratings of perceived exertion were recorded as described in chapter 3.12. Differentiated RPE was collected immediately post fight for all Poule and DE fights (Figure 5.1).

5.3.14 Thermal Sensation

Thermal sensation was recorded as described in chapter 3.13. Thermal sensation was recorded immediately post fight for all Poule and DE fights (Figure 5.1).

5.3.15 Statistical Analysis

Data are presented and analysed as described in chapter 3.14. Paired-Students t-test analysis was undertaken to compare pre T_{gast} in Poule 1 and DE 1 to determine if participants T_{gast} had returned to baseline levels and whether DE performance was not impacted by heat production in the Poule rounds. There was no significant differences in T_{gast} between pre Poule round 1 and Pre DE round 1 (37.63 ± 0.40°C vs. 37.65 ± 0.23°C; $t_{(6)} = 0.134$, $p = 0.897$, ES = 0.06), therefore, the Poule and DE were analysed separately. Paired-Students t-test analysis was also carried out to compare blood lactate and blood glucose concentrations between Poule 1 and Poule 7.

To determine changes across the seven Poule and seven DE rounds during the competition a two-way repeated measures ANOVA (round x time) was performed to compare T_{gast} and T_{skin} over Poule and DE rounds. To investigate significant interactions, one-way repeated measures ANOVA post hoc tests were performed, with Bonferroni correction applied, to test within group differences for round ($0.05 / 7 = p \leq 0.007$) and time ($0.05 / 3 = p \leq 0.017$).

To determine changes across the seven Poule and seven DE rounds during the competition one-way repeated measures ANOVA tests were performed to compare T_{mask}, core to skin temperature gradient, thermal sensation, heat storage, HR_{av}, HR_{max}, distance covered, distance covered per minute, training load per minute, fight duration, work to rest ratio, RPE_{O}, RPE_{A}, and RPE_{L}.

To determine the T_{skin} response during a fight and into recovery between fights. A one-way repeated measures ANOVA was also conducted to compare T_{skin} responses during the first and last minute of Poule and DE fights, and recovery between fights (Poule: 5th minute of recovery; DE: 5th minute and 10th minute of recovery).

Effect sizes were calculated as described in chapter 3.14.

Pearson’s correlation coefficients were determined to examine relationships between distance covered and thermal sensation, T_{gast}, T_{gast} change, core to skin temperature gradient, heat storage, and T_{skin}, and interpreted as described in chapter 3.14.

5.4 Results

5.4.1 Body Mass

There was no significant difference between body mass pre Poule and post Poule (81.4 ± 13.2kg vs. 81.2 ± 13.4kg; $t_{(6)}$ = 1.278, *p* = 0.248, ES = 0.02). There was a significantly lower body mass post DE 7 than pre DE 1 (81.0 ± 13.3kg vs. 81.5 ± 13.2kg; $t_{(6)}$ = 3.368, *p* = 0.015, ES = 0.04).

5.4.2 Poule

5.4.2.1 Thermoregulatory Responses during Poule Rounds

Gastrointestinal temperature responses to Poule fights are shown in Figure 5.2. There was no significant interaction for T_{gast} during the Poule rounds ($F_{(2.034,12.205)} = 1.095$, $p = 0.366$, $\eta^2 = 0.154$). There was a significant main effect for time for T_{gast} ($F_{(1,6)} = 8.064$, $p = 0.030$, $\eta^2 = 0.573$) with an average rise pre to post fight for T_{gast} ~0.28°C. There was no significant main effect for round for T_{gast} ($F_{(1.641,9.845)} = 2.138$, $p = 0.173$, $\eta^2 = 0.263$). However, towards the end (post P5 onwards) of the Poule rounds T_{gast} remained above 38.0°C both pre and post fight.

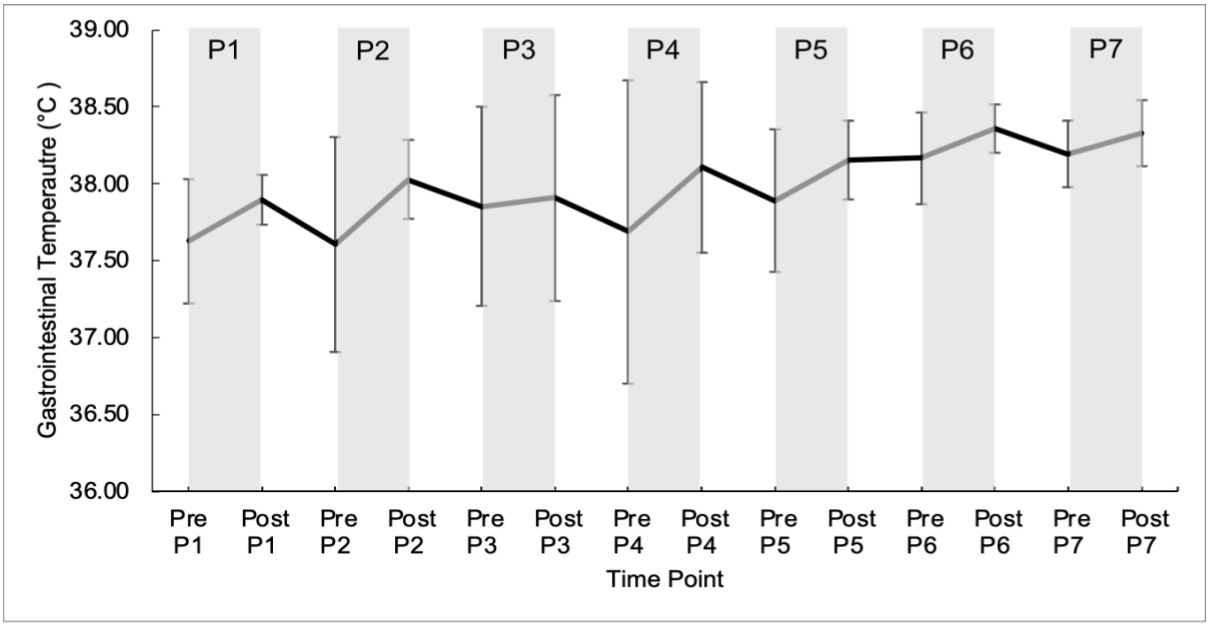


Figure 5.2. Gastrointestinal temperature (°C) across Poule rounds (mean ± SD).

P = Poule.

Figure 5.3 shows the T_{skin} response across the Poule rounds. There was a significant interaction determined for T_{skin} during Poule rounds ($F_{(6,36)} = 2.463$, $p = 0.042$, $\eta^2 = 0.291$). Post-hoc analysis, using the Bonferroni correction ($p < 0.007$), indicated average T_{skin} during the fight increased to the 5th minute of recovery for P1 ($p = 0.003$), P2 ($p = 0.001$), and P5 ($p = 0.005$). There was also a tendency for a greater T_{skin} in the 5th minute of recovery compared to the average T_{skin} during the fight for P3 ($p = 0.008$), P6 ($p = 0.021$), and P7 ($p = 0.038$). There was a significant main effect for time ($F_{(1,6)} = 60.825$, $p < 0.001$, $\eta^2 = 0.910$) determined with an average increase in T_{skin} at the 5th minute of recovery than average T_{skin} during the fight ~0.43°C. There was no significant main effect for round ($F_{(6,36)} = 1.084$, $p = 0.390$, $\eta^2 = 0.153$) for T_{skin} during Poule rounds. Figure 5.4 shows the T_{skin} response during the first minute of a Poule fight, last minute of a Poule fight and 5th minute of recovery between Poule fights. There was a significant difference of T_{skin} over time during a Poule fight and into recovery between fights ($F_{(2,96)} = 46.346$, $p < 0.001$, $\eta^2 = 0.491$). Post-hoc analysis showed there was a significantly greater T_{skin} in the first minute of the fight than the last minute of the fight ($p < 0.001$). There was also a greater T_{skin} in the 5th minute of recovery than in the last minute of the fight ($p < 0.001$). Furthermore, T_{skin} was greater in the 5th minute of recovery than in the first minute of the fight ($p < 0.001$).

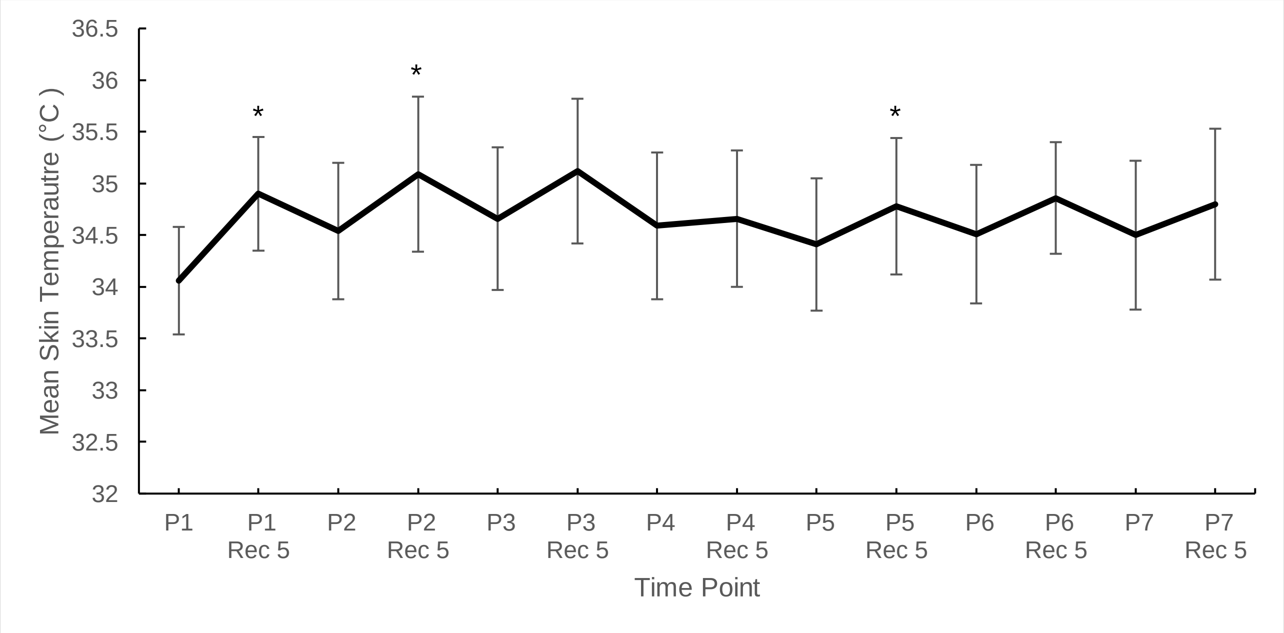


Figure 5.3. Mean skin temperature (°C) response during the Poule rounds (mean ± SD)

P = Poule, Rec 5 = 5th minute of recovery between fights. * significant difference to average fight T_{skin} ($p < 0.007$ Bonferroni correction)

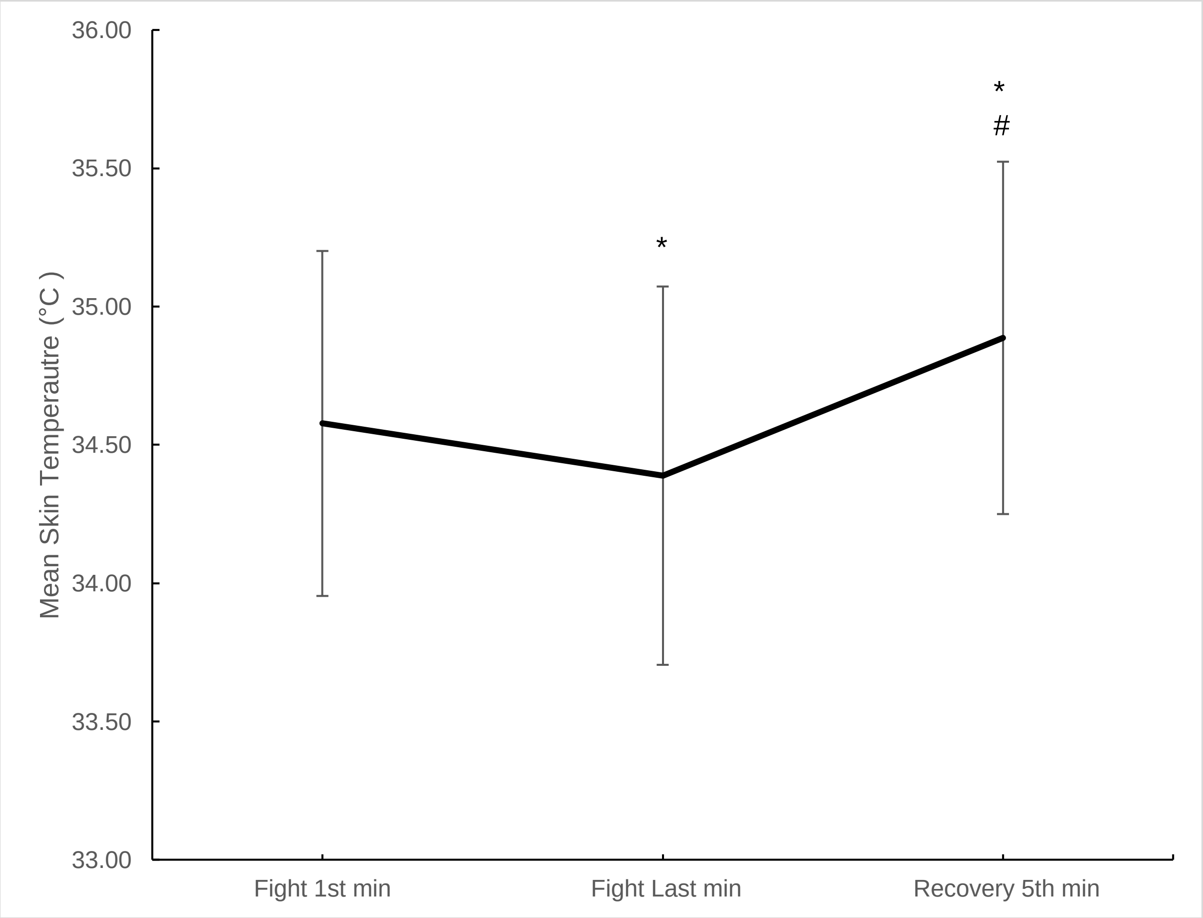


Figure 5.4. Mean skin temperature (°C) responses during first and last minute of the Poule fights and 5th minute of recovery between fights (mean ± SD).

* Significant difference to fight 1st minute ($p < 0.001$), # significant difference to fight last minute ($p < 0.001$).

There was a significance difference determined for average fight T_{mask} during the Poule rounds ($F_{(6,26)} = 19.714$, $p < 0.001$, $\eta^2 = 0.767$) as shown in Figure 5.5. Post-hoc analysis revealed average fight T_{mask} was greater in P5, P6 and P7 than P1 ($p = 0.013$, $p = 0.011$, $p = 0.022$, respectively). There was a greater average fight T_{mask} recorded in P5, P6 and P7 than P2 ($p = 0.033$, $p = 0.008$, $p = 0.014$, respectively). Furthermore, average fight T_{mask} was greater in P6 and P7 than P3 ($p = 0.009$, $p = 0.009$).

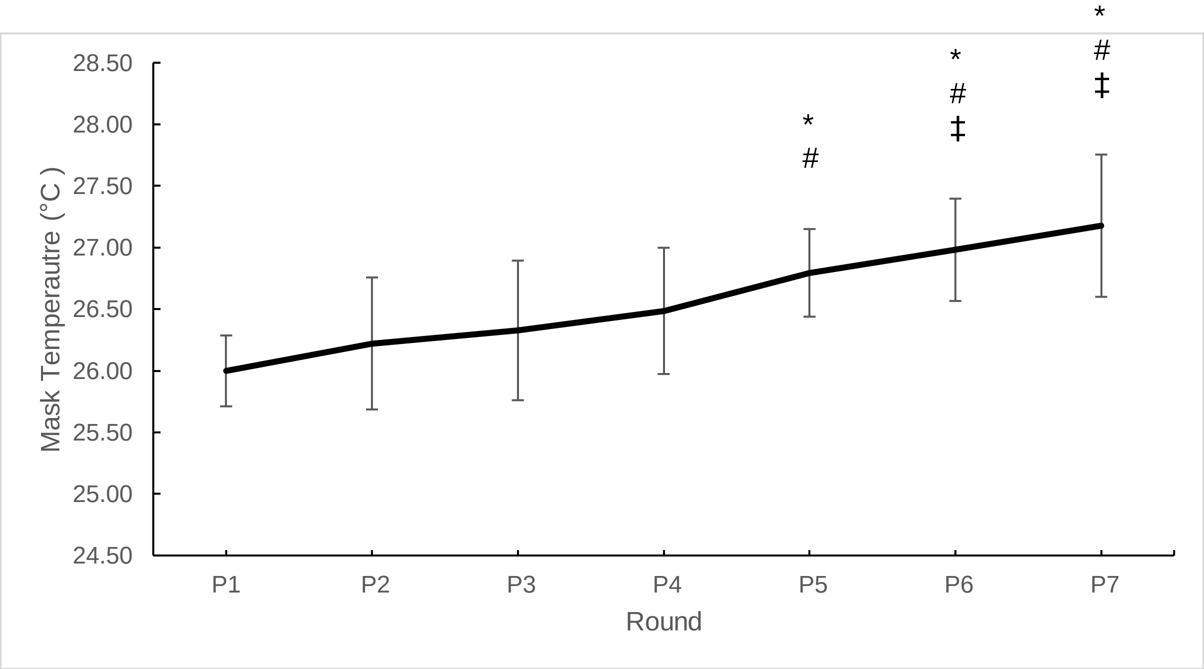


Figure 5.5. Mask temperature (°C) during the Poule rounds (mean ± SD).

P = Poule. * significant difference to P1 ($p < 0.05$), # significant difference to P2 ($p < 0.05$), ‡ significant difference to P3 ($p < 0.05$).

There was a significant difference determined across Poule rounds for change in T_{mask} from the first minute of the fight to the last minute of the fight ($F_{(6,36)} = 2.992$, $p = 0.018$, $\eta^2 = 0.333$, Figure 5.6). However, post-hoc analysis could not reveal where the greatest change in T_{mask} occurred.

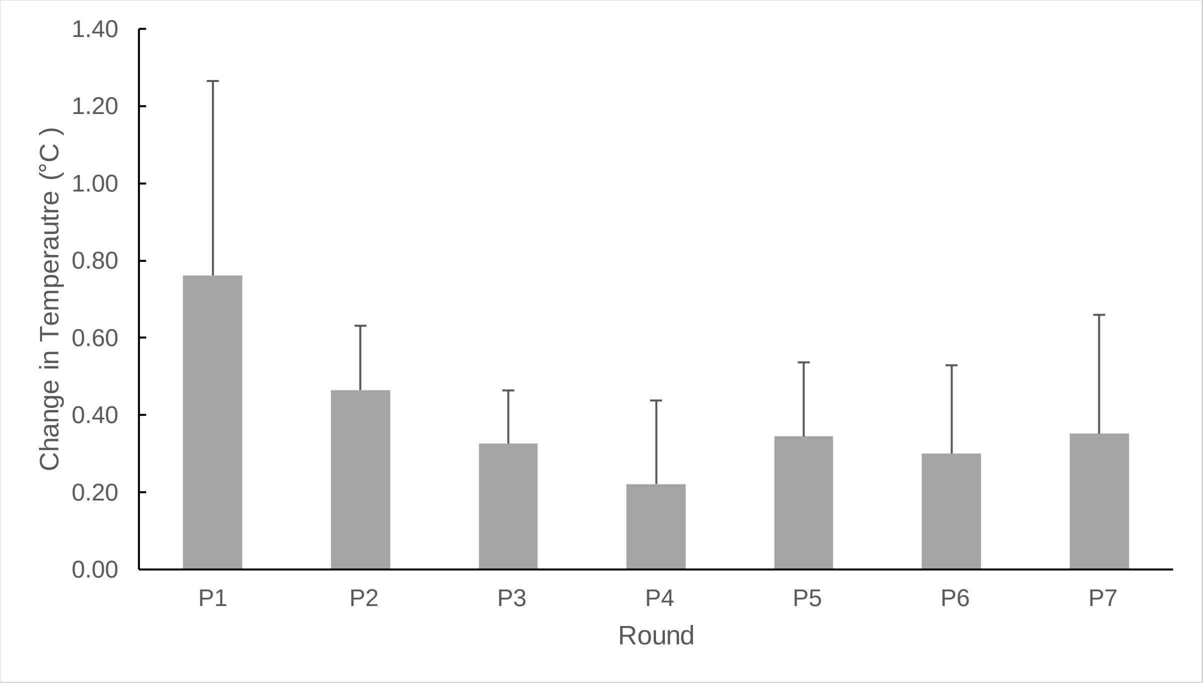


Figure 5.6. Change in T_{mask} (°C) between the first and last minute of the fight (mean ± SD).

P = Poule.

There were no significant differences determined between Poule rounds for heat storage ($F_{(6,30)} = 0.482$, $p = 0.817$, $\eta^2 = 0.088$) and core to skin temperature gradient ($F_{(6,36)} = 1.175$, $p = 0.341$, $\eta^2 = 0.164$), Table 5.2.

Table 5.2. Heat storage and core to skin temperature gradient during Poule rounds (mean ± SD (95% CI)).

Round	Heat Storage ($J.g^{-1}$)	Core to Skin Temperature Gradient (°C)
P1	0.45 ± 0.66 (-0.25, 1.14)	3.87 ± 0.58 (3.33, 4.41)
P2	0.52 ± 0.99 (-0.52, 1.46)	3.60 ± 0.77 (2.89, 4.31)
P3	0.44 ± 0.66 (-0.25, 1.13)	3.34 ± 0.85 (2.56, 4.12)
P4	-0.07 ± 0.25 (-0.33, 0.20)	3.32 ± 0.94 (2.45, 4.20)
P5	0.21 ± 0.78 (-0.60, 1.03)	3.85 ± 0.69 (3.21, 4.48)

P6	0.41 ± 0.60 (-0.22, 1.04)	3.92 ± 0.71 (3.26, 4.58)
P7	0.24 ± 1.02 (-0.82, 1.31)	3.89 ± 0.80 (3.15, 4.62)

P = Poule

5.4.2.2 Physiological Responses during Poule Rounds

There were no significant differences during the Poule rounds for HR_{av} ($F_{(6,36)} = 0.723$, $p = 0.634$, $\eta^2 = 0.108$) and HR_{max} ($F_{(6,36)} = 0.784$, $p = 0.588$, $\eta^2 = 0.116$), as shown in Table 5.3.

Table 5.3. Heart rate responses during Poule rounds (mean ± SD (95%CI)).

Round	HR_{av} (% HR_{APM})	HR_{max} (% HR_{APM})
P1	85.0 ± 4.7 (80.7, 89.3)	92.4 ± 4.4 (88.3, 96.5)
P2	86.3 ± 5.0 (81.6, 90.9)	93.3 ± 3.7 (89.9, 96.7)
P3	87.0 ± 5.4 (82.0, 92.0)	93.6 ± 5.3 (88.7, 98.4)
P4	84.3 ± 6.0 (78.7, 89.9)	92.6 ± 4.7 (88.2, 96.9)
P5	85.7 ± 6.6 (79.6, 91.8)	91.9 ± 6.3 (86.0, 97.7)
P6	84.1 ± 9.2 (75.7, 92.6)	90.0 ± 9.1 (81.5, 98.5)
P7	84.1 ± 7.9 (76.9, 91.4)	91.0 ± 8.4 (83.2, 98.8)

P = Poule, HR_{av} = average heart rate, HR_{max} = maximum heart rate, and HR_{APM} = age predicted maximum heart rate).

There was a significantly greater blood lactate concentration between P1 and P7 with a moderate effect size (P1: 3.50 ± 1.56 $mmol.L^{-1}$ (2.05, 4.94) vs. P7: 2.33 ± 1.29 $mmol.L^{-1}$ (1.14, 3.53), $t_{(6)} = 4.108$, $p = 0.006$, ES = 0.82). There was no significant difference in blood glucose concentration between P1 and P7, however there was a large effect size reported (P1: 4.87 ± 0.53 $mmol.L^{-1}$ (4.38, 5.37) vs. P7: 5.71 ± 0.78 $mmol.L^{-1}$ (4.99, 6.43), $t_{(6)} = -2.157$, $p = 0.074$, ES = 1.26).

Figure 5.7 shows distance covered and distance covered per minute during the Poule rounds. There was a significant difference between Poule rounds for distance covered ($F_{(6,36)} = 3.131$, $p = 0.014$, $\eta^2 = 0.343$). Post-hoc analysis could not determine where the difference occurred, there was a tendency for decreased distance covered in P4 than P1 ($p = 0.078$). There was no significant difference between Poule rounds for distance covered per minute ($F_{(6,36)} = 0.745$, $p = 0.618$, $\eta^2 = 0.110$).

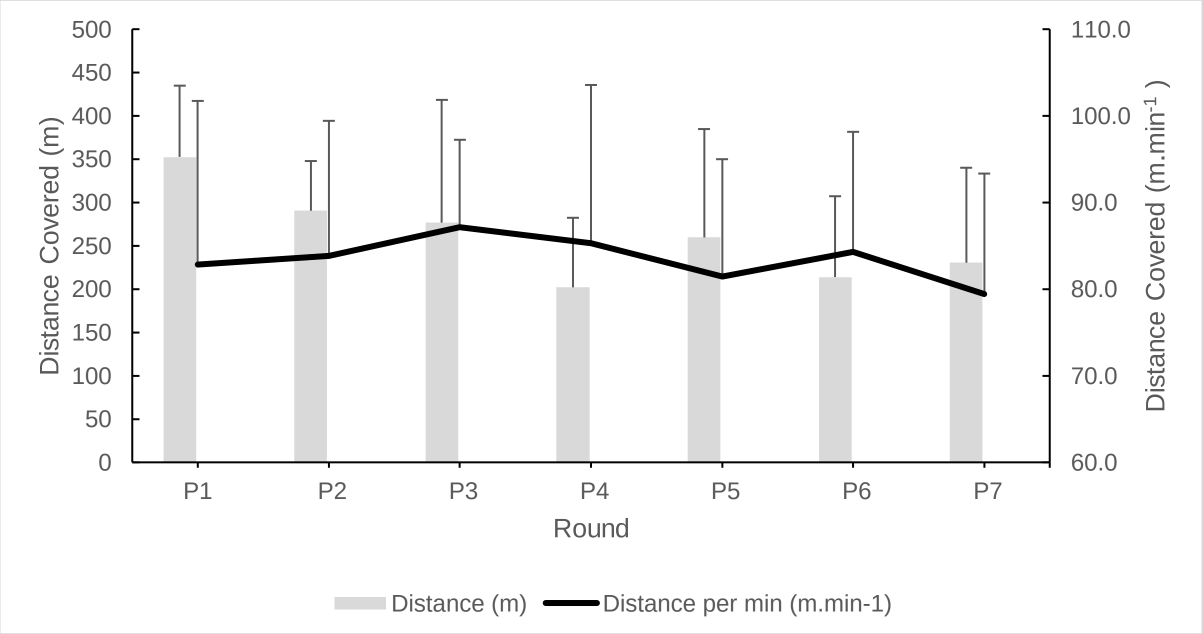


Figure 5.7. Distance covered (m) and distance covered per minute ($m.min^{-1}$) during Poule rounds (mean ± SD). Bars indicate distance covered (m), line indicates distance covered per minute ($m.min^{-1}$).

P = Poule.

Table 5.4 shows effective fight duration, training load per minute and work to rest ratios during the Poule rounds. There was a significant difference determined between Poule rounds for fight duration ($F_{(6,36)} = 3.343$, $p = 0.010$, $\eta^2 = 0.358$). However, post-hoc analysis could not show where the difference occurred. There is a potential decrease in fight time as the Poule progresses from P1 to P7. There was a significant difference determined for work to rest ratio across the Poule rounds ($F_{(6,36)} = 6.096$, $p < 0.001$, $\eta^2 = 0.504$). Post-hoc analysis revealed that work to rest ratio was greater in P2 than P7 ($p = 0.019$), there was also a tendency for a greater work to rest ratio in P1 than P5 and P7 ($p = 0.088$, and $p = 0.060$, respectively), and between P2 and P6 ($p =$

0.085). There were no significant differences for training load per minute across Poule rounds ($F_{(6,36)} = 0.997$, $p = 0.442$, $\eta^2 = 0.143$).

Table 5.4. Effective fight duration (min), training load per minute (AU.min^{-1}) and work to rest ratio during Poule rounds (mean ± SD (95% CI)).

Round	Effective Fight Duration (min)	Training Load per minute (AU.min^{-1})	Work to rest ratio
P1	4:25 ± 1:21 (3:10, 5:40)	3.14 ± 0.28 (2.88, 3.40)	2.9 : 1.0 ± 0.7 (2.3, 3.6)
P2	3:32 ± 0:52 (2:44, 4:20)	3.43 ± 0.48 (2.98, 3.88)	2.5 : 1.0 ± 0.3 (2.2, 2.8)
P3	3:07 ± 1:26 (1:48, 4:26)	3.22 ± 0.51 (2.75, 3.70)	2.4 : 1.0 ± 0.7 (1.7, 3.0)
P4	2:19 ± 0:33 (1:49, 2:50)	3.29 ± 0.41 (2.91, 3.67)	2.4 : 1.0 ± 0.7 (1.8, 3.0)
P5	3:16 ± 1:37 (1:47, 4:46)	3.30 ± 0.43 (2.91, 3.70)	1.8 : 1.0 ± 0.3 (1.6, 2.1)
P6	2:27 ± 0:49 (1:41, 3:13)	3.26 ± 0.76 (2.56, 3.97)	1.9 : 1.0 ± 0.2 (1.7, 2.0)
P7	2:47 ± 1:00 (1:52, 3:43)	3.00 ± 0.74 (2.32, 3.69)	1.7 : 1.0 ± 0.1 (1.6, 1.9)*

P = Poule. * significant difference to P2 ($p < 0.05$).

5.4.2.3 Perceptual Responses during Poule Rounds

Table 5.5 shows the perceptual responses for differentiated RPE and thermal sensation during the Poule rounds. There were no significant differences determined for RPE_O ($F_{(6,36)} = 0.226$, $p = 0.966$, $\eta^2 = 0.036$), RPE_A ($F_{(6,36)} = 1.439$, $p = 0.227$, $\eta^2 = 0.193$), RPE_L ($F_{(6,36)} = 0.984$, $p = 0.451$, $\eta^2 = 0.141$), and thermal sensation ($F_{(6,36)} = 2.004$, $p = 0.091$, $\eta^2 = 0.250$).

Table 5.5. Perceptual responses during Poule rounds (mean ± SD (95%CI)).

Round	RPE_O	RPE_A	RPE_L	Thermal Sensation
P1	13 ± 2 (12, 15)	10 ± 3 (7, 13)	12 ± 2 (10, 13)	5.5 ± 0.5 (5.0, 6.0)
P2	13 ± 2 (11, 14)	10 ± 2 (9, 12)	12 ± 2 (10, 14)	5.5 ± 1.0 (4.5, 6.0)
P3	13 ± 2 (11, 15)	12 ± 3 (9, 14)	13 ± 2 (11, 15)	5.5 ± 0.5 (5.0, 6.0)
P4	13 ± 2 (11, 15)	11 ± 1 (10, 12)	12 ± 3 (9, 14)	5.0 ± 1.0 (4.0, 6.0)
P5	14 ± 2 (12, 16)	13 ± 1 (12, 13)	13 ± 3 (11, 15)	6.0 ± 0.5 (5.5, 6.5)
P6	13 ± 2 (12, 15)	12 ± 2 (10, 14)	13 ± 2 (11, 15)	6.0 ± 0.5 (5.0, 6.5)
P7	13 ± 1 (12, 14)	12 ± 2 (10, 14)	13 ± 2 (11, 14)	6.0 ± 1.0 (5.0, 6.5)

P = Poule, RPE_O = overall ratings of perceived exertion, RPE_A = arms ratings of perceived exertion, and RPE_L = legs ratings of perceived exertion.

5.4.3 Direct Elimination

5.4.3.1 Thermoregulatory Responses during Direct Elimination Rounds

There was no significant interaction determined for T_{gast} during DE rounds ($F_{(6,36)}$ = 1.816, p = 0.124, η^2 = 0.232, Figure 5.8). There was a significant main effect for round for T_{gast} during DE rounds ($F_{(1.983,11.900)}$ = 10.962, p = 0.002, η^2 = 0.646). Post-hoc analysis revealed lower T_{gast} in DE 1 than DE 2 (p = 0.004), DE 3 (p = 0.033), and DE 7 (p = 0.010), and lower T_{gast} in DE 7 than DE 2 (p = 0.031). There was a significant main effect for time ($F_{(1,6)}$ = 34.087, p = 0.001, η^2 = 0.850) with an average increase ~0.42°C pre to post fight. Furthermore, average T_{gast} was ≥38.5°C post fight for all DE rounds and ≥38.0°C pre fight for DE 2 to DE 7.

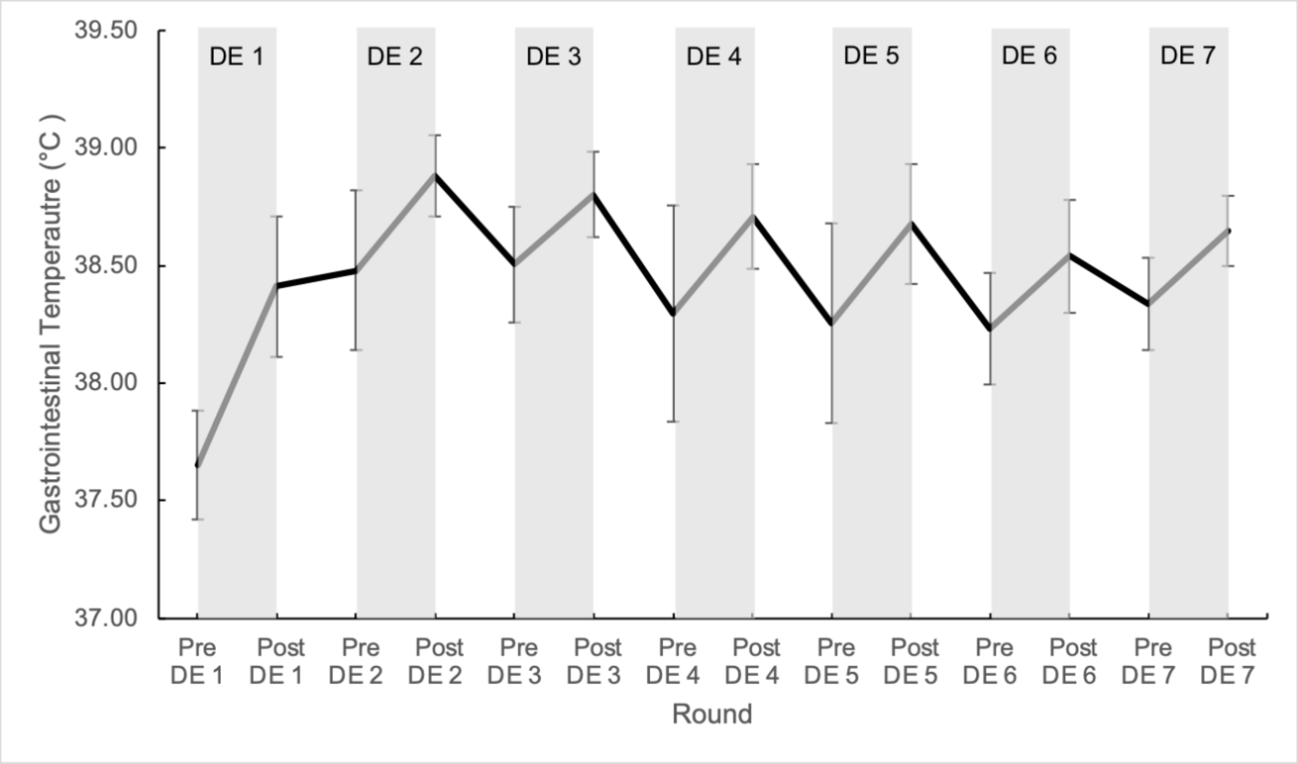


Figure 5.8. Gastrointestinal temperature (°C) across the DE rounds (mean ± SD).

DE = Direct Elimination.

Figure 5.9 shows the T_{skin} response across the DE rounds and during recovery between fights. There was a significant interaction determined for T_{skin} during DE rounds ($F_{(12,72)} = 3.082$, $p = 0.001$, $\eta^2 = 0.339$). Post-hoc analysis, using the Bonferroni correction ($p < 0.007$), indicated a greater T_{skin} recorded in the 5th minute of recovery compared to the average T_{skin} recorded during the fight for DE 1 ($p < 0.001$), DE 3 ($p = 0.005$), DE 4 ($p = 0.001$), and DE 5 ($p = 0.002$). There was also a tendency for a greater T_{skin} in the 5th minute of recovery compared to the average T_{skin} during the fight for DE 7 ($p = 0.037$). Post-hoc analysis, using the Bonferroni correction ($p < 0.007$), indicated there were no significant differences for T_{skin} between average T_{skin} recorded during the fight and the 10th minute recovery, and between the 5th minute of recovery and the 10th minute recovery. However, T_{skin} showed a tendency to be greater at the 10th minute of recovery compared to the average T_{skin} during the fight for DE 1 ($p = 0.009$), DE 3 ($p = 0.011$), DE 4 ($p = 0.017$), and DE 5 ($p = 0.010$). Furthermore, post-hoc analysis revealed, using the Bonferroni correction ($p < 0.017$), there was a significantly greater average T_{skin} during the fight ($F_{(6,36)} = 11.906$, $p = 0.001$, $\eta^2 =$

0.665) for DE 2 than DE 4 ($p = 0.002$), DE 5 ($p = 0.005$), DE 6 ($p = 0.013$), and DE 7 ($p = 0.008$) and a tendency ($p < 0.05$) for a greater T_{skin} during the fight for DE 2 than DE 1 ($p = 0.022$). Post-hoc analysis, using the Bonferroni correction ($p = 0.017$), determined a significantly greater T_{skin} during the 5th minute of recovery ($F_{(1.968,11.809)} = 5.643$, $p = 0.001$, $\eta^2 = 0.485$) for DE 1 than DE 3 ($p = 0.010$), DE 4 ($p = 0.012$), and DE 7 ($p = 0.007$) and a tendency ($p < 0.05$) for greater T_{skin} during the 5th minute of recovery for DE 1 than DE 5 ($p = 0.037$), and DE 3 than DE 7 ($p = 0.025$). Post-hoc analysis, using the Bonferroni correction ($p < 0.017$) showed a significantly greater T_{skin} during the 10th minute of recovery ($F_{(2.018,12.107)} = 5.962$, $p = 0.016$, $\eta^2 = 0.498$) for DE 1 ($p < 0.001$), DE 2 ($p = 0.013$), and DE 3 ($p = 0.001$) than DE 7.

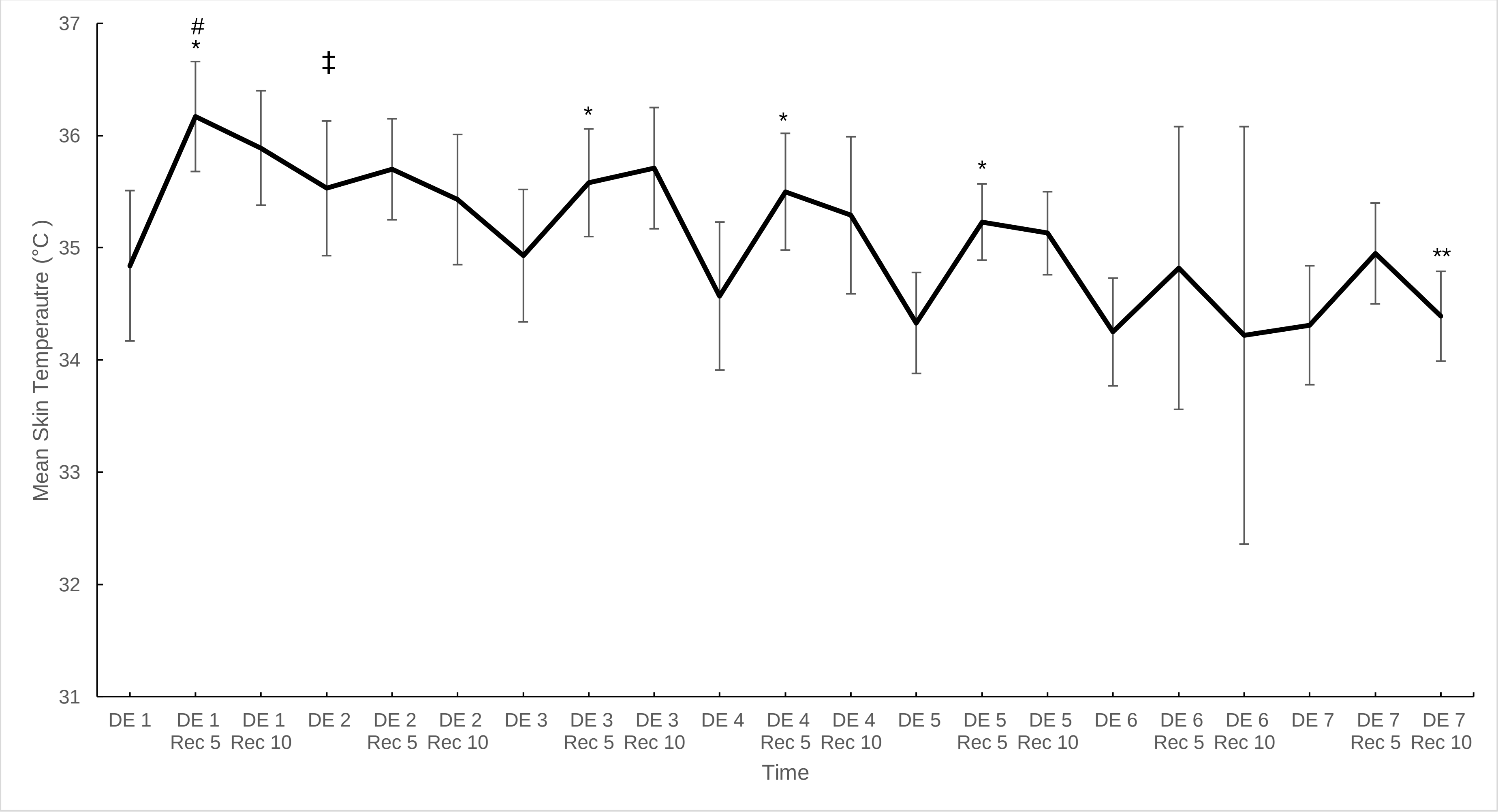


Figure 5.9. Mean skin temperature (°C) across the DE rounds and during 5th and 10th minute of recovery (mean ± SD).

DE = Direct Elimination, Rec 5 = 5th minute of recovery between fights, Rec 10 = 10th minute of recovery between fights. * Significant difference to average fight T_{skin} for DE round ($p < 0.007$ Bonferroni correction), ‡ significant difference to DE 4, DE 5, DE 6 and DE 7 ($p < 0.017$, Bonferroni correction), # significant difference to DE 3, DE 4 and DE 7 5th minute recovery T_{skin} ($p < 0.017$ Bonferroni correction), ** significant difference to DE 1, DE 2 and DE 3 10th minute recovery T_{skin} ($p < 0.017$ Bonferroni correction).

There was a significant difference of T_{skin} over time during a DE fight and into recovery between fights ($F_{(3,144)} = 33.246$, $p < 0.001$, $\eta^2 = 0.409$) as shown in Figure 5.10. Post-hoc analysis showed a significantly greater ($p < 0.001$) T_{skin} in the last minute of the fight, 5th and 10th minute of recovery between fights than in the first minute of the fight. Mean skin temperature was also greater in the 5th minute of recovery than the last minute of the fight and the 10th minute of recovery ($p < 0.001$, $p = 0.003$, respectively). There was no significant difference between the last minute of the fight and 10th minute of recovery between fights for T_{skin} ($p = 1.000$).

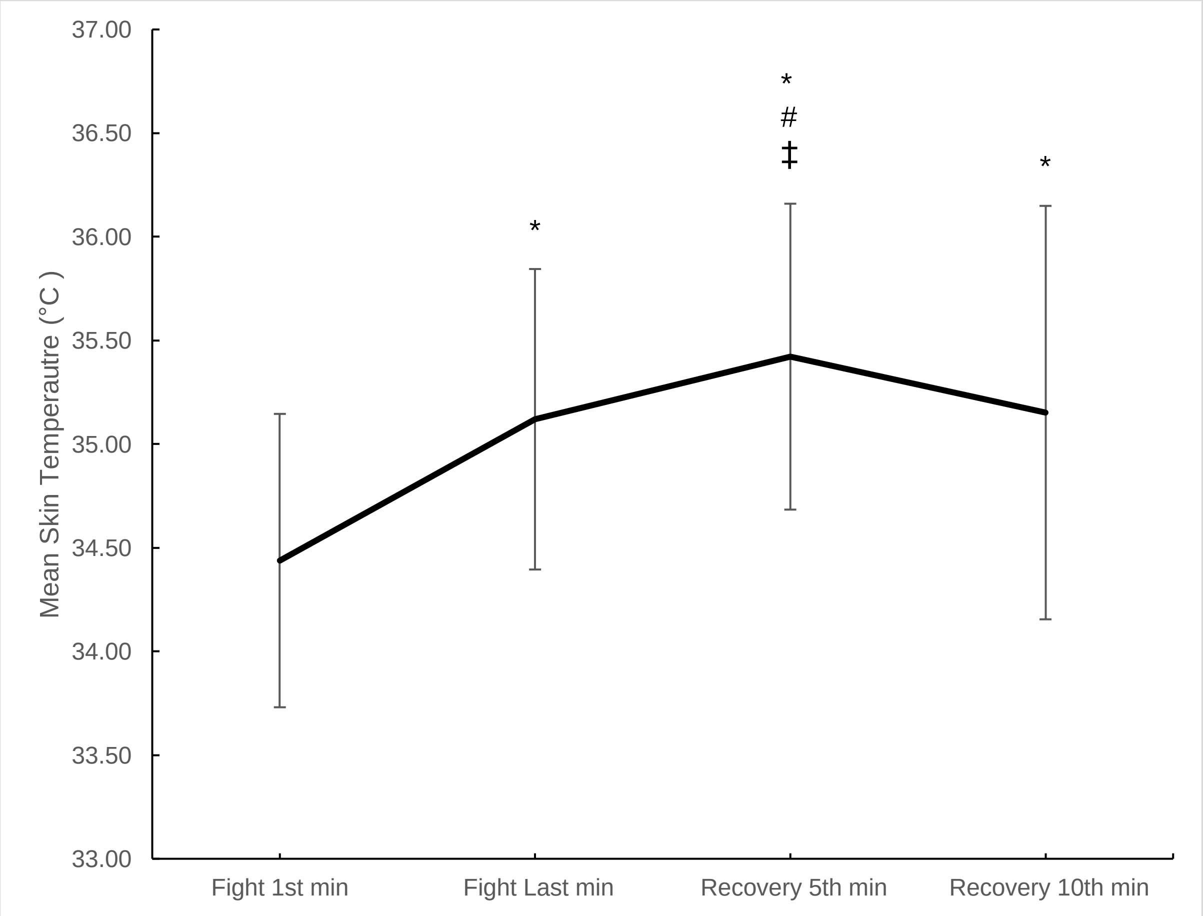


Figure 5.10. Mean skin temperature (°C) responses during first and last minute of a DE fight and during recovery between fights (mean ± SD).

DE = Direct Elimination. * significant difference from fight 1st minute ($p < 0.001$), # significant difference from fight last minute ($p < 0.001$), ‡ significant difference from recovery 10th min ($p < 0.05$).

There was a significant difference determined for T_{mask} across the DE rounds ($F_{(6,36)} = 7.948$, $p < 0.001$, $\eta^2 = 0.570$) as shown in Figure 5.11. Post-hoc analysis showed greater average T_{mask} in DE 7 than DE 1, DE 4 and DE 5 ($p = 0.028$, $p = 0.036$, and $p = 0.021$).

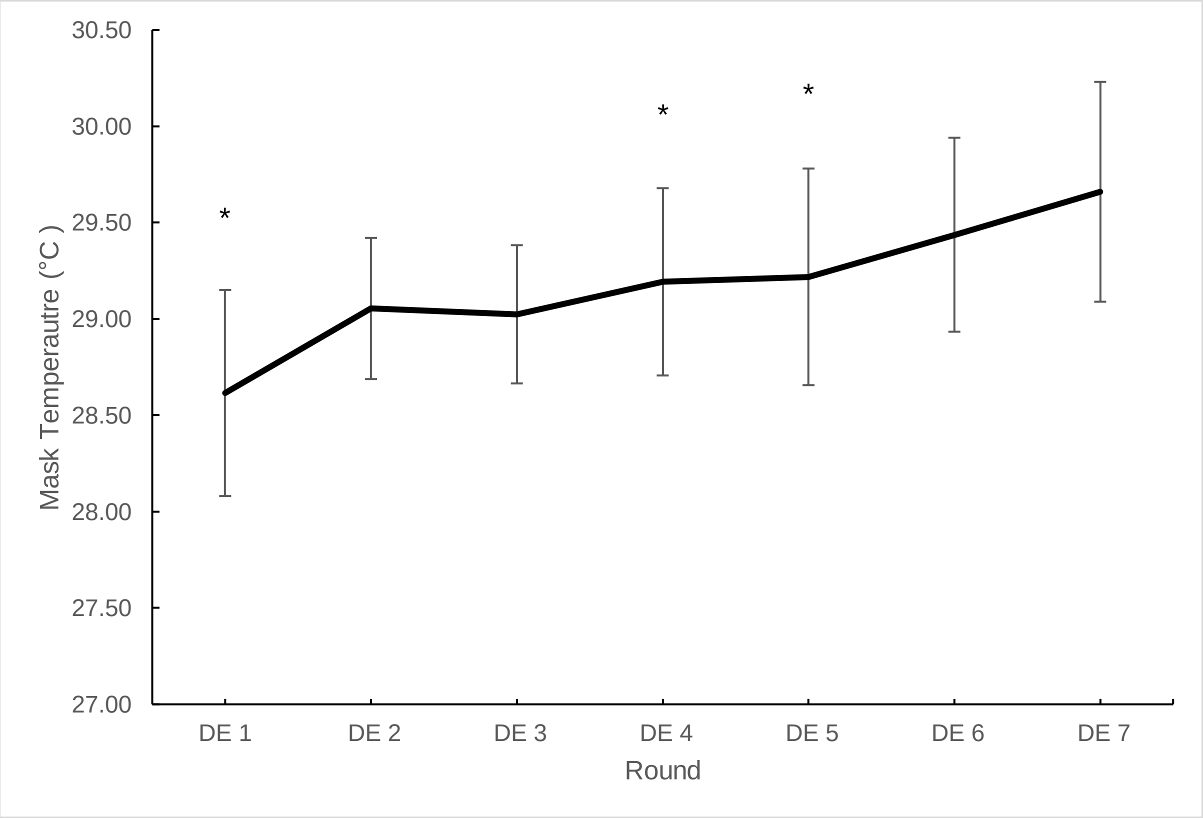


Figure 5.11. Average T_{mask} (°C) during DE fights across DE rounds (mean ± SD).

DE = Direct Elimination. * significant difference from DE 7 ($p < 0.05$).

There was no significant difference determined for change in T_{mask} across DE rounds ($F_{(6,36)} = 1.044$, $p = 0.414$, $\eta^2 = 0.148$, Figure 5.12). Change in T_{mask} across all DE rounds was 1.10 ± 0.56°C (range -0.36°C – 2.45°C).

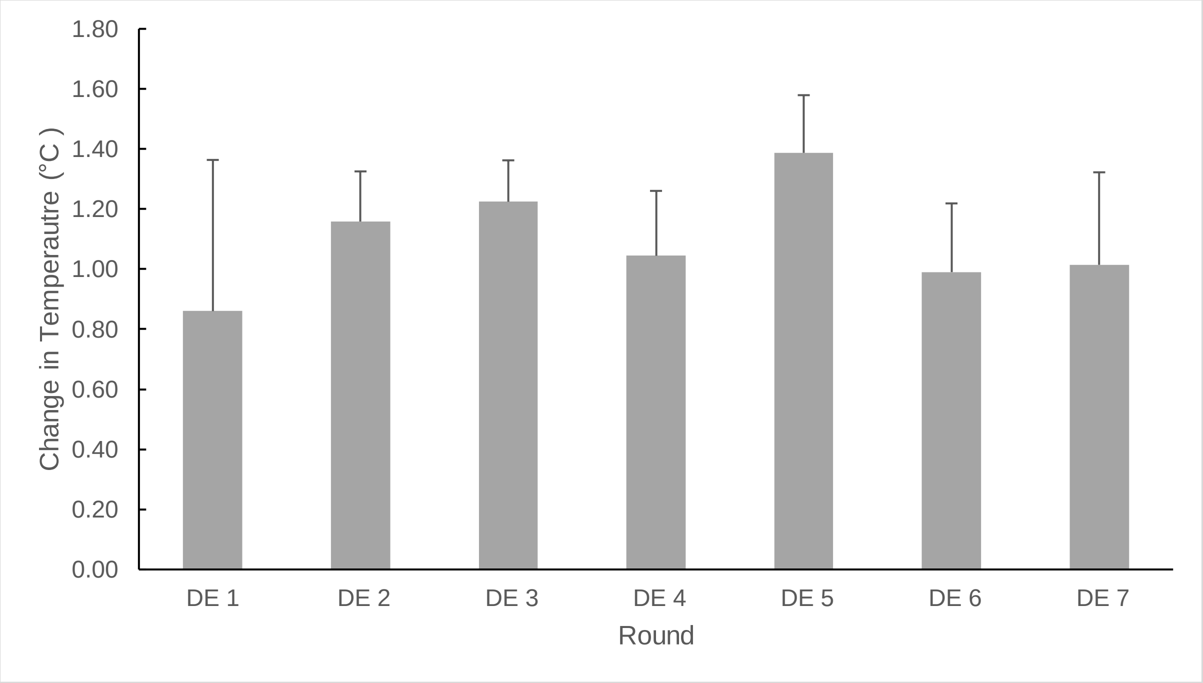


Figure 5.12. Change in T_{mask} (°C) during DE rounds (mean ± SD).

DE = Direct Elimination.

Table 5.6 shows heat storage and Figure 5.13 shows core to skin temperature gradient across DE rounds. There was a significant difference determined for heat storage across the DE rounds ($F_{(6,36)} = 3.941$, $p = 0.004$, $\eta^2 = 0.396$). Post-hoc analysis showed heat storage was greater during DE 1 than DE 3 and DE 6 ($p = 0.016$, and $p = 0.017$). There was a significant difference determined for core to skin temperature gradient across DE rounds ($F_{(6,36)} = 10.841$, $p < 0.001$, $\eta^2 = 0.644$). Post-hoc analysis could not reveal where the difference occurred, however there was a tendency for a lower core to skin temperature gradient in DE 2 than DE 4 and DE 7 ($p = 0.058$, and $p = 0.052$, respectively).

Table 5.6. Heat storage and core to skin temperature gradient across DE rounds (mean ± SD (95% CI))

Round	Heat Storage (J.g^{-1})
DE 1	3.35 ± 1.01 (2.41, 4.29)
DE 2	1.46 ± 1.44 (0.13, 2.79)
DE 3	1.15 ± 0.62 (0.59, 1.74)*
DE 4	1.46 ± 0.99 (0.54, 2.38)
DE 5	1.51 ± 1.63 (0.00, 3.02)
DE 6	1.04 ± 0.98 (0.14, 1.96)*
DE 7	1.29 ± 0.69 (0.65, 1.93)

DE = Direct Elimination. * significant difference to DE 1 ($p < 0.05$).

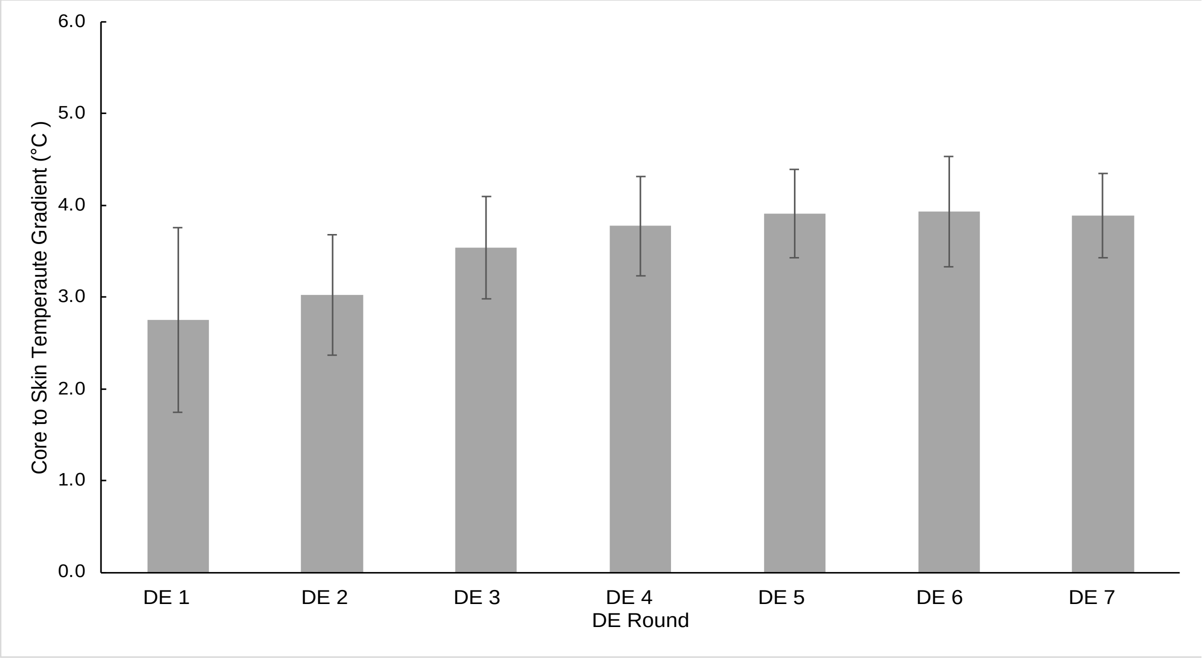


Figure 5.13. Core to skin temperature gradient (°C) during DE rounds (mean ± SD). Dots represent individual data points.

DE = Direct Elimination.

5.4.3.2 Physiological Responses during DE rounds

There were no significant differences for HR_{av} ($F_{(6,36)} = 1.667$, $p = 0.158$, $\eta^2 = 0.217$) or HR_{max} ($F_{(6,36)} = 1.032$, $p = 0.421$, $\eta^2 = 0.147$), as shown in Table 5.7.

Table 5.7. Heart rate response across DE rounds (mean ± SD (95%CI)).

Round	HR_{av} (% HR_{APM})	HR_{max} (% HR_{APM})
DE 1	89.0 ± 5.4 (84.0, 94.0)	97.9 ± 6.7 (91.7, 104.0)
DE 2	89.6 ± 4.7 (85.2, 93.9)	96.7 ± 3.4 (93.6, 99.8)
DE 3	89.4 ± 2.3 (87.3, 91.6)	98.7 ± 1.7 (97.1, 100.3)
DE 4	88.0 ± 3.3 (84.9, 91.1)	96.1 ± 3.2 (93.2, 99.1)
DE 5	87.4 ± 4.5 (83.3, 91.6)	95.6 ± 5.3 (90.7, 100.4)
DE 6	86.4 ± 6.5 (80.5, 92.4)	95.0 ± 7.7 (87.9, 102.1)
DE 7	86.4 ± 5.3 (81.5, 91.3)	94.3 ± 5.1 (89.6, 99.0)

DE = Direct Elimination

There was no significant difference for blood lactate concentration across DE rounds ($F_{(3,18)} = 2.512$, $p = 0.091$, $\eta^2 = 0.295$). Average blood lactate concentration for DE 1 was 4.90 ± 2.58 $mmol.L^{-1}$ (2.52, 7.29), DE 3 was 3.50 ± 0.43 $mmol.L^{-1}$ (3.10, 3.90), DE 5 was 3.91 ± 1.30 $mmol.L^{-1}$ (2.71, 5.12), and DE 7 was 2.72 ± 1.23 $mmol.L^{-1}$ (1.59, 3.86). There was no significant difference for blood glucose concentration across DE rounds ($F_{(3,18)} = 2.137$, $p = 0.131$, $\eta^2 = 0.263$). Average blood glucose concentration for DE 1 was 5.33 ± 0.71 $mmol.L^{-1}$ (4.68, 5.98), DE 3 was 5.31 ± 0.54 $mmol.L^{-1}$ (4.80, 5.81), DE 5 was 4.67 ± 0.75 $mmol.L^{-1}$ (3.97, 5.37), and DE 7 was 4.69 ± 0.51 $mmol.L^{-1}$ (4.22, 5.16).

Figure 5.14 shows distance covered, and distance covered per minute across DE rounds. There was a significant difference determined for distance covered across DE rounds ($F_{(6,36)} = 2.761$, $p = 0.026$, $\eta^2 = 0.315$). Post-hoc analysis could not determine where the difference occurred, however there was a tendency for a lower distance covered in DE 6 than DE 1 and DE 3 ($p = 0.063$, and $p = 0.063$, respectively). There was also a significant difference for distance covered per minute across DE rounds ($F_{(6,36)} = 2.528$, $p = 0.038$, $\eta^2 = 0.296$). Post-hoc analysis could not determine where the difference occurred, however there seems to be a decrease in distance covered per minute from DE 1 to DE 7.

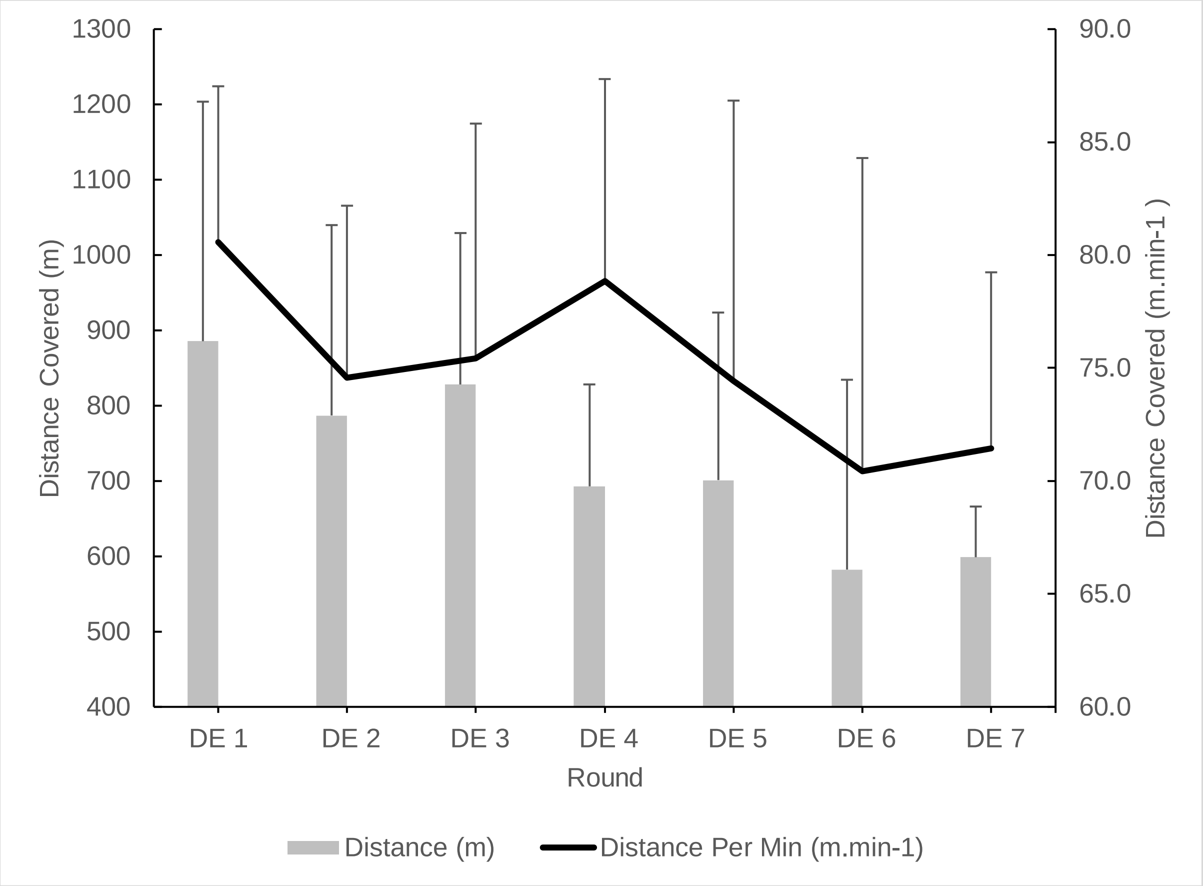


Figure 5.14. Distance covered (m) and distance covered per minute ($m.min^{-1}$) across DE rounds (mean ± SD).

DE = Direct Elimination.

Table 5.8 shows effective fight duration, training load per minute and work to rest ratio across DE rounds. There was no significant difference for fight duration ($F_{(6,36)} = 1.933$, $p = 0.102$, $\eta^2 = 0.244$), Training load per minute ($F_{(6,36)} = 1.903$, $p= 0.107$, $\eta^2 = 0.241$), and work to rest ratio ($F_{(6,36)} = 0.652$, $p = 0.688$, $\eta^2 = 0.098$) across DE rounds.

Table 5.8.Effective fight duration, training load per minute and work to rest ratio across DE rounds (mean ± SD (95%CI)).

Round	Effective Fight Duration (min)	Training Load per minute (AU.min^{-1})	Work to rest ratio
DE 1	11:02 ± 3:59 (7:21, 14:43)	3.81 ± 0.70 (3.16, 4.46)	1.5 : 1.0 ± 0.3 (1.3, 1.9)
DE 2	10:30 ± 3:10 (7:34, 13:26)	3.83 ± 0.46 (3.40, 4.26)	1.9 : 1.0 ± 0.7 (1.2, 2.5)
DE 3	11:13 ± 3:19 (8:09, 14:17)	3.98 ± 0.55 (3.47, 4.48)	1.7 : 1.0 ± 0.3 (1.5, 2.0)
DE 4	8:43 ± 1:02 (7:45, 9:40)	3.69 ± 0.41 (3.31, 4.07)	1.9 : 1.0 ± 0.5 (1.4, 2.3)
DE 5	9:17 ± 1:49 (7:36, 10:58)	3.60 ± 0.43 (3.21, 4.00)	1.6 : 1.0 ± 0.2 (1.4, 1.8)
DE 6	8:09 ± 2:49 (5:33, 10:46)	3.46 ± 0.80 (2.72, 4.21)	1.6 : 1.0 ± 0.6 (1.1, 2.1)
DE 7	8:26 ± 0:52 (7:37, 9:14)	3.55 ± 0.70 (2.90, 4.20)	1.6 : 1.0 ± 0.3 (1.3, 1.9)

DE = Direct Elimination

5.4.3.3 Perceptual Responses during DE Rounds

Table 5.9 shows differentiated RPE and thermal sensation responses across DE rounds. There was no significant differences determined for RPE_O ($F_{(6,36)} = 0.647$, $p = 0.692$, $\eta^2 = 0.097$), RPE_A ($F_{(6,36)} = 0.854$, $p = 0.538$, $\eta^2 = 0.125$), RPE_L ($F_{(6,36)} = 0.243$, $p = 0.959$, $\eta^2 = 0.039$), or thermal sensation ($F_{(6,36)} = 0.558$, $p = 0.761$, $\eta^2 = 0.085$) across DE rounds. Average thermal sensation was rated as very hot (mean ± SD: 7.0 ± 1.0; range: 5.0 (warm) – 8.0 (unbearably hot)) during the DE rounds.

Table 5.9. Perceptual Responses during DE rounds (mean ± SD (95% CI)).

Round	RPE_O	RPE_A	RPE_L	Thermal Sensation
DE 1	16 ± 3 (13, 18)	14 ± 3 (11, 17)	15 ± 3 (13, 18)	6.5 ± 1.0 (5.5, 7.5)
DE 2	15 ± 3 (12, 18)	13 ± 4 (9, 17)	15 ± 4 (11, 18)	7.0 ± 1.0 (6.0, 7.5)
DE 3	16 ± 1 (15, 17)	13 ± 3 (11, 16)	15 ± 2 (12, 17)	7.0 ± 0.0 (7.0, 7.0)
DE 4	14 ± 2 (13, 16)	13 ± 3 (10, 15)	14 ± 2 (12, 16)	7.0 ± 0.0 (7.0, 7.0)
DE 5	16 ± 2 (14, 17)	14 ± 3 (12, 17)	15 ± 2 (13, 17)	7.0 ± 1.0 (6.0, 7.5)
DE 6	15 ± 2 (13, 17)	14 ± 3 (12, 17)	14 ± 2 (12, 17)	6.5 ± 0.5 (6.0, 7.0)
DE 7	15 ± 2 (13, 17)	15 ± 3 (13, 18)	15 ± 2 (14, 17)	6.5 ± 1.0 (6.0, 7.5)

DE = Direct Elimination, RPE_O = overall ratings of perceived exertion, RPE_A = arms ratings of perceived exertion, and RPE_L = legs ratings of perceived exertion.

5.4.4 Correlation Analysis

Table 5.10 shows the relationship between distance covered and physiological and perceptual variables for Poule and DE fights. There was a significant moderate positive relationship determined between distance covered and HR_{av}, HR_{max}, RPE_O, Thermal sensation, training load per minute and work to rest ratio during Poule fights. There was no significant relationship between distance covered and thermoregulatory variables or for RPE_L and RPE_A for Poule fights. There was a significant moderate positive relationship between distance covered and change in T_{gast}, average fight T_{skin}, HR_{max}, RPE_O, RPE_L and work to rest ratio during DE fights. There was a significant moderate negative relationship between distance covered and core to skin temperature gradient during DE fights. There was also a significant large positive relationship between distance covered and thermal sensation during DE fights. There was no significant relationship determined between distance covered and post fight T_{gast}, HR_{av}, RPE_A and training load per minute during DE fights.

Table 5.10. Pearson's Correlation Coefficients between distance covered (m) in Poule and DE fights with physiological and perceptual variables.

	Poule Distance Covered (m)		DE Distance Covered (m)	
	Pearson’s Correlation Coefficient	Significance	Pearson’s Correlation Coefficient	Significance
Post Fight T_{gast} (°C)	0.004	0.979	0.150	0.303
Change in T_{gast} (°C)	0.121	0.408	0.367*	0.010
Fight T_{skin} (°C)	0.189	0.194	0.371*	0.009
Core to Skin Temperature Gradient (°C)	-0.190	0.193	-0.425*	0.002
HR_{av} (% HR_{APM})	0.364*	0.010	0.121	0.407
HR_{max} (% HR_{APM})	0.462*	0.002	0.381*	0.007
RPE_O	0.360*	0.011	0.494*	<0.001
RPE_L	-0.040	0.778	0.334*	0.019
RPE_A	-0.060	0.707	0.047	0.748
Thermal Sensation	0.297*	0.038	0.566*	<0.001
Training Load per minute (AU)	0.351*	0.014	0.275	0.056
Work to Rest Ratio	0.445*	0.001	0.462*	0.001

DE = Direct elimination, HR_{av} = average heart rate, HR_{max} = maximum heart rate, HR_{APM} = age predicted maximum heart rate, RPE_O = overall ratings of perceived exertion, RPE_L = legs ratings of perceived exertion, RPE_A = arms ratings of perceived exertion. * significant correlation coefficient ($p < 0.05$)

There was a significant small positive relationship between mean skin temperature and thermal sensation in Poule fights, Figure 5.15. There was a significant moderate relationship between mean skin temperature and thermal sensation during DE fights, Figure 5.15. Table 5.11 shows Pearson's correlation coefficients between thermal sensation and physiological and perceptual variables for Poule and DE fights. There was a significant moderate relationship between thermal sensation and post fight T_{gast} during Poule fights but no relationship during DE fights. There were significant moderate positive relationships shown between thermal sensation and HR_{av}, HR_{max}, RPE_L, and RPE_A for Poule fights. A significant large positive correlation was determined between thermal sensation and RPE_O for Poule fights. There were significant moderate positive relationships between thermal sensation and HR_{av}, HR_{max}, RPE_A, training load per minute and work to rest ratio during DE fights. There were also significant large positive relationships between thermal sensation and RPE_O and RPE_L.

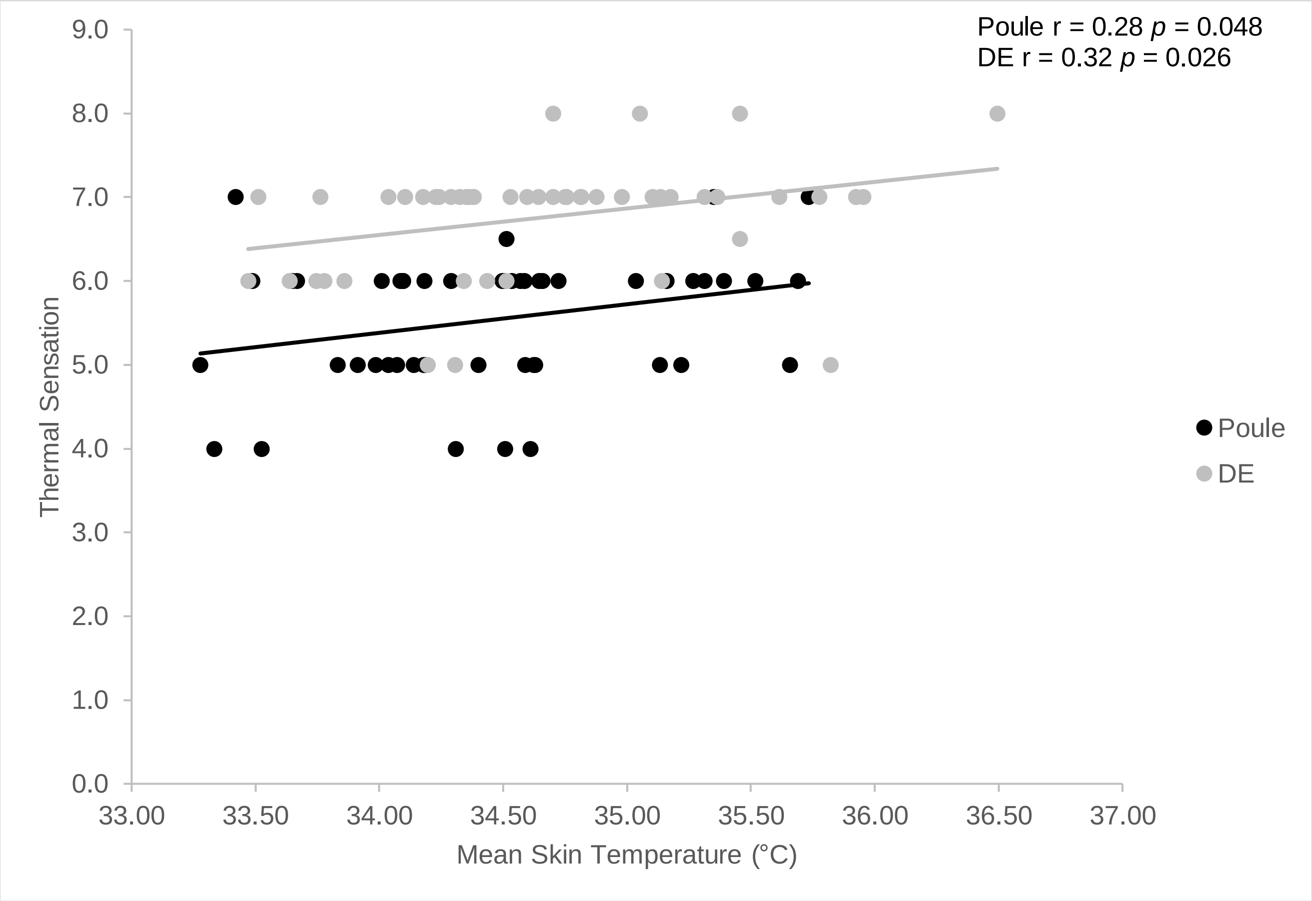


Figure 5.15. Relationship between mean skin temperature and thermal sensation during Poule and DE fights.

Table 5.11. Pearson's correlation coefficients between thermal sensation and physiological and perceptual variables during Poule and DE fights.

	Poule Thermal Sensation		DE Thermal Sensation	
	Pearson’s Correlation Coefficient	Significance	Pearson’s Correlation Coefficient	Significance
Post Fight T_{gast} (°C)	0.493*	<0.001	0.184	0.205
Change in T_{gast} (°C)	-0.050	0.751	0.131	0.371
Core to Skin Temperature Gradient (°C)	0.036	0.808	-0.278	0.053
Last Minute T_{mask} (°C)	0.242	0.093	0.063	0.665
HR_{av} (% HR_{APM})	0.358*	0.012	0.323*	0.024
HR_{max} (% HR_{APM})	0.372*	0.008	0.471*	0.001
RPE_O	0.495*	<0.001	0.654*	<0.001
RPE_L	0.321*	0.025	0.581*	<0.001
RPE_A	0.399*	0.004	0.437*	0.002
Training Load per minute (AU)	0.203	0.161	0.389*	0.006
Work to Rest Ratio	-0.060	0.684	0.311*	0.030

DE = Direct elimination, HR_{av} = average heart rate, HR_{max} = maximum heart rate, HR_{APM} = age predicted maximum heart rate, RPE_O = overall ratings of perceived exertion, RPE_L = legs ratings of perceived exertion, RPE_A = arms ratings of perceived exertion. * significant correlation coefficient ($p < 0.05$)

5.5 Discussion

The aims of this chapter were to investigate the thermoregulatory demands of epée fencing during competition across Poule and DE rounds. Furthermore, as a competition progresses DE fights are performed with a minimum resting period of 10 minutes between fights, therefore a further aim was to determine if there were any differences in thermoregulatory, cardiovascular, and perceptual responses between DE fights as athletes' fatigue. This study showed during Poule rounds there was a moderate rise in thermoregulatory variables such as T_{gast}, T_{skin}, T_{mask} and thermal sensation. There was a greater increase in these variables in DE rounds with T_{gast} staying above 38.0°C pre and post fight. There were also high T_{skin} (>35.0°C) and narrow core to skin temperature reported especially in early DE rounds. There was an increase in T_{skin} into the recovery between Poule and DE fights. Participants perceived DE rounds as hard (≥15) and hot (≥7) despite lowering thermoregulatory responses in later DE rounds (T_{gast} and T_{skin}) indicating a potential impact on cognitive function. There was also a decrease in distance covered and distance covered per minute as DE rounds progressed.

5.5.1 Thermoregulatory, physiological, and perceptual responses to Poule fights

Across the Poule rounds there were no significant increases determined for T_{gast} pre to post fight. This could have been due to the short duration of the Poule fights not producing large increases in body temperature.

There was an initial decrease in T_{skin} from the first to last minute within the Poule fights (Figure 5.4) as the Poule fights have a low duration this could have been due to an initial vasoconstriction lowering skin blood flow and the exercise not being long enough for vasodilation to occur (Johnson, 2010). There was an increase in T_{skin} in the 5th minute of recovery between Poule fights compared to T_{skin} recorded during the fight (Figure 5.3 and Figure 5.4). This could indicate the body increasing blood flow to the skin in recovery to dissipate heat produced during the fight and the body reaching an internal threshold to cause vasodilation to occur (Johnson, 2010). From observation of the video recording between Poule fights a fencing jacket was only removed 3 times by a participant, potentially inhibiting heat loss causing increases in T_{gast} and T_{skin}.

There was a potential increase in heat lost from the head during the Poule rounds through an increase in T_{mask} being reported (Figure 5.5). It has been previously reported that the head can contribute to heat loss during exercise (Rasch et al., 1991). With the fencing mask covering the whole head the heat may not dissipate effectively until after the fight. There could also be a potential increase in T_{mask} due to a slight increase in WBGT during the Poule rounds by 1.5°C from P1 to P7. There could be a microclimate created within the protective clothing causing an increase in internal body temperature during fencing as shown by a greater T_{mask} than the ambient temperature (Average Poule: T_{mask} to WBGT gradient 5.91 ± 0.61°C; T_{mask} to ambient temperature gradient 1.11 ± 0.65°C).

Thermal sensation post fight was reported on average between warm and hot (5.5 ± 1.0) during the Poule rounds indicating participants were relatively comfortable. However, perceptions of thermal sensation were significantly correlated with T_{gast} ($r = 0.49$), T_{skin} ($r = 0.28$), HR_{av} ($r = 0.36$), HR_{max} ($r = 0.37$), and differentiated RPE ($r = 0.32$-0.50). This indicated that participants were feeling warmer with greater T_{gast}, T_{skin}, heart rates and RPE during Poule fights. There was also a small significant relationship between thermal sensation and distance covered ($r = 0.30$). These associations potentially shows that the greater the distance covered by the participants the hotter they were perceiving the fight. This could be due to the increased muscle activity when covering more distance generating and accumulating more heat.

Despite decreases in distance covered and work to rest ratios across the Poule there was no difference in distance covered per minute indicating participants were performing at a similar intensity throughout the Poule rounds. Work to rest ratios at the end of the Poule were at a similar level to the DE. A decrease in work to rest ratio may have meant participants were taking slightly longer between points towards to end of the Poule to recover for longer.

Overall, during the Poule rounds there was a moderate increase in thermoregulatory variables, where T_{gast} remained ~38.0°C, T_{skin} below 35°C, and thermal sensation ~5.5 indicating participants were relatively comfortable during this phase of competition. With the Poule lasting ~90-120 minutes these thermoregulatory responses could be beneficial for fencers starting the DE without a large heat load and potential detrimental effects of initial overheating.

5.5.2 Thermoregulatory, physiological, and perceptual responses to Direct Elimination fights

There was a significant rise in T_{gast} by DE 2 and remained on average above 38.0°C pre fight and 38.5°C post fight during the remaining DE rounds. The peak T_{gast} was ~38.9°C post DE 2. Gastrointestinal temperature may not have shown any further increase throughout DE rounds due a lower distance covered as the rounds progressed (Figure 5.7), and thus less heat produced due to less muscle activity. Additionally, there was also a small positive relationship ($r = 0.37$) between change in T_{gast} from pre to post fight with distance covered. The T_{gast} response in this study is similar to other protective clothing sports such as ice hockey (Batchelder et al., 2010; Driscoll et al., 2020) and motor racing (Barthel et al., 2020; Carlson et al., 2014) with T_{gast} ~38.5°C. It appears T_{gast} in fencing is not overly problematic due to T_{gast} remaining below 39.0°C.

A similar increase in T_{skin} into the recovery period was determined in the DE rounds as in the Poule rounds. There was a greater T_{skin} at 5 and 10 minutes into recovery than recorded during the fight (Figure 5.9 and Figure 5.10). This could indicate the body attempting to dissipate heat by increasing blood flow from the core to the skin during recovery. This could cause strain on the cardiovascular system to redistribute blood flow to dissipate heat produced during a fight in the recovery period. Hot skin temperatures (>35°C as defined by (Sawka et al., 2012)) were recorded during DE fights 1-4, with peak T_{skin} recorded in DE 2 (average fight ~35.5°C and last minute of fight ~35.9°C). Recovery skin temperatures were hot (>35°C) for DE 1-5 at both 5- and 10-minutes post fight, with peak recovery T_{skin} recorded ~36.0°C post DE 2. This caused a narrowing of core to skin gradient in the early DE rounds (Figure 5.13) which could have caused increased blood flow to the skin and has been shown to decrease exercise performance (Sawka et al., 2012). These early high T_{skin} during the DE rounds could have potentially impacted later rounds whereby T_{skin} was lower due to less mechanical heat produced due to lower distances covered and fatiguing the cardiovascular system. This is shown by the relationships between T_{skin} ($r = 0.37$) and core to skin temperature gradient (r = -0.43) with distance covered. There could have potentially been less heat produced as fight duration and, therefore, distance covered decreased due to a lower energy expended (~13 kcal.min^{-1} as shown in chapter 4) during a fight. Furthermore, the full-body protective clothing worn by fencers could impact upon the body's ability to dissipate heat effectively. The multiple and thick layers of protection will impede the body's convective and evaporative cooling mechanisms during exercise, as shown in American football (Armstrong et al., 2010), therefore skin temperature could increase both during a fencing fight and in the recovery between fights. One potential mechanism of heat loss could be to remove the fencing jacket, however as mentioned in chapter 2.4 fencers are reluctant to remove their jacket. From observation of the video recording within the DE there were only 9 occasions where a participant removed their fencing jacket between fights. Due to the hot skin temperatures recorded during DE fights and in the recovery between fights, fencers could benefit from cooling strategies between fights to lower the thermal load placed on the body.

There was an average increase in T_{mask} ~1.10°C during DE fights, with an increase in T_{mask} as the DE rounds progressed from DE 1 to DE 7 (Figure 5.11). This could be due to the head being an important source of heat dissipation from the body during exercise and the protective fencing mask potentially impeding this heat loss due to covering the head completely. It has been shown that heat loss from the head is larger than the heat brought to the brain through arterial blood and can act as a heat sink for the body (Rasch et al., 1991).

The increase in T_{mask} could have impacted cognitive function of the athletes, as it has been previously shown that cognitive function, in particular complex tasks, are impaired during heat exposure (Gaoua et al., 2012, 2011). It has been shown that the face is an important mediator of thermal sensation and can improve exercise performance if cooled without a decrease in core and skin temperatures (Flouris & Schlader, 2015; Schlader et al., 2011). Furthermore, Gaoua et al. (2012) showed high T_{skin} impaired decision-making during heat exposure. This could impact fencers' decision-making processes during a fight if T_{skin} rises too high. Therefore, future research should consider assessing cognitive function during fencing.

During DE fights the participants perceptual ratings of exertion and thermal sensation were high (Table 5.9). Overall RPE was generally scored as a 15 (hard) or above and thermal sensation was rated on average as a 7.0 (hot). Therefore, this could have been due to higher T_{gast}, T_{skin}, T_{mask} and fight duration in the DE rounds than Poule rounds. Interestingly, RPE_O and thermal sensation remained high despite decreasing T_{gast} and T_{skin} during later DE rounds. Thermal sensation was also correlated positively to T_{skin}, differentiated RPE, distance covered, training load per minute, work to rest ratio and heart rate responses. However, thermal sensation was not correlated to T_{gast}. It has been previously shown that thermal sensation can be predicted from T_{skin} (Lan, Xia, Tang, Wyon, & Liu, 2019; Liu, Tian, Yang, & Deng, 2021; Nakayama, Suzuki, & Kameyama, 2009) suggesting perceptual sensations of heat could have been related to peripheral thermal factors (such as T_{skin} and active muscle activity) not central body temperature (i.e. T_{gast}). Therefore, there could have been a potential impact on cognitive performance due to participants feeling too hot or perceiving the effort as hard (Gaoua et al., 2012). As DE rounds are knockout rounds it is important for athletes to maintain function both physically and cognitively to maintain performance and progress through the rounds. Fencing is a tactical and cognitively demanding sport whereby fencers have to respond to an opponent's movements and decide when to initiate an attack to score points (Roi & Bianchedi, 2008). Therefore, increases in the perception of body temperature and exertion during fencing could impact a fencer's decision-making ability and allow opponents to score more points due to decreases in cognitive function. Cooling between fights may have a perceptual benefit for fencers that has been shown to benefit exercise performance (Gibson et al., 2020; Tyler et al., 2015)

There was a performance decrease in distance covered and distance covered per minute during the DE rounds, despite a similar work to rest ratio in the fights. Therefore, there could have potentially been a tactical shift later in the DE where participants moved less and were in more static combative periods to not give away hits to their opponent, however this is beyond the scope of this thesis. Furthermore, the work to rest ratios determined in this chapter was greater (~1.5-2:1 vs. ~1:1) than those reported previously for epée (Aquili et al., 2013; Bottoms et al., 2013; Roi & Bianchedi, 2008). Decreased distance covered and distanced covered per minute could also be due to the hot T_{skin}, high RPE_O, and hot thermal sensations recorded with participants covering less distance until they cool down.

5.5.3 Conclusions

Overall, this is the first study to show the thermoregulatory demands of fencing and in particular epée fencing. During Poule rounds there was a moderate rise in thermoregulatory variables such as T_{gast}, T_{skin}, T_{mask} and thermal sensation which could benefit fencers going into the DE rounds. During DE rounds there was a greater increase in these variables with T_{gast} staying above 38.0°C pre and 38.5°C post fight. There was also high T_{skin} and narrow core to skin temperature gradients reported especially in earlier DE rounds and had significant relationships between distance covered. During both Poule and DE rounds there was an increase in T_{skin} into the recovery between fights. Furthermore, participants perceived DE rounds as hard and hot indicating a potential impact on the cognitive performance of the participants. Perceptual ratings of heat and exertion were also be related more to peripheral thermoregulatory factors such as T_{skin}, and distance covered than central factors such as T_{gast}. Mask temperature and T_{skin} could indicate a micro-climate due to protective clothing in fencing that is hotter than the environment and could negatively impact fencing performance. Therefore, fencing athletes could potentially benefit from cooling strategies between fights, particularly in DE rounds, to lower the thermoregulatory demands of fencing and maintain performance in later DE rounds.

Chapter 4 and 5 both used a simulated competition protocol. To determine if this protocol is a valid measure of the physiological and thermoregulatory responses of epée chapter 6 will compare heart rate and movement data recorded in this thesis with data collected at actual competition using 3 participants recruited in chapters 4 and 5.

As highlighted in chapter 5 there is a high thermoregulatory demand of epée fencing especially in DE rounds with increasing T_{skin} in the recovery between fights. Therefore, cooling strategies between fights may be beneficial to lower the thermoregulatory demands of epée and maintain performance in later DE rounds. Chapter 7 will examine the effects of cooling between fights on physiological, thermoregulatory, perceptual, cognitive and performance variables during fencing.

Chapter 6

6 Study 3 – Pilot Testing: Heart Rate and Movement Responses to Simulated vs. Actual Epée Competition

6.1 Introduction

When researching sports performance, it is important to ensure the demands of simulated testing is similar to that of actual performance (Currell & Jeukendrup, 2008). This is to ensure a true representation of performance can be determined and valid results can be used by athletes and coaches. Laboratory protocols may differ from competition data due to missing skill-based components of performance, using average match analysis data and a lower stress response when simulating competition (Bridge, McNaughton, Close, & Drust, 2013; Drust et al., 2007). However, some protocols have the ability to produce similar physiological profiles to competition such as the DRUST protocol in soccer (Drust et al., 2007).

Therefore, the aim of this chapter was to compare heart rate and movement data from the simulated competition protocols, in chapter 4 and 5, to actual competition data in competitive fencers during pilot testing. Furthermore, heart rate data from this thesis was compared with previous research by Bottoms et al. (2013) to compare similar methods of simulated fencing competition and to compare this thesis to previous laboratory fencing data. Data was collected from three participants at the British Fencing National Championships who had also volunteered to take part in the studies relating to chapter 4 or 5.

6.2 Methods

6.2.1 Participants

Three well-trained epée fencers volunteered to participate in this study. All three participants had volunteered to take part in either chapter 4 or chapter 5 of this thesis. Table 6.1 shows the participant characteristics. All participants provided informed consent to take part in the study as described in chapter 3.2. Participant numbers were low due to some fencers being worried of a potential interference of the data collection during the National Championships.

Table 6.1. Participant characteristics (n = 3)

Variable	Mean ± SD
Age (years)	19 ± 1
Stature (cm)	177.4 ± 4.7
Body Mass (kg)	72.2 ± 0.9

6.2.2 Procedures

Heart rate and movement data was collected from the participants at the 2019 British Fencing National Championships. This competition was selected to ensure a high standard of competition for the participants. Each participant competed in 6 Poule fights and then DE fights until knocked out. One participant was knocked out in the last 64, one participant was knocked out in the last 16 and one participant was knocked out in the last 8. During all Poule and DE fights each participant had heart rate and movement data collected. The participants data from chapter 4 and chapter 5 was taken from the same round in the Poule and DE rounds during competition. The first six Poule fights from the chapters in this thesis were used to compare to the six Poule fights at the National Championships. The participant knocked out in the last 64 had data compared to DE 1, the participant knocked out in the last 16 had data compared to DE 1, DE 2 and DE 3 for the last 64, 32 and 16, respectively, and the participant knocked out in the last 8 had data compared to DE 1, DE 2, DE 3 and DE 4 for the last 64, 32, 16 and 8, respectively. This method was chosen to compare the same time point in the National Championships to that of the chapters in this thesis.

Furthermore, as shown in chapter 4 and chapter 5 various physiological and movement variables change over the DE rounds. Due to potential differences in fencing styles data from only those participants recruited in chapter 4 and chapter 5 that volunteered to take part in this chapter were used for comparison and not data from other participants.

6.2.3 Heart Rate Monitoring and Movement Data

During the National Championships, chapter 4 and chapter 5 heart rate and movement data were collected as described in chapter 3.9. The following variables were taken for all Poule and DE fights: HR_{av}, HR_{max}, fight duration, distance covered, distance covered per minute, average speed, and training load per minute. Average and maximum heart rate were also taken from research by Bottoms et al. (2013).

6.2.4 Statistical Analysis

Data are presented as mean ± 2SD unless stated otherwise. Two SD was used as 95% of data points should fall within 2SD of the mean (Altman & Bland, 2005). Data was analysed as described in chapter 3.14. Paired-Students t-test analysis was undertaken to compare HR_{av}, HR_{max}, fight duration, distance covered, distance covered per minute, average speed, and training load per minute for Poule and DE fights between the National Championships and the chapters in this study. Effect sizes (ES) were calculated as described in chapter 3.14.

6.3 Results

6.3.1 Heart rate

Table 6.2 shows the comparison of HR_{av} and HR_{max} between the National Championships, chapter 4/5, and previous research by Bottoms et al. (2013). This thesis produced similar HR_{av} and HR_{max} results for Poule fights to research by Bottoms et al. (2013) during the simulated (SIM) fencing protocol but were greater than the laboratory (LAB) fencing protocol (Bottoms et al., 2013). This thesis produced greater HR_{av} and HR_{max} during DE fights than both the SIM and LAB fencing protocols by Bottoms et al. (2013). Table 6.2 and Figure 6.1 A-D shows the difference for HR_{av} and HR_{max} for Poule and DE fights for during the National Championships and the data collected in chapter 4/5. There were no significant differences for both Poule ($t_{(17)}$ = 1.694, p = 0.109, ES = 0.55) and DE ($t_{(7)}$ = 1.549, p = 0.165, ES = 0.92) for HR_{max} between the National Championships and chapter 4/5. Furthermore, the majority of individual data points were within two standard deviations of the National Championship mean data. There were significantly greater HR_{av} recorded for both Poule ($t_{(17)}$ = 2.285, p = 0.035, ES = 0.64) and DE ($t_{(7)}$ = 4.851, p = 0.002, ES = 2.66) fights in the National Championships than chapter 4/5. Despite this for Poule fights the majority of data points were with two standard deviations of the National Championship mean data and were all within the range, however for DE fights 50% of the data points were outside two standard deviations of the National Championship mean data. The simulated fencing competition in chapter 4/5 produced a more representative HR_{av} and HR_{max} during competition than the study by Bottoms et al. (2013) as shown in Table 6.2.

Table 6.2. Comparison of average and maximal heart rate recorded in the National Championships, this thesis and research by Bottoms et al (2013), data presented as mean ± SD.

	National Championships	This Thesis	Bottoms et al. (2013) LAB Protocol	Bottoms et al. (2013) SIM Protocol
Poule HR_{av} (% HR_{APM})	83.8 ± 5.2*	80.5 ± 5.2	74.9 ± 8.6	79.5
Poule HR_{max} (% HR_{APM})	90.9 ± 5.2	88.1 ± 4.9	82.8 ± 7.1	88.7
DE HR_{av} (% HR_{APM})	90.6 ± 2.3*	85.1 ± 1.8	74.3 ± 7.2	80.5
DE HR_{max} (% HR_{APM})	97.8 ± 2.6	94.9 ± 3.6	83.7 ± 6.7	91.8

DE = Direct Elimination, LAB = laboratory protocol from Bottoms et al. (2013), SIM = simulated fencing from Bottoms et al (2013), HR_{av} = average heart rate, HR_{max} = maximum heart rate, * significant difference to chapter 4/5 (comparison between National Championships and chapter 4/5 only).

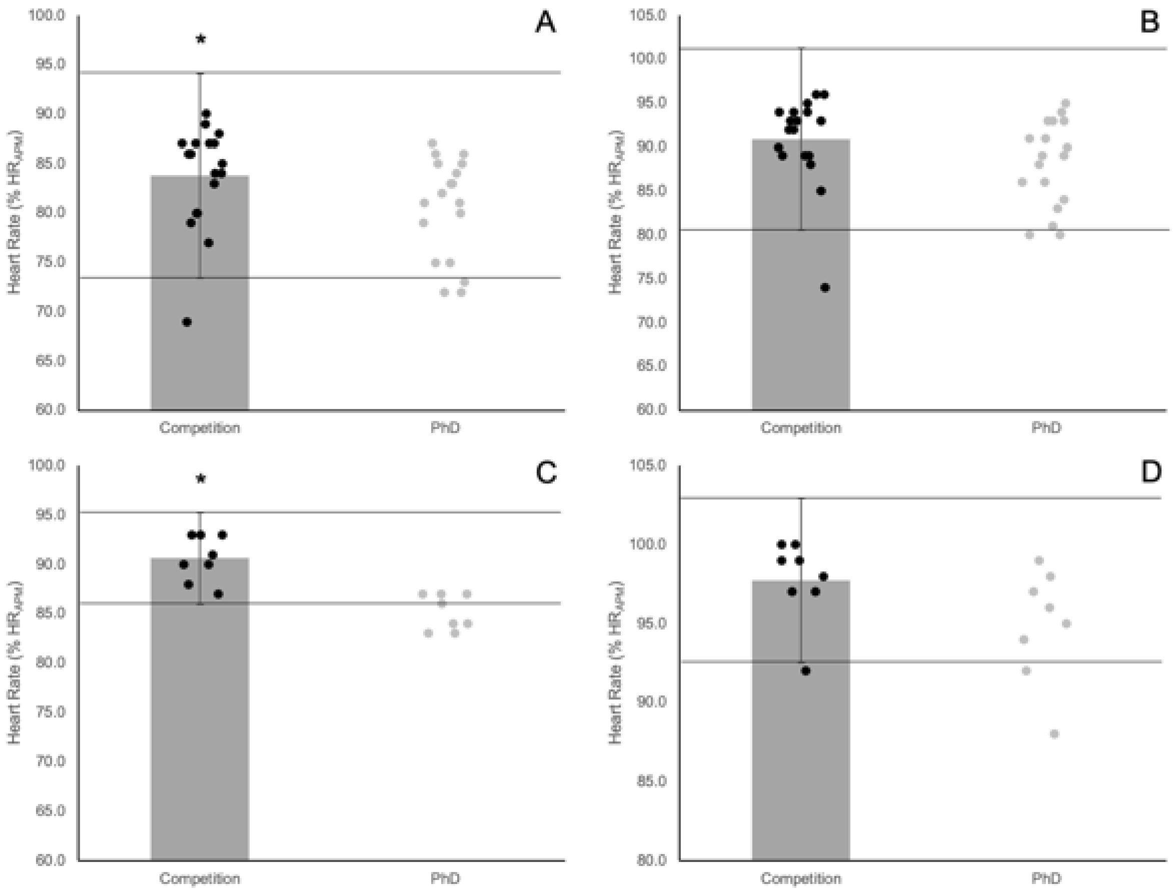


Figure 6.1. A-D. Poule average (A), Poule maximum (B), DE average (C) and DE maximum (D) heart rate (% HR_{APM}) comparison between National Championship and chapter 4/5 data. circles represent individual data points. * significant difference to chapter 4/5 $p < 0.05$

6.3.2 Distance Covered

Figure 6.2. A-D shows the distance covered and distance covered per minute during Poule and DE fights between the National Championships and chapter 4/5. There were no significant differences for both Poule ($t_{(17)} = -1.146$, $p = 0.268$, ES = 0.47) and DE ($t_{(7)} = 0.335$, $p = 0.747$, ES = 0.20) for distance covered between the National Championships and chapter 4/5. Furthermore, the majority of individual data points were within two standard deviations of the mean National Championships mean data. There were no significant differences for distance covered per minute recorded for Poule fights between the National Championships and chapter 4/5 ($t_{(17)} = 0.238$, $p = 0.815$, ES = 0.08), all data points were within two standard deviations of the National

Championship mean data. There was a significantly greater distance covered per minute during DE fights in the National Championships than chapter 4/5 ($t_{(7)}$ = 2.714, p = 0.030, ES = 1.46). Despite this 75% of data points were with two standard deviations of the National Championship mean data.

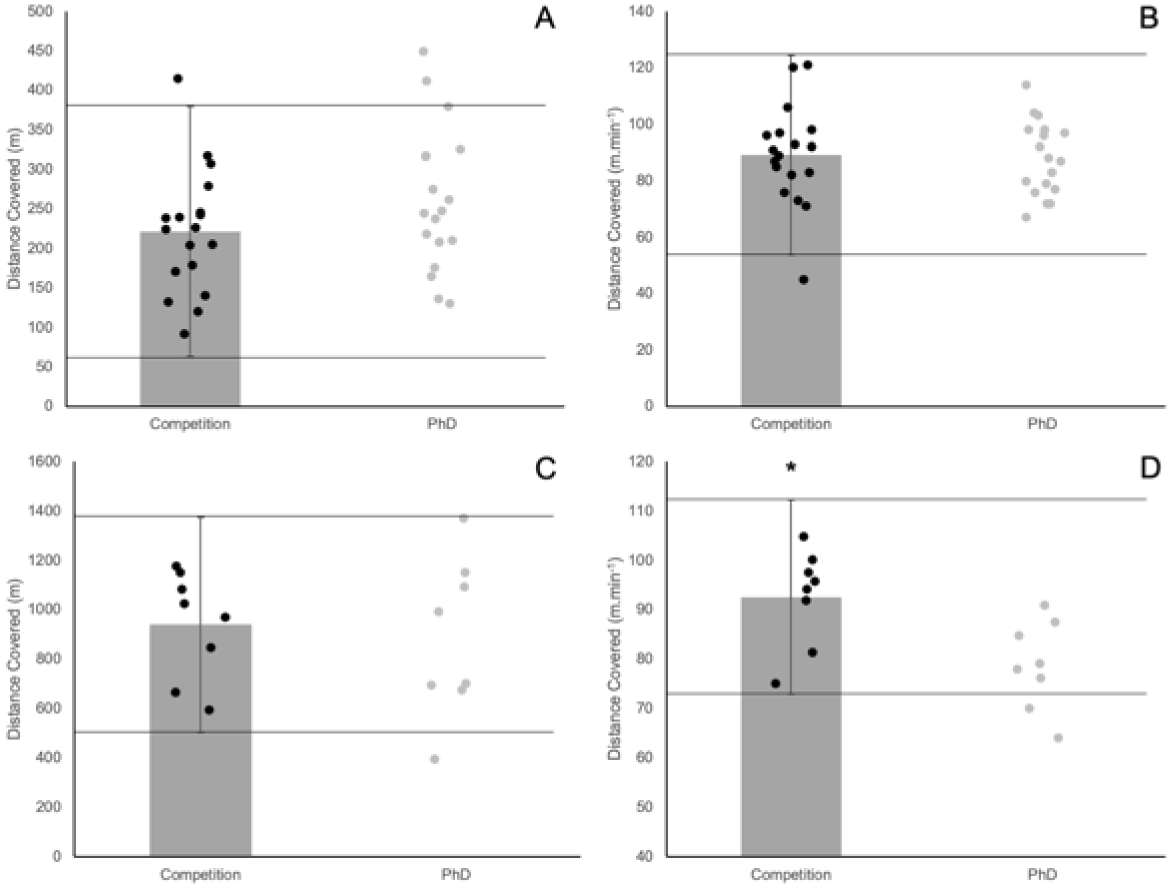


Figure 6.2. A-D. Poule distance covered (A), Poule distance covered per minute (B), DE distance covered (C) and DE distance covered per minute (D) comparisons between competition and PhD data. Circles represent individual data points. * significant difference to thesis data $p < 0.05$

6.3.3 Average Speed

There were no significant differences for both Poule ($t_{(17)}$ = 0.286, p = 0.778, ES = 0.10) and DE ($t_{(7)}$ = 2.277, p = 0.057, ES = 1.21) for average speed between the National Championships and chapter 4/5 (Figure 6.3). Furthermore, all the individual data points were within two standard deviations of the National Championship mean data.

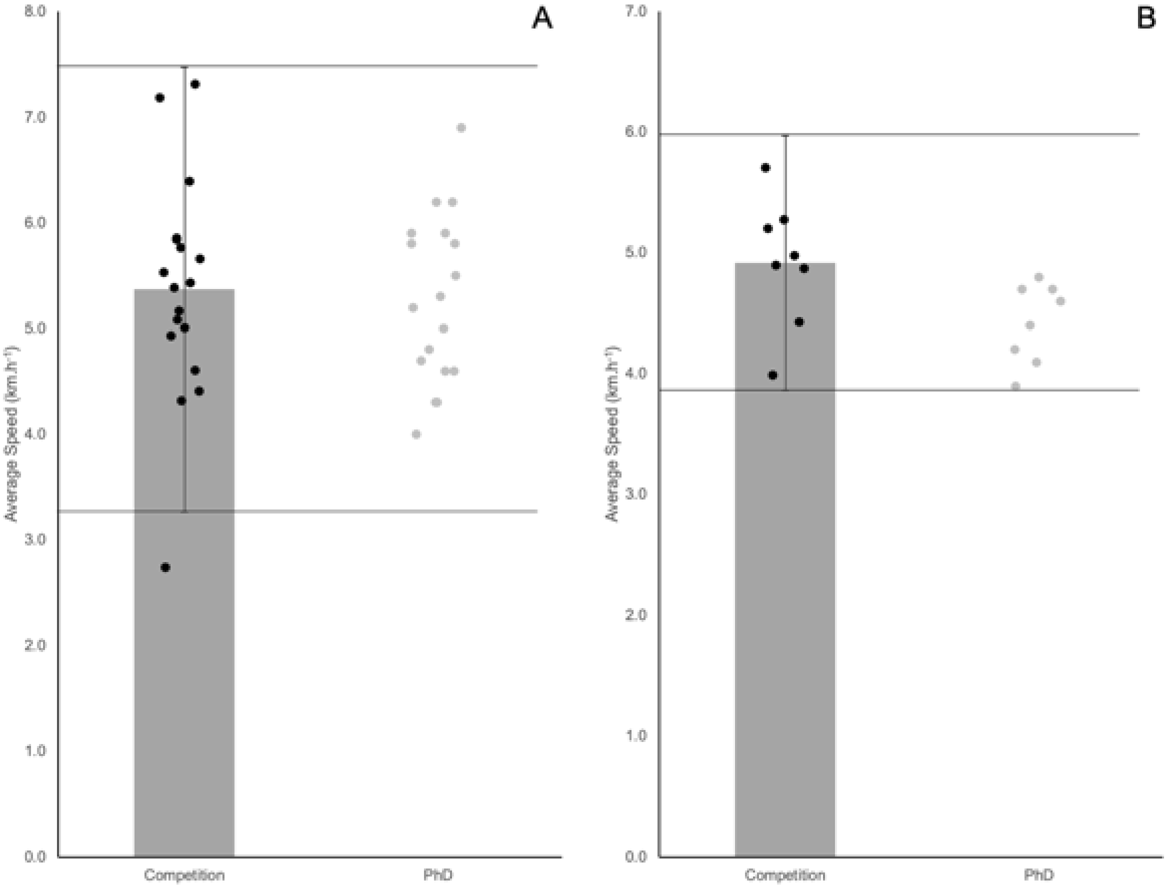


Figure 6.3. A-B. Poule (A), and DE (B) average speed (km.h^{-1}) comparison between National Championships and chapter 4/5 data. Circles represent individual data points.

6.3.4 Fight Duration

There were no significant differences for both Poule ($t_{(17)}$ = 1.280, p = 0.218, ES = 0.52) and DE ($t_{(7)}$ = -0.211, p = 0.839, ES = 0.16) for fight duration between the National Championships and chapter 4/5 (Figure 6.4). Furthermore, the majority of individual data points were within two standard deviations of the National Championship mean data.

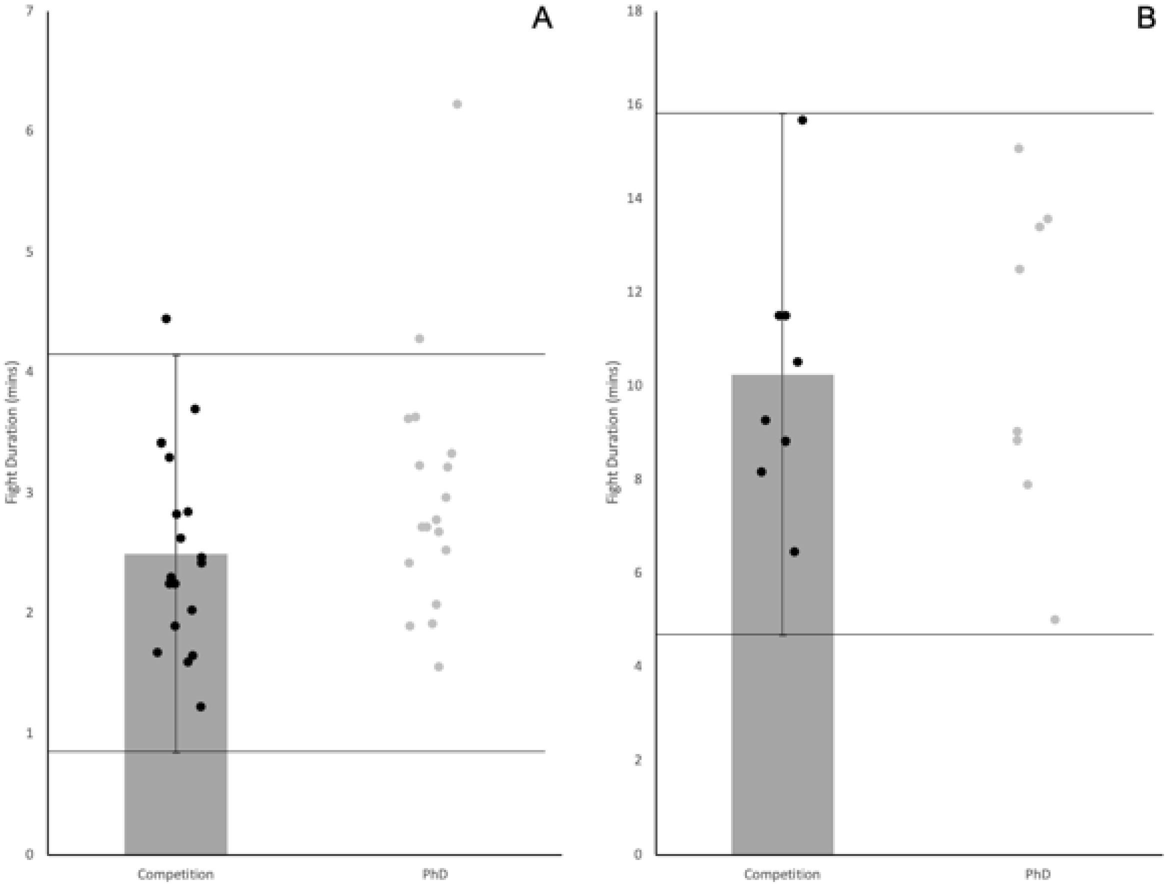


Figure 6.4. A-B. Poule (A), and DE (B) fight duration (mins) comparison between National Championships and chapter 4/5 data. Circles represent individual data points.

6.4 Discussion

The aims of this study were to compare the heart rate and movement responses of the simulated competition protocol in this thesis (chapter 4/5) to actual competition. Heart rate data was also compared to previous research by Bottoms et al. (2013). The key findings highlighted that the protocol used in this thesis was representative of actual competition.

Maximal heart rate was similar between this thesis and the National Championship data for both Poule and DE fights. Despite significantly lower HR_{av} for Poule and DE fights between this thesis and the National Championships the majority of individual data points were within two standard deviations of the mean National Championships data. Direct Elimination average heart rate had a greater discrepancy compared to Poule fights for this thesis and the National Championships than Poule fights (~5% for DE vs. 3% for Poule). This could potentially be due to the differences in competition standard. With the National Championships being the highest competition standard in the UK there could have been a greater release of catecholamines to increase heart rate due to higher levels of stress and anxiety during the National Championships compared to this thesis (Viru et al., 2010). Due to the knockout nature of the National Championships only 8 DE fights were completed for analysis, which could have limited the comparison to this thesis. However, the heart rate response during DE fights in this thesis produced a more representative response than previous research by Bottoms et al. (2013). The results from this study also highlights the requirement for physiological testing to match a competition structure in fencing, as the heart rates recorded in both the National Championships and this thesis were considerably higher than the LAB protocol described in previous research (Bottoms et al., 2013). This could be explained by the competitive nature and the need for decision making during a fight of the National Championships and this thesis when competing against an opponent, whereas the LAB protocol by Bottoms et al. (2013) only involved fencing footwork and lunge movements.

This thesis produced similar movement demands to that of the National Championships as evident from distance covered, average speed during a fight and fight duration. There was significant difference for distance covered per minute in the

DE fights between this thesis and the National Championships, however 75% of the data points were within two standard deviations of the National Championship mean data. There were, however, no significant differences for Poule fights for distance covered per minute. Lower distances covered per minute in this thesis compared to the National Championship data for DE fights could have been due to participants subconsciously knowing they had 7 DE fights in this thesis so might have paced themselves more in earlier DE rounds in this thesis to not fatigue too early. Therefore, if a participant was losing in a DE fight in the National Championships, they could have covered more distance per minute to win points or face being knocked out of the competition. This is evident as the highest distance covered per minute by each of the three participants was in the DE fight where they were knocked out of the National Championships. Furthermore, there could have been differences in opposition fencing styles in this thesis compared to the National Championships. Competing against a more attacking opponent may cause a greater distance covered per minute due to avoiding attacks than defensive styles whereby fights may be more tactical with less movement.

Overall, there were similar heart rate and movement responses of the Poule and DE fights in this thesis when compared to the National Championship data. Furthermore, the simulated competition protocol used in this thesis is in-line with actual competition data and matched real-world data more specifically than previous protocols, especially for the DE fights. Therefore, the simulated style of competition used in this thesis is a better research design for understanding the demands of epée fencing performance going forwards.

Chapter 7

7 Study 4 – The Effects of External and Mixed-Method Cooling on Epée Fencing Performance

7.1 Abstract

Fencing athletes are required to wear full body protective clothing when competing which can cause high T_{skin}, T_{gast}, and thermal sensation especially in DE fights as shown in chapter 5. The aims of this chapter were to determine the effects of external (EXT) and mixed-methods (MIX) cooling on physiological, perceptual and performance responses of epée fencing. Ten trained epée fencers competed in 3 DE fights with cooling applied (control (CON), EXT (wearing an ECV), or MIX (ECV + cold-water ingestion) for 10 minutes during the rest between fights. During DE fights T_{gast}, T_{skin}, T_{au}, HR, T_{mask}, blood lactate concentration, movement characteristics, points scored and conceded, points difference, thermal sensation, thermal comfort, and differentiated RPE were recorded. Cognitive function was assessed pre DE 1 and post DE 3. There were significantly lower ($p < 0.05$) T_{skin} recorded in DE 2 and DE 3 (~0.8-0.9°C) for EXT and MIX than CON. There was a lower thermal sensation pre DE 2 and DE 3 for EXT and MIX and post DE 2 and DE 3 for MIX compared to CON. There seemed to be an individual response for cooling on performance, with 7/10 participants having a positive points difference in DE 3 in MIX compared to 4/10 in both EXT and CON. Overall, EXT and MIX are practical, quick, and simple cooling methods for epée fencers, that decreases T_{skin} and thermal sensation of fencing performance. However, fencers should determine which is the most effective method to use in training prior to competition.

7.2 Introduction

As mentioned in chapter 2.1 fencing competitions tend to last between 9-11 hours consisting of Poule and DE fights. Between DE fights there is a minimum of 10 minutes rest which provides an opportunity for strategies to be implemented to maintain and improve performance. More specifically, cooling strategies may reduce the thermal load of the previous fight that was evident in chapter 5. To the authors knowledge there has been no previous research reporting efficacy of effective between fight cooling strategies in fencing.

As highlighted in chapters 4 and 5 epée fencing provides a high cardiovascular strain, especially during the DE rounds. Gastrointestinal temperature (T_{gast}) post fight in the DE rounds was consistently greater than 38.5°C with some participants recording T_{gast} >39.0°C. Chapter 5 also reported pre-fight T_{gast} for DE fights above 38.0°C. Furthermore, mean skin temperature (T_{skin}) was considered 'hot' >35°C (Sawka et al., 2012) during DE fights with an average increase in T_{skin} into the recovery between fights ~0.75°C by the 5th minute of recovery. The increase in T_{skin} during the recovery between fights could indicate longer recovery times are required due to increased skin vasodilation to dissipate heat. With regards to performance measures, chapter 5 reported a decrease in distance covered in DE 7 compared to DE 1 which was associated with high T_{skin} and thermal sensation. Therefore, there could have been a tactical shift to a more static style of fencing to offset fatigue in later DE rounds, due to increased cardiovascular strain to dissipate heat. These results highlight that fencers could benefit from cooling interventions pre or between fights to reduce both the thermal and cardiovascular strain experienced during competition, particularly during DE fights. However, cooling methods should ensure fencers do not cool too much and maintain muscle temperature to ensure there are no decrements in power, which is a key determinant of fencing performance (Turner et al., 2014). Cooling methods, such as ice/cooling vests and cold water/ice slurry ingestion, targeting the core and avoiding cooling the leg muscles that are involved in powerful fencing movements such as lunges may be more beneficial for fencing.

In addition to the physiological demands of fencing mental fatigue could also impact upon performance (chapter 2.1) as suggested in chapter 4 and 5. Ratings of perceived exertion in chapters 4 and 5 were rated as ‘hard’ with thermal sensation in chapter 5 rated as ‘hot’. These ratings could have led to decreases in cognitive function, and motivation to perform (Gaoua et al., 2012, 2011) especially as competition progressed in the DE rounds. During competition it could be important to maintain cognitive function during knockout DE rounds. Mental fatigue has been shown to cause increased perception of effort during cycling exercise which decreased performance (Marcora & Staiano, 2010; Marcora et al., 2009). It has also been previously shown that T_{core} >38.5°C (Gaoua et al., 2011; Schmit et al., 2017) and T_{skin} ~35-36°C (Gaoua et al., 2012) can negatively impact cognitive function. As shown in chapter 5 fencers' T_{core} was >38.5°C and T_{skin} was >34.5°C (>35°C in early DE rounds) which could, therefore, negatively affect cognitive function, and cause fencers to make mistakes through decreased decision-making ability, concentration and focus that could result in being knocked out of a competition.

There are various different techniques and methods proposed for cooling athletes to maintain or improve exercise performance (Bongers, Thijssen, et al., 2015), as discussed in chapter 2.7. These include internal methods, external methods and mixed-method approaches which combine internal and external methods (Bongers et al., 2017; Gibson et al., 2020). As discussed in chapter 2.7 and by Bongers et al. (2017) these cooling interventions have been shown to improve exercise performance on average between 3.4-7.3% when used as pre-cooling techniques, and 4.4-18.5% when used as per-cooling. However, the practicalities of some of these interventions do not lend themselves to fencing as discussed in chapter 2.7. At competition fencers would have access to cold water so cold-water ingestion and evaporative cooling vests (ECV) may provide a more practical and feasible option, despite not being as aggressive for cooling the body (Bongers et al., 2017). Nevertheless, there are benefits to these less aggressive methods on the physiological, perceptual and performance responses during exercise as described in chapters 2.7.2 and 2.7.3 which could transfer well to fencing. There have been no reports combing ECV and cold-water ingestion which are two simple and practical methods for fencers to employ at competition with no requirement for freezers to store ice packs for other external methods of cooling, or power requirements for fan cooling. As well as cooling improving traditional performance measures (i.e. time trial and time to exhaustion), cooling has also been shown to improve cognitive function of complex tasks

(Bandelow et al., 2010; Lee et al., 2014). Fencing would certainly be classified in this category due to the technical and tactical elements and responding to an opponent's actions (Roi & Bianchedi, 2008).

The aims of this chapter were, therefore, to assess the effects of external (EXT; evaporative cooling vest) and mixed-method (MIX; evaporative cooling vest and cold-water ingestion) cooling interventions performed during the recovery period between DE fights on the physiological responses, cognitive function, and performance variables during fencing. A secondary aim was to determine if MIX cooling would provide a greater physiological and performance benefit (as indicated by points difference) than EXT cooling.

7.2.1 Hypotheses

H1: EXT and MIX cooling between DE fights will lower the thermoregulatory demands of fencing (T_{core}, $T_{skin,}$ and T_{mask}).

H2: EXT and MIX cooling between DE fights will lower the cardiovascular demands of fencing (HR_{av}, and HR_{max}).

H3: EXT and MIX cooling between DE fights will improve or maintain fencing performance (points scored, points conceded, points difference, and movement data).

H4: EXT and MIX cooling between DE fights will benefit perceptual (RPE, thermal sensation and thermal comfort) and cognitive function during fencing performance.

H5: MIX cooling would have a greater physiological, performance, perceptual and cognitive function benefit to fencing performance than EXT cooling.

7.3 Methods

7.3.1 Participants

Ten (eight male and two female) trained epée fencers volunteered to take part in this study. Post-hoc power analysis (ANOVA repeated measures, within factors) on effect size for T_{skin} ($\eta^2 = 0.327$, using $n = 10$ and $\alpha = 0.05$) indicated this sample size provided adequate statistical power. All fencers competed at a club level, trained a minimum of two times per week in fencing and had a minimum of two years previous experience in epée fencing. Table 7.1 shows the participant characteristics.

Table 7.1. Participant characteristics

Variable	Mean ± SD
Age (years)	35 ± 9
Stature (cm)	174.8 ± 8.1
Body Mass (kg)	74.7 ± 14.6
Fencing (Hours per Week)	3.2 ± 1.2
Strength and Conditioning (Hours per Week)	2.2 ± 3.0
Previous Fencing Experience (years)	15.6 ± 9.5

7.3.2 Procedures

Participants were required to attend three testing sessions conducted at their usual training venue in a sports hall. During testing the participants completed three DE fights, following a standardised 10 minute warm-up, with 15 minutes rest between fights whereby one of the three cooling interventions were implemented for 10 minutes in a randomised order: EXT, MIX or control (CON) condition. The EXT condition involved participants wearing a ECV and ingesting 300ml of room temperature water (21.8 ± 2.0°C). The MIX condition involved participants wearing a ECV and ingesting 300ml of cold water. The CON involved participants ingesting 300ml of room temperature water only. Room temperature water was given to control for hydration in the CON and EXT cooling interventions. All DE fights were standardised for volume with 3 x 3-minute bouts with 1-minute rest between bouts undertaken on a rolling clock. During each testing session the participants competed against the same opponent matched for ability by the coach for all 3 DE fights to control for differences in fencing style.

Due to differences in the thermoregulatory responses and performance (in hot and humid conditions) during different phases of the menstrual cycle (Janse De Jonge, Thompson, Chuter, Silk, & Thom, 2012), and potential influence of hormonal contraceptives on thermoregulatory responses (Kaciuba-Uscilko & Grucza, 2001) both female participants were tested during the follicular phase of the menstrual cycle. Neither female participant reported the use of hormonal contraceptives. The follicular phase of the menstrual cycle has been shown to have a lower resting (~0.3-0.7°C) and exercise core temperature than the luteal phase due to lower levels of progesterone (F. C. Baker, Siboza, & Fuller, 2020; Janse De Jonge et al., 2012). Furthermore, during hot and humid conditions the luteal phase demonstrates decreased endurance exercise performance compared to the follicular phase (Janse De Jonge et al., 2012). Therefore, the follicular phase was chosen as protective fencing equipment creates a hot micro-climate as shown in chapter 5 and was less likely to affect physiological responses and performance due to hormonal influences of progesterone.

Preliminary questionnaires, body mass and stature were recorded as described in chapters 3.2 and 3.3. Body mass was recorded pre and post each testing session to assess sweat rate. Participants were instructed to towel dry before body mass measurements. Physiological, cognitive, and perceptual measurements were recorded during each testing session as shown in Figure 7.1.

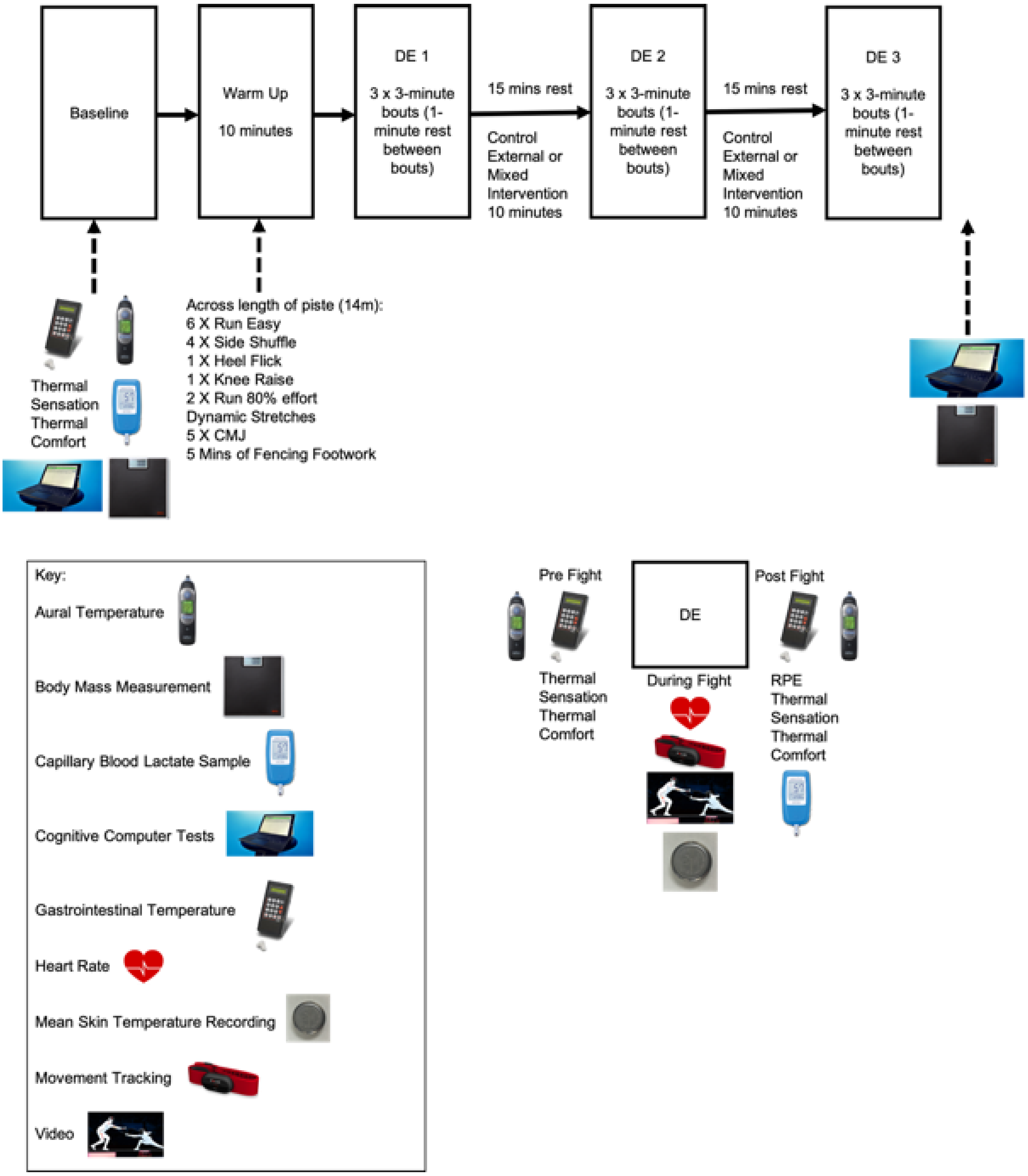


Figure 7.1. Timeline of testing protocol and measurement timings.

7.3.3 Environmental Conditions

Environmental conditions were recorded as described in chapter 3.4. Environmental conditions were classed as a low risk of potential heat illness or hyperthermia (Sawka, Leon, Montain, & Sonna, 2011). Table 7.2 shows the environmental conditions between the three intervention conditions (CON, EXT and MIX). There were no significant differences ($p > 0.05$) between the three interventions for WBGT, black bulb temperature, and humidity. There was a significant difference between conditions for ambient temperature ($F_{(2,18)} = 3.729$, $p = 0.044$, $\mu = 0.293$), however post-hoc analysis could not determine where the difference occurred (CON vs. EXT $p = 0.081$, CON vs. MIX $p = 0.764$, and EXT vs. MIX $p = 0.420$). Furthermore, WBGT temperature would account for any differences in ambient temperature and there were no significant differences between trials for WBGT.

Table 7.2. Environmental conditions for the CON, EXT, and MIX trials (mean ± SD).

Trial	WBGT (°C)	Ambient Temperature (°C)	Black Bulb Temperature (°C)	Humidity (%)
CON	18.3 ± 1.4	22.9 ± 1.8	22.6 ± 1.7	52.4 ± 7.7
EXT	17.3 ± 1.6	21.7 ± 1.4	21.4 ± 1.3	53.2 ± 9.6
MIX	17.6 ± 1.7	22.3 ± 1.8	22.0 ± 1.8	50.2 ± 6.2

CON = Control, EXT = External, MIX = Mixed-Methods, WBGT = Wet Bulb Globe Temperature

7.3.4 Warm-up

Participants completed a 10-minute standardised warm-up along the length of a fencing piste (14m), led by the researcher. The warm-up consisted of: running, side shuffling, heel kicks, knee raises, dynamic stretching, counter movement jumps (CMJ) and fencing footwork. The warm-up was completed along the length of a fencing piste (14m). The fencing footwork consisted of a standard fencing warm-up where the participants started in the on guard (Figure 2.2A) stance and followed the researcher's movement forwards and backwards on the piste whilst maintaining the same distance between themselves and the researcher, using appropriate fencing footwork. When the researcher clapped, the participants were required to perform an attacking lunge. Participants completed the warm-up in full protective fencing equipment apart from the mask and sword. To ensure the warm-up was consistent during the three cooling conditions differences in average heart rate (HR_{av}), distance covered and overall RPE were recorded.

7.3.5 Direct Elimination Fight

During each testing session the participants competed in three DE fights (3 x 3-minute bouts with 1-minute rest between bouts). To standardise exercise duration the DE fights were conducted using a rolling clock, therefore a DE fight lasted 11 minutes in total including rest periods between bouts. Points scored, points conceded, and points difference were recorded as performance measurements during DE fights. The participants competed against the same fencer during the three DE fights in each testing session, to control for differences in fencing style. Between each DE fight there was a 15-minute rest period whereby either the CON, EXT or MIX interventions were applied for 10 minutes. The 15 minute rest period is representative of a typical rest period between DE fights during competition.

7.3.6 Cooling Interventions

During the 15-minute resting period between DE 1 and DE 2 (intervention period 1) and between DE 2 and DE 3 (intervention period 2) the participants were given the cooling intervention or CON for 10 minutes. The same intervention was applied during both rest periods in each trial. For all intervention periods participants removed their fencing jacket and had only one upper body layer beneath the jacket. To control for hydration status and the effects of dehydration on performance during the CON and EXT trials participants consumed the same volume (300ml) of room temperature water (21.8 ± 2.0°C) as cold water (1.4 ± 0.5°C) in the MIX intervention. Aliquots of 300ml were chosen as this has been shown to have an effective benefit on T_{core} and T_{skin} during exercise (Byrne et al., 2011; Lee et al., 2008). Furthermore, 300ml would be an easy volume for fencers to calculate at competition when filling up their water bottle. Single aliquots were given over multiple aliquots as done by Byrne et al (2011) and Lee et al. (2008) due to participants having a short recovery period between fights (10 minutes for cooling interventions to be applied). Furthermore, the 3 x 300ml aliquots given by Byrne et al. (2011) and Lee et al. (2008) were given over 30-35 minutes, therefore it was calculated that one aliquot per ~10 minutes rest should be given. Water temperature was measured by placing an iButton thermochron inside a sealed polythene bag which was placed inside the room temperature and cold-water bottles. The iButton was programmed as described in chapter 3.8. The cold-water bottles were placed inside an ice box filled with ice and were placed inside the ice box a minimum of 3 hours before the testing.

7.3.6.1 Control Intervention

The CON intervention consisted of the participants consuming 300ml of room temperature water (21.8 ± 2.0°C). Participants were required to consume the water within the first 2 minutes of the intervention.

7.3.6.2 External Cooling Intervention

The EXT cooling intervention consisted of the participants wearing the ECV (Figure 7.2; BodyCool Xtreme Evaporative PVA Cooling Vest, Inuteq, Deventer, The Netherlands) for 10 minutes and consuming 300ml of room temperature water (21.8 ± 2.0°C) as in the CON trial. The ECV were activated as per manufacturer instructions by submerging the jacket in room temperature water for a minimum of one minute and wringing out the excess water. The Polyvinyl Alcohol (PVA) fabric panels in the vest allows evaporation of heat from the body through the water absorbed into the jacket. The jacket provides up to 15°C cooling below ambient temperature (EZ Cooldown, 2021) and was worn on the upper body. In house testing showed average cooling temperature of the jacket was 18.4 ± 0.2°C at an ambient temperature of 20.3 ± 0.0°C on Day 1 and 18.4 ± 0.2°C at an ambient temperature of 20.4 ± 0.2°C on Day 2. In house reliability testing showed excellent ICC ratings between different areas of the jacket and for individual measurement sites across two separate days (Appendix C).

Figure 7.2. BodyCool Xtreme Evaporative PVA Cooling Vest. Image taken from EZ Cooldown website (EZ Cooldown, 2021).

7.3.6.3 Mixed-Method Cooling Intervention

The MIX intervention consisted of wearing the ECV (Figure 7.2; BodyCool Xtreme Evaporative PVA Cooling Vest, Inuteq, Deventer, The Netherlands) for 10 minutes and consuming 300ml of cold water (1.4 ± 0.5°C). The ECV were activated and worn as described in chapter 7.3.6.2.

7.3.7 Points Scored and Work to Rest Ratio

Participants were connected to a conventional commercially available electronic fencing scoring system. All DE fights were videoed using a camcorder (Sony CX450 Handycam, Sony Europe B.V. Weybridge, U.K) recording at 30Hz with the scoring system in view and on guard line in view. Points scored by each participant were determined from the video recording using the electronic scoring system. Points difference was also calculated for each DE fight by subtracting points conceded from points scored. Work to rest ratios were calculated for all DE fights as described in chapter 3.11.

7.3.8 Heart Rate Monitoring and Movement Data

Heart rate and movement data were recorded as described in chapter 3.9. Both absolute heart rate (beats.min^{-1}) and relative heart rate (% HR_{APM}) average heart rate (HR_{av}) and maximum heart rate (HR_{max}) were recorded during the warm-up and for all DE fights. Distance covered (m), distance covered per minute (m.min^{-1}), average speed (m.s^{-1}) and peak speed (m.s^{-1}) were recorded for the warm-up and all DE fights.

7.3.9 Training Load

Training load (AU) and training load per minute (AU.min^{-1}) were determined as described in chapter 3.10.

7.3.10 Gastrointestinal Temperature Measurements

Gastrointestinal temperature was measured as described in chapter 3.7.1. During each condition T_{gast} was measured pre and post each DE fight. Due to issues with the gastrointestinal pills not turning on when activated participants were given the pills upon arrival ~60 minutes before DE 1. However, likely due to the core temperature pills not being far enough into the digestive tract core temperature readings were influenced by the fluid consumed during the intervention periods. Therefore, halfway through the data collection period core temperature was also measured for all remaining participants using aural temperature (T_{au}) as described in chapter 3.7.2.

Overall, valid full data sets for gastrointestinal temperature across all three conditions were obtained for 6 participants and T_{au} for 5 participants. Due to uncertainty of the gastrointestinal pills results are presented for T_{au} with T_{gast} results (for the 6 participants) presented in Appendix D.

7.3.11 Skin Temperature Measurements

Mean skin temperature (T_{skin}) was measured and calculated as described in chapter 3.8. Mean skin temperature was calculated during all DE fights, in the first and tenth minute of intervention period 1 (recovery period where cooling intervention or CON was applied for 10 minutes between DE 1 and DE 2) and intervention period 2 (recovery period where cooling intervention or CON was applied for 10 minutes between DE 2 and DE 3) for all conditions.

7.3.12 Mask Temperature Measurements

Fencing T_{mask} was determined by placing an iButton thermochron (as described in chapter 3.8) inside the top of the fencing mask so it did not disturb the vision of the participants. Mask temperature was measured during all DE fights.

7.3.13 Blood Lactate Concentration

Capillary blood lactate samples were collected and analysed as described in chapter 3.6.2. Capillary blood samples were collected at baseline and post all DE fights. Capillary blood samples were collected at baseline after a minimum of 10 minutes rest. Post fight capillary blood samples were collected within 3 minutes of the fight terminating. Capillary blood samples were collected for 5 participants only during this study, this was due to limited time for testing during the training sessions at the fencing clubs.

7.3.14 Perceptual Measurements

Differentiated ratings of perceived exertion, and thermal sensation were recorded as described in chapter 3.12 and chapter 3.13, respectively. Differentiated RPE was collected immediately post fight for all DE fights. Thermal sensation was recorded pre and post all DE fights. Thermal comfort was recorded using the 6-point scale by (Zhang & Zhao, 2008), Figure 7.3. Participants were familiarised on how to use the thermal comfort scale for accurate recordings.

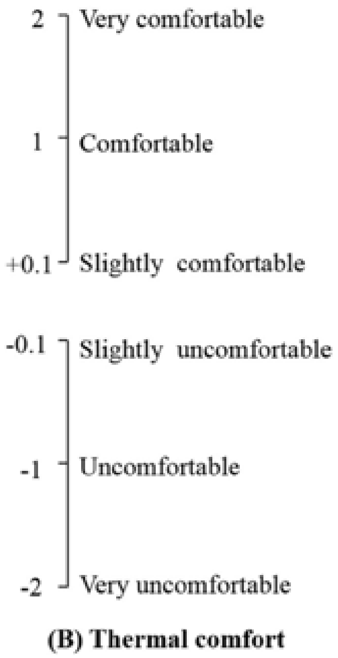


Figure 7.3. Thermal Comfort Scale.

7.3.15 Cognitive Function Tests

Participants completed a battery of cognitive function tests lasting approximately 15 minutes: Corsi Block-tapping test, Stroop test, and Visual search test. The participants completed the battery of cognitive function tests pre DE 1 and post DE 3. Each participant completed the tests on a laptop using the Psychology Experiment Building Language software (PEBL; Mueller & Piper, 2014). Computer-based cognitive tests have been shown to be as effective as sport-specific tests for measuring cognitive function (Hülsdünker, Ostermann, & Mierau, 2019).

7.3.15.1 Corsi Block-tapping test

The Corsi Block-tapping test assessed visuospatial short-term working memory (Corsi, 1972). Nine squares appeared on the screen where the squares randomly lit up. Participants were then required to replicate the order of the squares lighting up by clicking on the boxes. The sequence length started at two and participants had two trials at each sequence length. After the second trial the sequence length increased by one. If participants could not replicate two trials of the same sequence length the test was terminated. Participants had three practice trials before the Corsi Block-tapping test was performed. Performance was determined by Corsi Block total score which is the number of correct trials multiplied by the block span (last correct sequence length). This has been suggested to be a more reliable scoring method due to taking into account performance on both trials with an equal length compared to Block Span alone (Kessels, Van Zandvoort, Postma, Kappelle, & de Haan, 2010). The digital Corsi Block-tapping test has been shown to have greater test-retest reliability than the physical version and can be used as an effective method of visuospatial short-term working memory (Arce & McMullen, 2021; Brunetti, Del Gatto, & Delogu, 2014).

7.3.15.2 Stroop Test

The Stroop test measures the ability to suppress an automated response, measures frontal lobe function, and is a task to measure executive function and selective attention (Stroop, 1935). During the test a target word appeared in the middle of the screen and participants had to press the corresponding key board key with the correct colour of the word as quickly as possible (1 = red, 2 = green, 3 = blue and 4 = yellow). There were thirty trials in the Stroop test with three different conditions congruent, incongruent, and neutral, that were carried out in a random order (10 trials for each condition). During a congruent trial the word text was a colour that matched the colour of the word (Figure 7.4 A). An incongruent trial the word was a colour that did not match the colour of word (Figure 7.4 B). During a neutral trial the word text was not a colour and was a random word (Figure 7.4 C). There was a 1000ms interval between each word. Performance was determined by percentage of correct responses for each condition (congruence, incongruence and neutral) and average response time for each condition (congruence, incongruence and neutral). The Stroop test has been shown to have good test-retest reliability (Franzen, Tishelman, Sharp, & Friedman, 1987; Strauss, Allen, Jorgensen, & Cramer, 2005).

Figure 7.4 A-C. Congruence trial (A), incongruence trial (B) and neutral trial (C) during the Stroop test

7.3.15.3 Visual Search Test

The visual search test measured perception and visual processing abilities of the participants and is an appropriate method to use to test these abilities (Treisman, 1985). The visual search test determines how well participants can filter distracting information and interpret specific information (Malcolm, Cooper, Folland, Tyler, & Sunderland, 2018). During the test the participants had to identify a target letter either “X” or “O” amongst other letters (Figure 7.5). If the letter was not there the participants had to select “NONE” as their response. The participants were required to click the mouse when they had identified whether the target letter was present or not, then the letters would be covered up by circles and the participants had to then click the position where the target letter was or select “NONE” if it was not there. The target letters’ text colour was either white or green and all the distractor letters’ text colour were white. There were three different conditions where the number of letters on screen was different either field size of 10 letters, 20 letters or 30 letters. There were 36 trials during the visual search test and the target letters and colours were random. Performance was measured as the total response time for field size 10, 20 and 30.

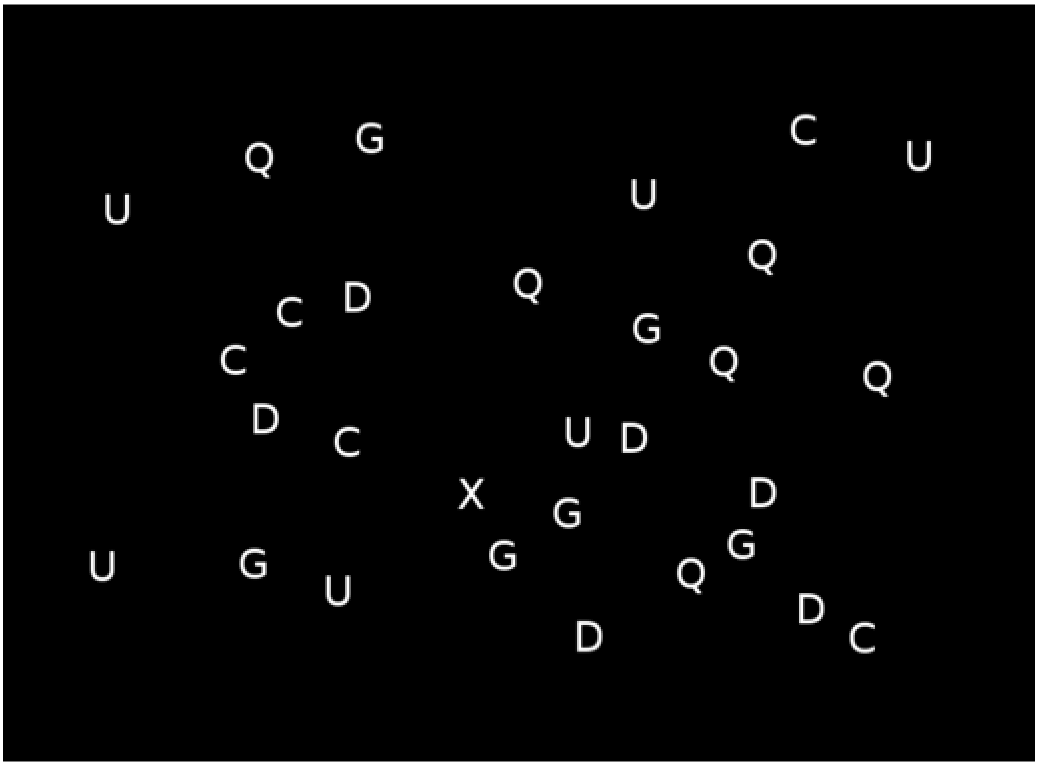


Figure 7.5. Example visual search test with field size 30 with target white 'X'.

7.3.16 Statistical Analysis

Data are presented and analysed as described in chapter 3.14. Figures were created using Microsoft Excel (Microsoft Excel for Mac Version 16.52, Microsoft, Redmond, WA, USA) and Prism (Prism 9 for macOS version 9.2.0, GraphPad Software, San Diego, CA, USA). To determine whether the participants had a similar response to the warm-up a one-way repeated measures ANOVA was conducted to compare differences between the CON, EXT and MIX conditions for distance covered, HR_{av} and RPE_{O} during the warm-up. To determine if the participants had a similar response prior to cooling being applied a one-way repeated measures ANOVA was undertaken to compared differences between the CON, EXT and MIX conditions post DE 1 for HR_{av}, T_{gast}, T_{au}, T_{skin}, RPE_{O}, distance covered, and distanced covered per minute.

A two-way repeated measures ANOVA (condition x fight) was performed to compare responses between the condition (CON, EXT and MIX) and between each fight (DE 1, DE 2 and DE 3). The following variables were analysed: T_{skin}, T_{mask}, HR_{av}, HR_{max}, blood lactate concentration, average speed, peak speed, distance covered, distance covered per minute, training load, training load per minute, points scored, points conceded, points difference, work to rest ratio, RPE_{A}, RPE_{L}, RPE_{O}, Corsi Block total score, Stroop test accuracy, Stroop test response time, and visual search test response time.

To determine the impact of the EXT and MIX on thermoregulatory responses a three-way repeated measures ANOVA (condition (CON, EXT, MIX) x fight (DE 1, DE 2, DE 3) x time (pre and post fight)) was performed to compare responses for T_{au}, T_{gast}, thermal comfort, and thermal sensation. To assess the cooling power of the EXT and MIX interventions a three-way repeated measures ANOVA (condition (CON, EXT, MIX) x intervention time period (intervention period 1 and 2) x minute of intervention (1st and 10th minute of intervention)) was also conducted for T_{skin}.

Effect sizes were calculated as described in chapter 3.14.

Pearson's correlation coefficients were determined to examine relationships between T_{skin} and T_{mask} during all DE fights and after cooling had been completed in DE 2 and DE 3 and interpreted as described in chapter 3.14.

7.4 Results

7.4.1 Warm-up

There were no significant differences for HR_{av} ($F_{(2,18)}$ = 2.078, p = 0.154, η^2 = 0.188), distance covered ($F_{(2,18)}$ = 0.460, p = 0.638, η^2 = 0.049) and RPE_O ($F_{(2,18)}$ = 1.576, p = 0.234, η^2 = 0.149) between the CON, EXT and MIX conditions during the warm-up, as shown in Table 7.3.

Table 7.3. Average heart rate, distance covered and RPE_O comparison during the warm-up for the CON, EXT, and MIX interventions (mean ± SD (95% CI)).

Variable	CON	EXT	MIX
HR_{av} (% HR_{APM})	80.6 ± 6.1 (76.2, 85.0)	82.6 ± 6.4 (78.0, 87.2)	79.9 ± 8.9 (73.6, 86.2)
Distance Covered (m)	510 ± 71 (460, 561)	515 ± 69 (466, 565)	492 ± 105 (417, 567)
RPE_O	14 ± 2 (13, 16)	14 ± 2 (12, 15)	13 ± 2 (12, 15)

CON = Control, EXT = External, MIX = Mixed-Methods, HR_{av} = average heart rate, HR_{APM} = age predicted maximum heart rate, RPE_O = overall ratings of perceived exertion

7.4.2 DE 1 comparison

There were no significant differences for HR_{av} ($F_{(2,18)}$ = 1.894, p = 0.179, η^2 = 0.174), T_{gast} ($F_{(2,10)}$ = 0.888, p = 0.441, η^2 = 0.151), T_{au} ($F_{(2,10)}$ = 3.123, p = 0.088, η^2 = 0.384), T_{skin} ($F_{(2,18)}$ = 2.509, p = 0.109, η^2 = 0.218), distance covered ($F_{(2,18)}$ = 0.349, p = 0.710, η^2 = 0.037), distance covered per minute ($F_{(2,18)}$ = 0.371, p = 0.696, η^2 = 0.040) and RPE_O ($F_{(2,18)}$ = 1.925, p = 0.175, η^2 = 0.176) between the CON, EXT and MIX conditions for DE 1, as shown in Table 7.4.

Table 7.4. Average heart rate, T_{mask}, T_{gast}, T_{au}, distance covered and RPE_O comparison for DE 1 prior to interventions applied for between the CON, EXT and MIX intervention (mean ± SD (95% CI)).

Variable	CON	EXT	MIX
HR_{av} (% HR_{APM})	87.3 ± 6.5 (82.6, 92.0)	85.6 ± 8.0 (79.9, 91.3)	84.0 ± 6.8 (79.1, 88.9)
T_{gast} (°C) n = 6	37.5 ± 0.7	37.5 ± 0.6	37.8 ± 0.2
T_{au} (°C) n = 6	37.6 ± 0.4	37.4 ± 0.3	37.3 ± 0.5
T_{skin} (°C)	34.3 ± 1.1 (33.5, 35.0)	34.0 ± 1.2 (33.1, 34.8)	33.8 ± 0.9 (33.1, 34.4)
Distance covered (m)	621 ± 201 (478, 765)	594 ± 189 (460, 730)	600 ± 172 (477, 724)
Distance covered per minute ($m.min^{-1}$)	69 ± 22 (53, 85)	66 ± 21 (51, 81)	67 ± 19 (53, 80)
RPE_O	14 ± 1 (13, 15)	14 ± 2 (13, 15)	13 ± 2 (12, 15)

CON = Control, EXT = External, MIX = Mixed-Methods, HR_{av} = average heart rate, HR_{APM} = age predicted maximum heart rate, T_{skin} = mean skin temperature, RPE_O = overall ratings of perceived exertion

7.4.3 Physiological responses to CON, EXT and MIX interventions

7.4.3.1 Mean Skin Temperature

7.3.3.1.1 Mean Skin Temperature during DE fights

There was a significant interaction ($F_{(2.365,\ 21.285)} = 4.382$, $p = 0.021$, $\eta^2 = 0.327$) for mean skin temperature between the CON, EXT and MIX interventions during the DE fights. Post-hoc analysis revealed there was no significant difference between cooling interventions for DE 1 ($F_{(2, 18)} = 2.509$, $p = 0.109$, $\eta^2 = 0.218$). However, there was a significant difference between cooling interventions for DE 2 ($F_{(2, 18)} = 4.773$, $p = 0.022$, $\eta^2 = 0.347$) with the CON intervention having a greater mean skin temperature than the EXT ($p = 0.049$; mean difference = 0.72°C) and MIX ($p = 0.027$; mean difference = 0.78°C) interventions. Furthermore, there was a significant difference between cooling interventions for DE 3 ($F_{(1.298, 11.680)} = 5.808$, $p = 0.027$, $\eta^2 = 0.392$) with the CON intervention having a greater mean skin temperature than the EXT ($p = 0.009$; mean difference = 0.80°C) and MIX ($p = 0.027$; mean difference = 1.08°C) interventions. There were no significant differences between EXT and MIX interventions for T_{skin} for DE 2 ($p = 1.000$) and DE 3 ($p = 1.000$).

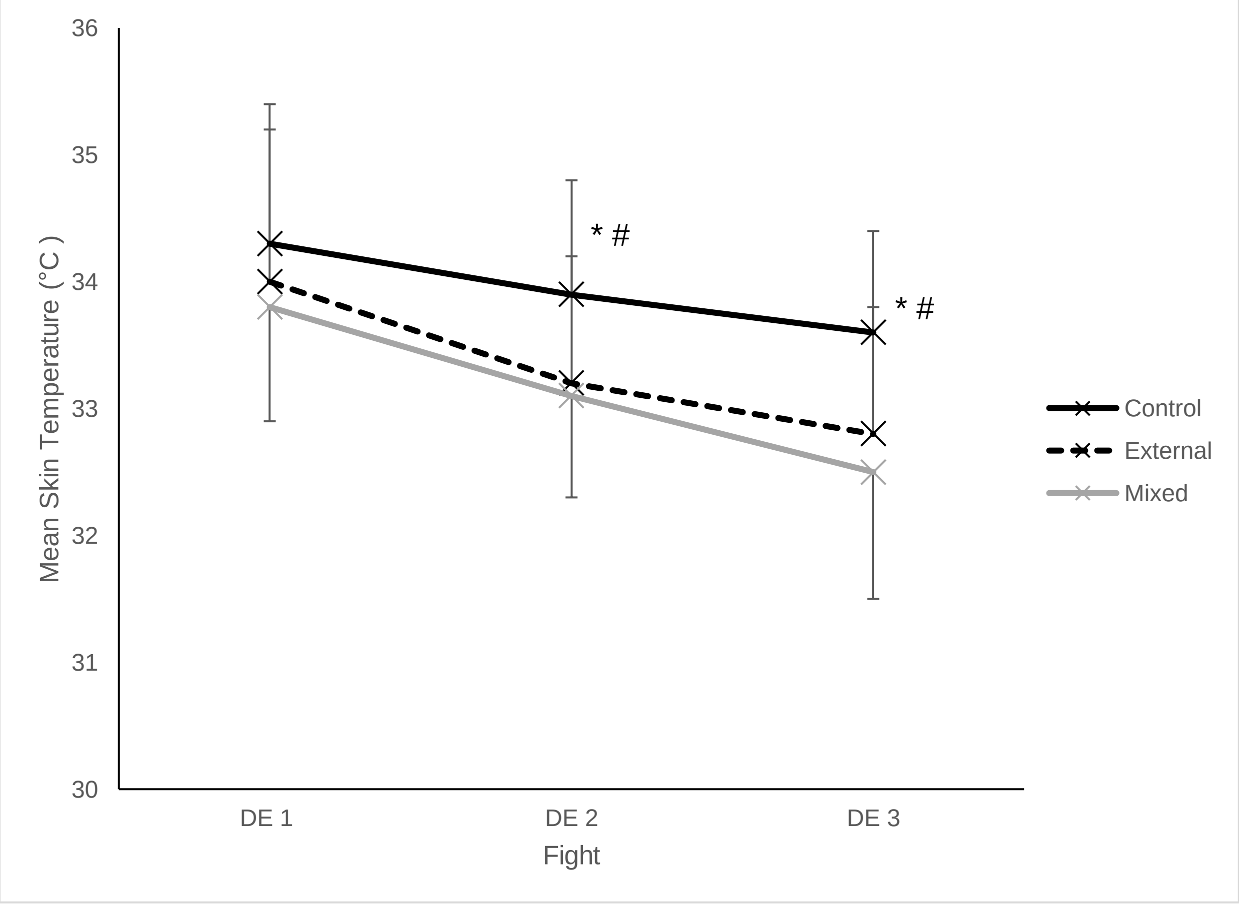


Figure 7.6. Mean skin temperature (°C) during the DE fights for the CON, EXT, and MIX interventions (mean ± SD).

DE = Direct Elimination. * Significant difference to EXT $p < 0.05$, # significant difference to MIX $p < 0.05$.

7.3.3.1.2. Cooling Power of EXT and MIX

There were no significant differences for change in T_{skin} across intervention period 1 ($F_{(2, 18)}$ = 1.978, p = 0.167, η^2 = 0.180) or intervention period 2 ($F_{(2, 18)}$ = 3.336, p = 0.059, η^2 = 0.270) between CON, EXT, and MIX (Figure 7.7). Average change in T_{skin} for CON was -0.91°C (intervention period 1) and -0.79°C (intervention period 2), for EXT was -0.73°C (intervention period 1) and -0.82°C (intervention period 2) and for MIX was -1.15°C (intervention period 1) and -1.19°C (intervention period 2). However, there was a significant difference for T_{skin} during the 1st minute of intervention period 1 ($F_{(2, 18)}$ = 4.652, p = 0.024, η^2 = 0.341) and intervention 2 ($F_{(2, 18)}$ = 3.608, p = 0.048, η^2 = 0.286) as shown in Figure 7.7. Post-hoc analysis for the 1st minute of intervention period 1 revealed greater T_{skin} in the CON than EXT (p = 0.040) and a tendency for greater T_{skin} in the CON than MIX (p = 0.051). There was no difference between the EXT and MIX trials. Post-hoc analysis for the 1st minute of intervention period 2 could not determine differences between the CON, EXT, and MIX trials.

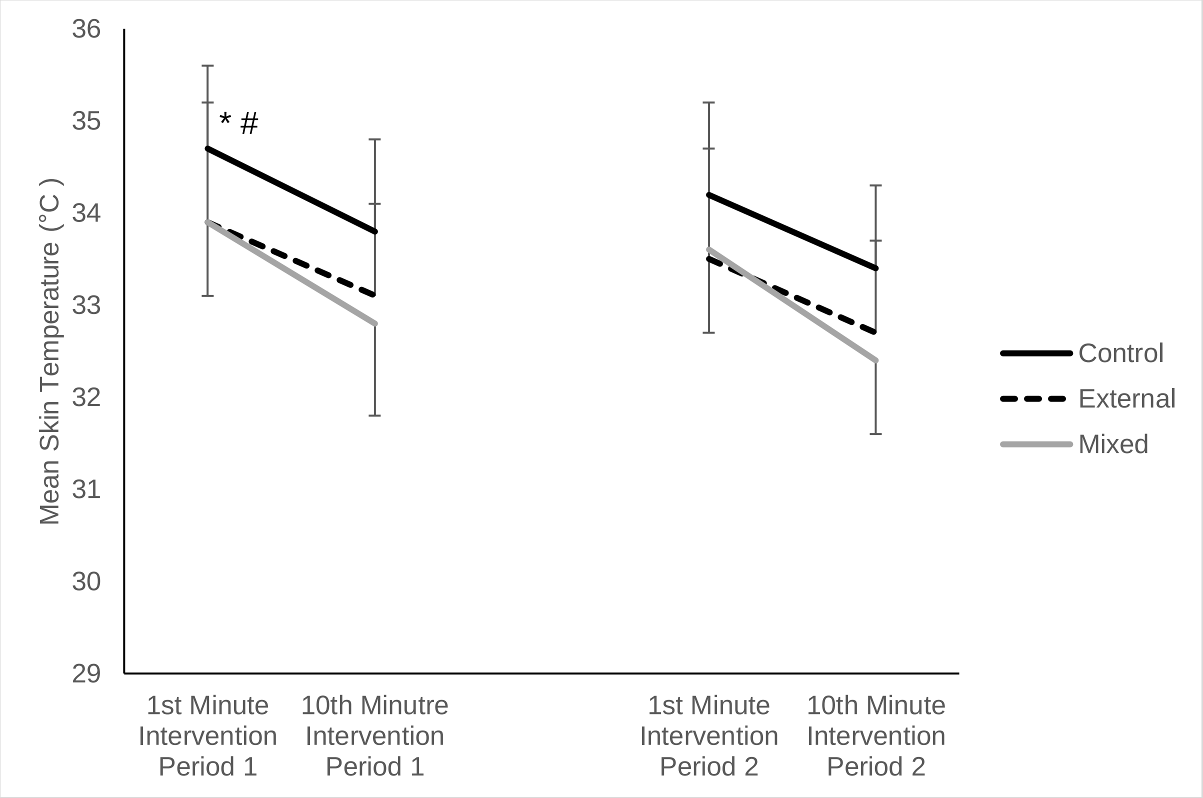


Figure 7.7. Mean skin temperature (°C) during 10-minute intervention period for 1st and 10th minute of each intervention period for CON, EXT, and MIX cooling interventions (mean ± SD).

* significant difference to EXT $p < 0.05$, # tendency for significant difference to MIX $p < 0.10$

7.4.3.2 Aural Temperature

Figure 7.8 shows the T_{au} response between the cooling interventions. There were no significant three way interactions ($F_{(4, 16)} = 0.612$, $p = 0.660$, $\eta^2 = 0.133$) for T_{au} between conditions pre and post the three DE fights. Furthermore, there were no significant two way interactions (condition x time: $F_{(2, 8)} = 0.103$, $p = 0.903$, $\eta^2 = 0.025$; condition x fight: $F_{(4, 16)} = 2.469$, $p = 0.087$, $\eta^2 = 0.382$; and time x fight: $F_{(2, 8)} = 0.953$, $p = 0.425$, $\eta^2 = 0.192$) for T_{au} pre and post-fight during the DE fights for the cooling interventions.

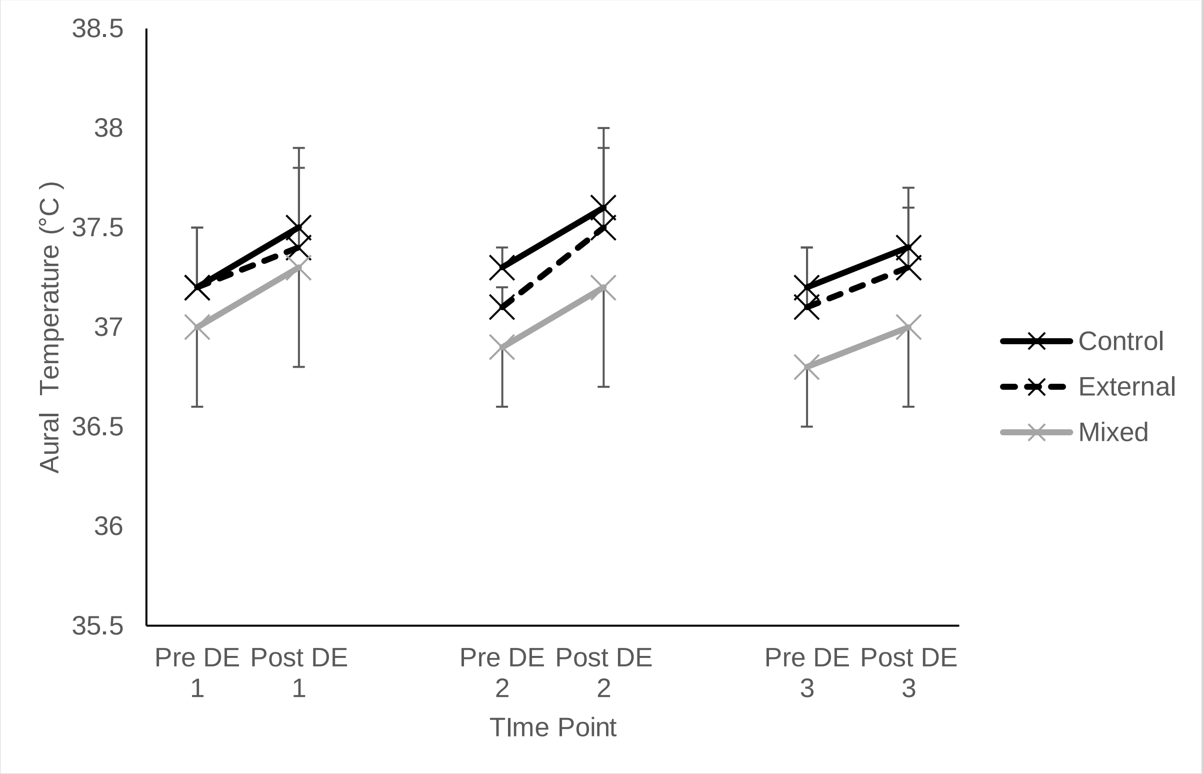


Figure 7.8. Pre-fight and post-fight T_{au} (°C) for the DE fights for the CON, EXT and MIX interventions (mean ± SD).

DE = Direct Elimination. N = 5 complete data sets.

7.4.3.3 Mask Temperature

There was no significant interaction determined for T_{mask} ($F_{(2.067,\ 18.600)} = 0.367$, $p = 0.705$, $\eta^2 = 0.039$) between the CON, EXT and mixed cooling conditions during the DE fights, as shown in Figure 7.9.

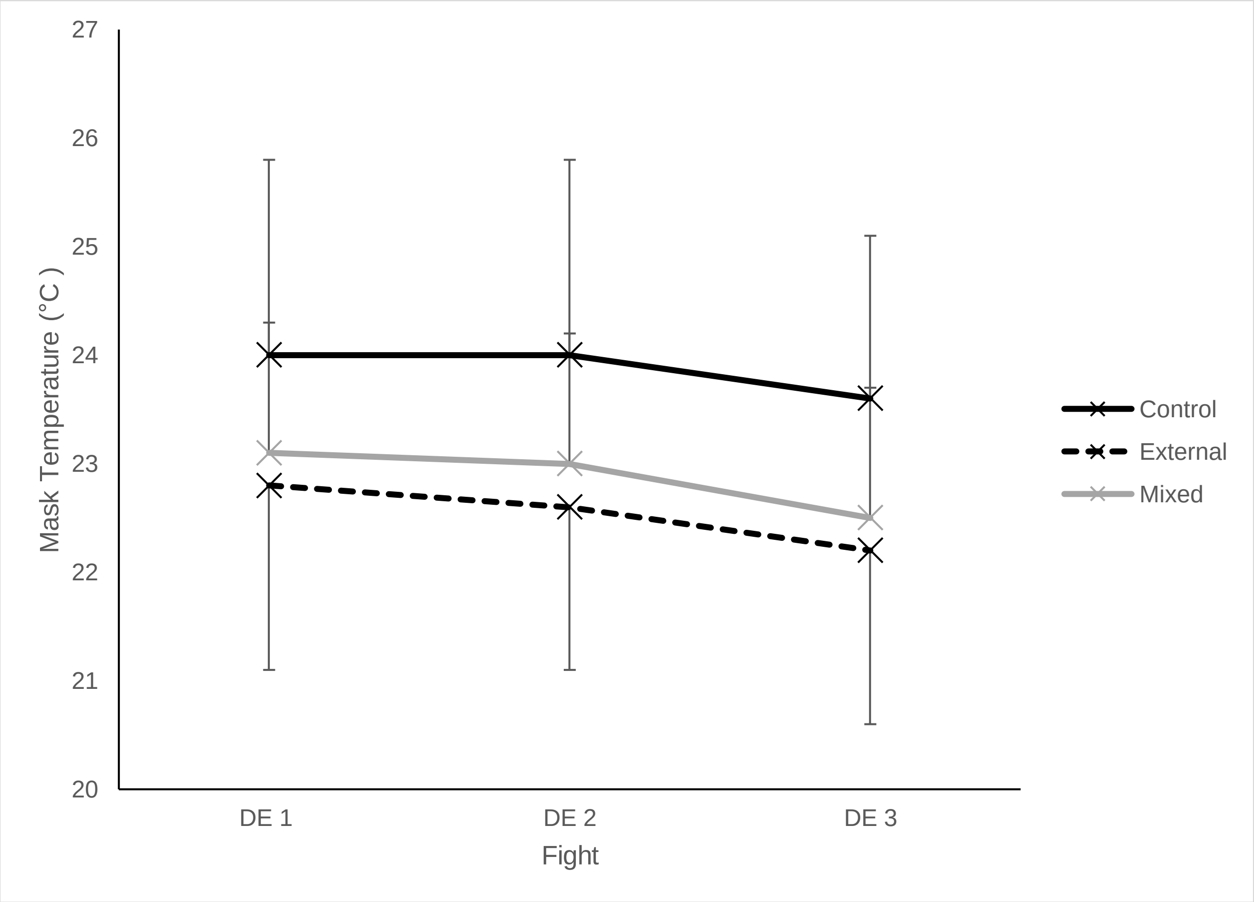


Figure 7.9. Mask temperature (°C) during the DE fights for the CON, EXT and MIX interventions (mean ± SD).

DE = Direct Elimination.

7.4.3.4 Relationship between Mask Temperature and Mean Skin Temperature

There was a significant large positive relationship determined between T_{skin} and T_{mask} for all DE fights (r = 0.675; Figure 7.10). There was a significant large positive relationship between T_{skin} and T_{mask} when cooling had been applied in DE 2 and DE 3 (r = 0.731; Figure 7.11).

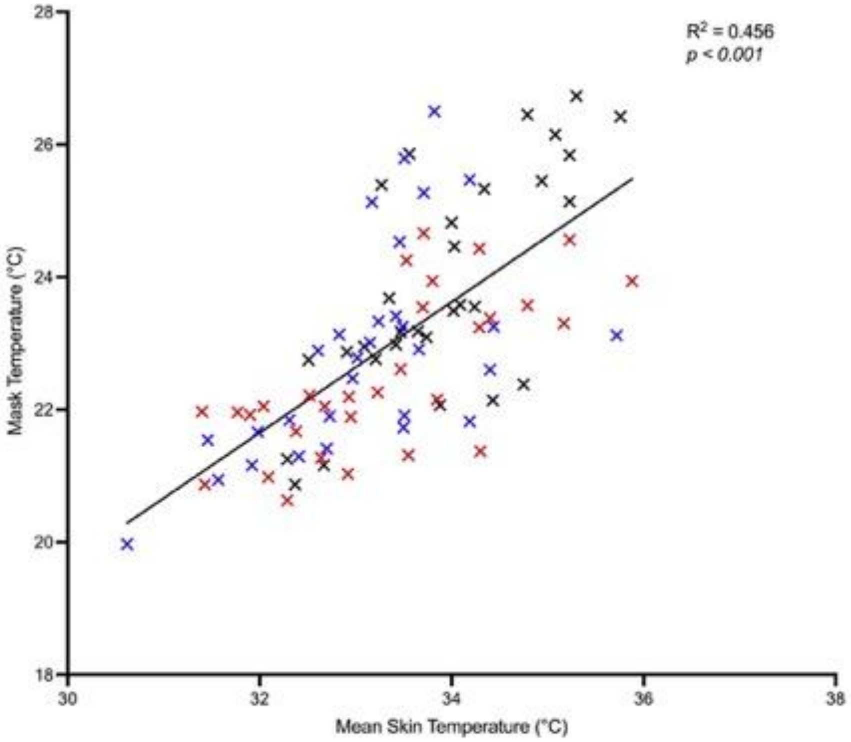


Figure 7.10. Pearson correlation between mean skin temperature (°C) and mask temperature (°C) for all cooling interventions for all DE fights. Black crosses = CON, red crosses = EXT, blue crosses = MIX.

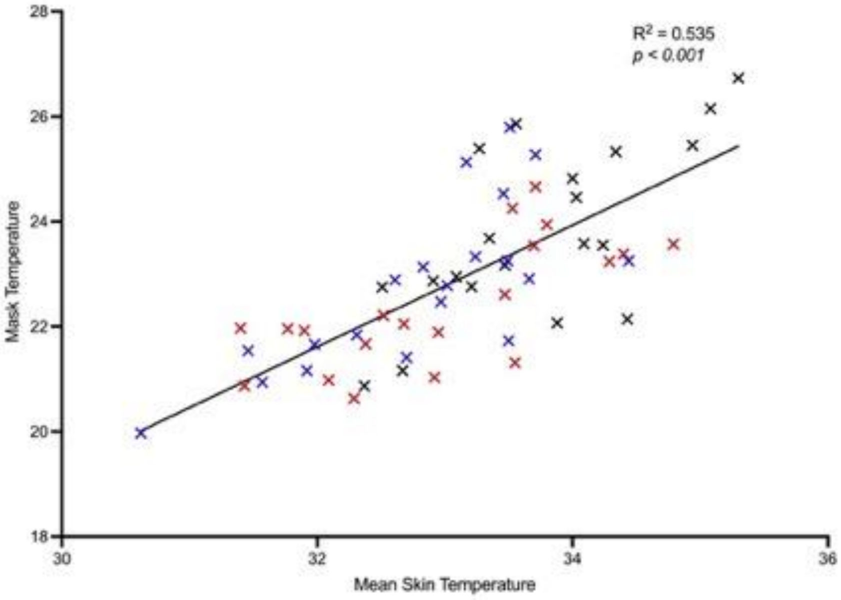


Figure 7.11. Pearson correlation between mean skin temperature (°C) and mask temperature (°C) for DE 2 and DE 3 where cooling had been completed for all cooling interventions. Black crosses = CON, red crosses = EXT, blue crosses = MIX.

7.4.3.5 Heart Rate Responses

There were no significant interaction for HR_{av} ($F_{(4, 36)}$ = 0.768, p = 0.554, η^2 = 0.079) and HR_{max} ($F_{(4, 36)}$ = 1.418, p = 0.248, η^2 = 0.136) between the CON, EXT and mixed cooling conditions during the DE fights, as shown in Table 7.5.

Table 7.5. Heart rate responses (% HR_{APM}) during the DE fights for the CON, EXT cooling and MIX interventions (mean ± SD (95%CI)).

	CON			EXT			MIX		
Variable	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3
HR_{av} (% HR_{APM})	87.3 ± 6.5 (82.6, 92.0)	85.8 ± 7.3 (80.6, 91.0)	84.0 ± 7.6 (78.6, 89.4)	85.6 ± 8.0 (79.9, 91.3)	83.4 ± 8.8 (77.1, 89.7)	81.7 ± 9.3 (75.0, 88.4)	84.0 ± 6.8 (79.1, 88.9)	81.0 ± 6.6 (76.2, 85.7)	78.4 ± 8.2 (72.6, 84.2)
HR_{max} (% HR_{APM})	95.8 ± 7.1 (90.7, 100.9)	94.9 ± 7.5 (89.6, 100.2)	93.9 ± 9.2 (87.3, 100.5)	94.3 ± 7.5 (88.9, 99.7)	92.8 ± 8.5 (86.7, 98.9)	91.1 ± 10.0 (84.0, 98.2)	92.7 ± 6.3 (88.2, 97.2)	90.4 ± 7.0 (85.4, 95.4)	87.7 ± 8.8 (81.4, 94.0)

CON = Control, EXT = External, MIX = Mixed-Methods, DE = Direct Elimination, HR_{av} = average heart rate, HR_{max} = maximum heart rate, HR_{APM} = age predicted maximum heart rate

7.4.3.6 Blood Lactate Concentration

There was no significant interaction for blood lactate concentration ($F_{(1.299,\ 5.195)}$ = 1.551, *p* = 0.235, η^2 = 0.279) between the CON, EXT and MIX interventions during the DE fights as shown in Figure 7.12. The standard deviation for MIX DE 1 is influenced by one participant recording blood lactate concentration of 16.0 mmol.L^{-1}.

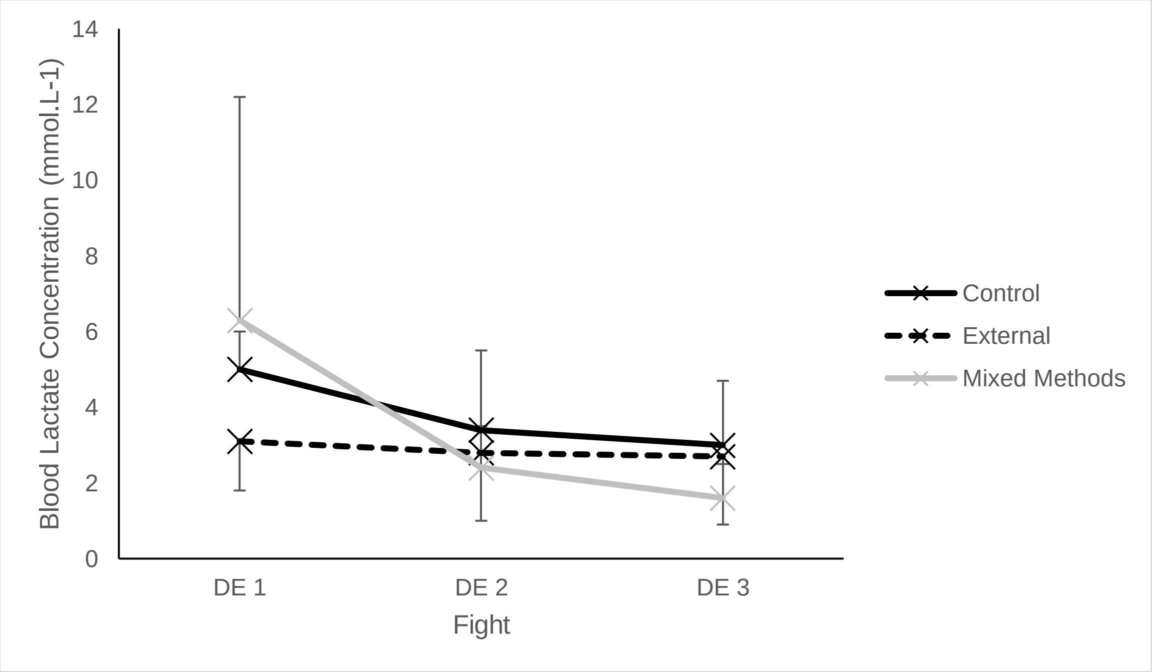


Figure 7.12. Post fight blood lactate concentration (mmol.L^{-1}) between CON, EXT and MIX interventions (mean ± SD).

DE = Direct Elimination.

7.4.3.7 Movement Data

There were no significant interactions for distance covered ($F_{(4,36)}$ = 0.467, *p* = 0.759, η^2 = 0.049), distance covered per minute ($F_{(4,\ 36)}$ = 0.529, *p* = 0.715, η^2 = 0.056), training load ($F_{(4,\ 36)}$ = 0.515, *p* = 0.725, η^2 = 0.054), and training load per minute ($F_{(4,\ 36)}$ = 0.479, *p* = 0.751, η^2 = 0.051) between the CON, EXT and MIX interventions during the DE fights, as shown in Table 7.6.

Table 7.6. Distance covered (m and $m.min^{-1}$) and training load (AU and $AU.min^{-1}$) during the DE fights for CON, EXT, and MIX interventions (mean ± SD (95% CI)).

	CON			EXT			MIX		
Variable	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3
Distance Covered (m)	621 ± 201 (478, 765)	601 ± 227 (440, 764)	600 ± 243 (426, 774)	595 ± 189 (460, 730)	566 ± 175 (441, 692)	569 ± 185 (437, 702)	600 ± 172 (477, 724)	569 ± 170 (447, 690)	550 ± 160 (435, 665)
Distance Covered per Minute ($m.min^{-1}$)	69 ± 22 (53, 85)	67 ± 25 (49, 85)	67 ± 27 (47, 86)	66 ± 21 (51, 81)	63 ± 19 (49, 77)	63 ± 21 (49, 78)	67 ± 19 (53, 80)	63 ± 19 (50, 77)	61 ± 18 (48, 74)
Training Load (AU)	35 ± 10 (28, 42)	33 ± 10 (26, 41)	32 ± 10 (24, 39)	33 ± 10 (26, 40)	30 ± 10 (23, 37)	29 ± 10 (21, 36)	31 ± 10 (24, 38)	28 ± 8 (22, 34)	25 ± 9 (19, 32)
Training Load per Minute ($AU.min^{-1}$)	3.9 ± 1.1 (3.1, 4.7)	3.7 ± 1.2 (2.9, 4.5)	3.5 ± 1.1 (2.7, 4.3)	3.7 ± 1.1 (2.9, 4.4)	3.3 ± 1.1 (2.5, 4.1)	3.2 ± 1.1 (2.4, 4.0)	3.4 ± 1.1 (2.7, 4.2)	3.1 ± 0.9 (2.4, 3.7)	2.8 ± 1.0 (2.1, 3.6)

CON = Control, EXT = External, MIX = Mixed-Methods, DE = Direct Elimination

There was no significant interaction for average speed ($F_{(4, 36)} = 0.808$, $p = 0.528$, $\eta^2 = 0.082$), peak speed ($F_{(4, 36)} = 0.551$, $p = 0.699$, $\eta^2 = 0.058$) and work to rest ratio ($F_{(4, 36)} = 2.615$, $p = 0.051$, $\eta^2 = 0.225$) between the CON, EXT, and MIX interventions during the DE fights as shown in Table 7.7.

Table 7.7. Average speed ($m.s^{-1}$), peak speed ($m.s^{-1}$), and work to rest ratio (s) between CON, EXT, and MIX interventions (mean ± SD (95%CI)).

	CON			EXT			MIX		
Variable	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3
Average speed ($m.s^{-1}$)	0.9 ± 0.3 (0.7, 1.1)	0.9 ± 0.4 (0.7, 1.2)	0.9 ± 0.4 (0.7, 1.2)	0.9 ± 0.3 (0.7, 1.1)	0.9 ± 0.3 (0.7, 1.0)	0.9 ± 0.3 (0.6, 1.1)	0.9 ± 0.3 (0.7, 1.1)	0.9 ± 0.3 (0.7, 1.0)	0.8 ± 0.2 (0.7, 1.0)
Peak Speed ($m.s^{-1}$)	2.8 ± 0.7 (2.3, 3.2)	2.7 ± 0.5 (2.4, 3.0)	3.0 ± 0.6 (2.6, 3.5)	2.6 ± 0.4 (2.4, 2.9)	2.6 ± 0.6 (2.2, 3.9)	2.7 ± 0.5 (2.3, 3.0)	3.0 ± 0.8 (2.4, 3.5)	2.9 ± 0.8 (2.4, 3.4)	3.0 ± 0.4 (2.7, 3.3)
Work to rest ratio (s)	2.5:1 ± 1.1 (1.7, 3.3)	3.0:1 ± 1.5 (1.9, 4.0)	2.7:1 ± 1.4 (1.7, 3.7)	2.7:1 ± 1.3 (1.8, 3.6)	2.6:1 ± 1.2 (1.7, 3.5)	3.0:1 ± 1.0 (2.3, 3.8)	2.6:1 ± 1.0 (1.9, 3.4)	2.8:1 ± 1.2 (2.0, 3.7)	2.6:1 ± 1.0 (1.8, 3.3)

CON = Control, EXT = External, MIX = Mixed-Methods, DE = Direct Elimination

7.4.4 Effects of CON, EXT, and MIX interventions on performance.

There was no significant interaction for points difference ($F_{(4, 36)} = 0.645$, $p = 0.634$, $\eta^2 = 0.067$) between the CON, EXT and MIX interventions for the three DE fights, as shown in Figure 7.13.

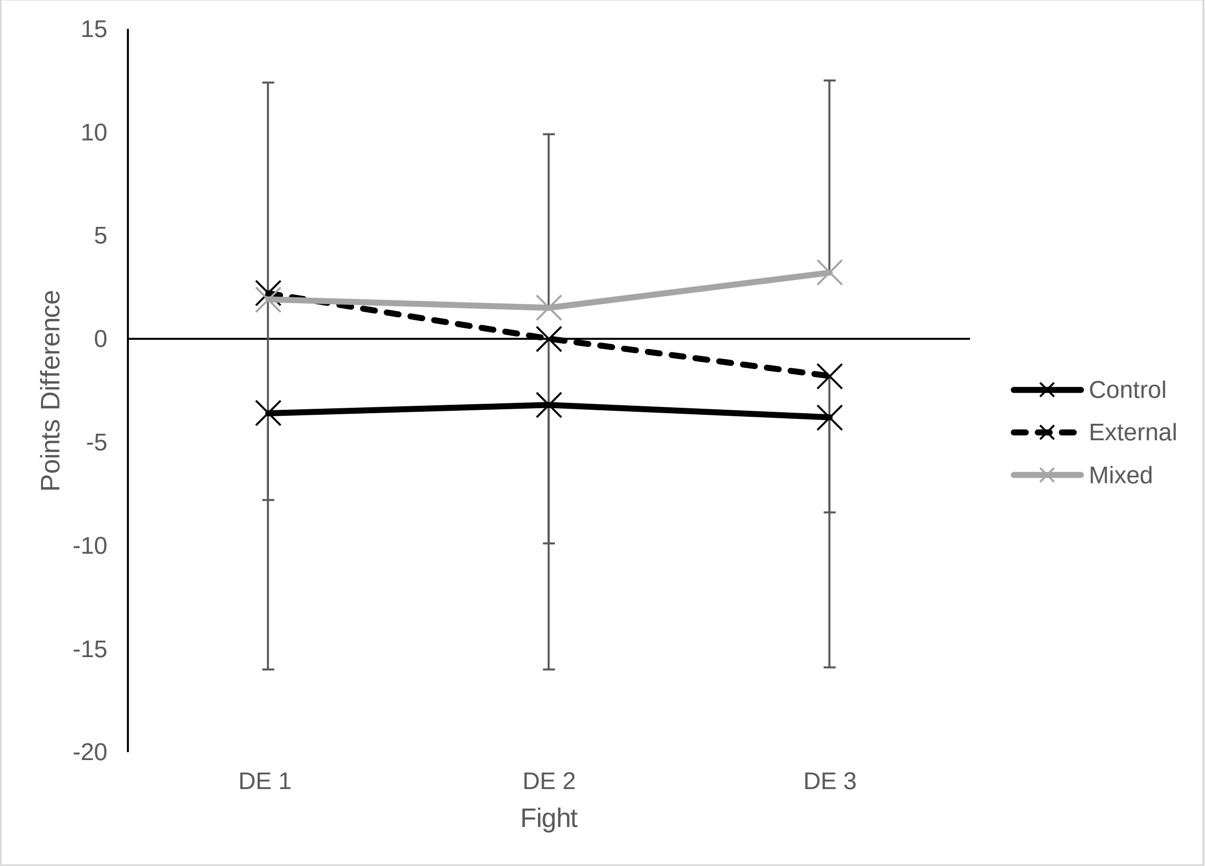


Figure 7.13. Points difference during the DE fights for CON, EXT and MIX interventions (mean ± SD).

DE = Direct Elimination.

There were no significant interactions for points scored ($F_{(4,\ 36)}$ = 2.055, p = 0.107, η^2 = 0.186) and points conceded ($F_{(4,\ 36)}$ = 0.377, p = 0.823, η^2 = 0.040) between the CON, EXT and MIX interventions for the DE fights, as shown in Table 7.8.

Table 7.8. Points scored and points conceded during the three DE fights for the CON, EXT, and MIX interventions (mean ± SD (95% CI)).

	CON			EXT			MIX		
Variable	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3
Points Scored	19 ± 9 (13, 26)	19 ± 8 (12, 25)	20 ± 11 (12, 27)	21 ± 9 (15, 28)	21 ± 11 (13, 28)	17 ± 8 (11, 23)	20 ± 6 (15, 24)	21 ± 7 (16, 25)	22 ± 7 (17, 27)
Points Conceded	23 ± 10 (16, 30)	22 ± 12 (13, 30)	24 ± 11 (16, 32)	19 ± 8 (13, 25)	21 ± 9 (14, 27)	19 ± 8 (14, 25)	18 ± 9 (11, 24)	19 ± 8 (13, 25)	19 ± 10 (12, 26)

CON = Control, EXT = External, MIX = Mixed-Methods, DE = Direct Elimination

7.4.5 Perceptual responses of the CON, EXT, and MIX interventions.

Figure 7.14 shows the thermal sensation response for the cooling interventions during the DE fights. There was no significant three-way interaction (condition x time x fight; $F_{(4, 36)} = 0.573$, $p = 0.684$, $\eta^2 = 0.060$) for thermal sensation pre and post each DE fight for the CON, EXT and MIX interventions. There was no significant two-way interaction (condition x time; $F_{(2, 18)} = 1.741$, $p = 0.204$, $\eta^2 = 0.162$) for thermal sensation pre and post fight for the CON, EXT and MIX interventions. There was a significant two-way interaction (condition x fight; $F_{(2.256, 20.308)} = 3.409$, $p = 0.048$, $\eta^2 = 0.275$) for thermal sensation for the CON, EXT and MIX interventions during the DE fights. Post-hoc analysis could not determine a significant interaction for pre-fight ($F_{(4, 36)} = 1.715$, $p = 0.168$, $\eta^2 = 0.160$) or post fight ($F_{(4, 36)} = 2.355$, $p = 0.072$, $\eta^2 = 0.207$) thermal sensation between the cooling interventions. There was a significant two-way interaction (time x fight; $F_{(1.172, 10.550)} = 9.368$, $p = 0.009$, $\eta^2 = 0.510$) pre and post fight for the DE fights between the cooling interventions. Post-hoc analysis determined there was not a significant difference for the CON intervention ($F_{(2, 18)} = 1.943$, $p = 0.172$, $\eta^2 = 0.178$), and MIX intervention ($F_{(2, 18)} = 3.273$, $p = 0.061$, $\eta^2 = 0.267$); however, there was a significant difference for the EXT intervention ($F_{(2, 18)} = 5.801$, $p = 0.011$, $\eta^2 = 0.392$). Further statistical analysis showed there was a greater increase in thermal sensation from pre to post fight in DE 2 and DE 3 than DE 1 (mean increase pre to post fight: 1.4 ± 0.7, 2.2 ± 1.1, and 2.5 ± 1.4 for DE 1, DE 2, and DE 3, respectively) for the EXT intervention.

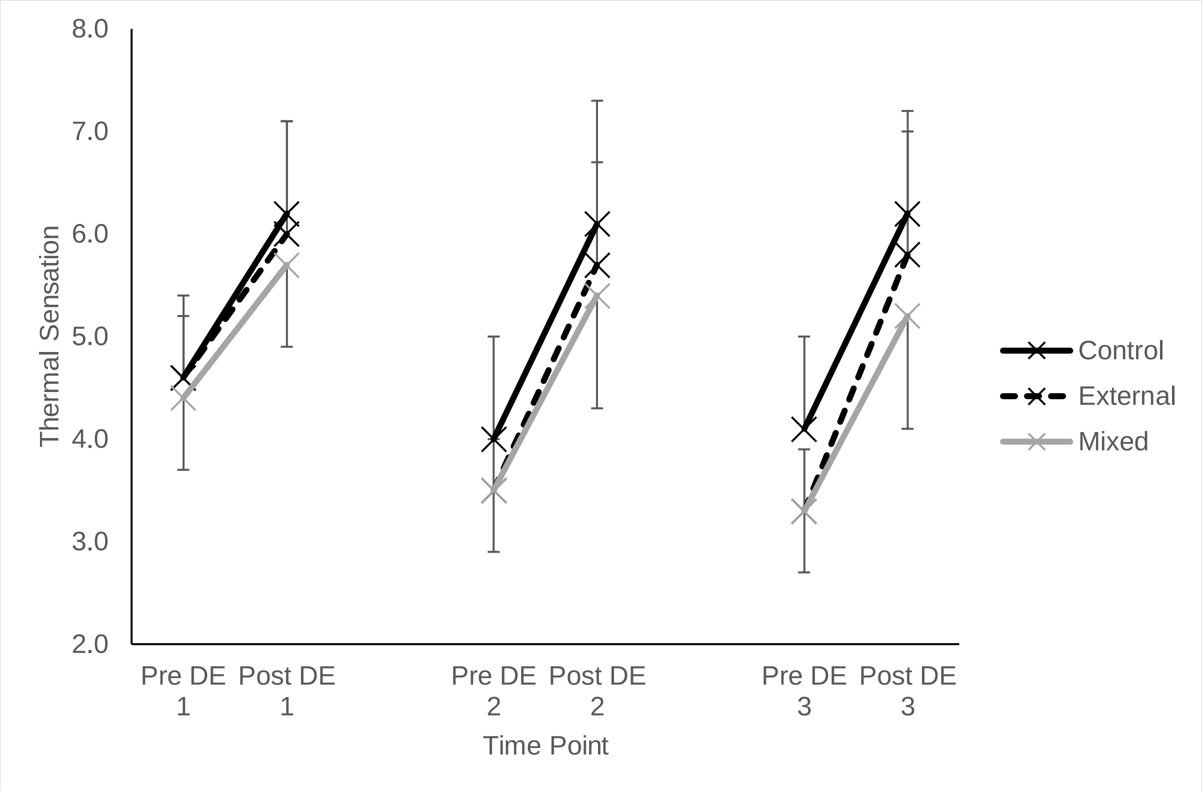


Figure 7.14. Thermal sensation ratings for CON, EXT, and MIX interventions pre and post the DE fights (mean ± SD).

There were no significant three way interactions ($F_{(4, 36)} = 0.503$, $p = 0.733$, $\eta^2 = 0.053$) for thermal comfort pre and post fight during the DE fights for the CON, EXT and MIX interventions. There were no significant two way interactions (condition x time: $F_{(2, 18)} = 0.034$, $p = 0.967$, $\eta^2 = 0.004$; condition x fight: $F_{(4, 36)} = 0.973$, $p = 0.434$, $\eta^2 = 0.098$; and time x fight: $F_{(2, 18)} = 0.732$, $p = 0.495$, $\eta^2 = 0.075$) for thermal comfort pre and post fight during the DE fights for the cooling interventions.

There was no significant interaction for RPE$_{O}$ ($F_{(4, 36)} = 0.194$, $p = 0.940$, $\eta^2 = 0.021$), RPE$_{A}$ ($F_{(2.270, 20.431)} = 1.874$, $p = 0.136$, $\eta^2 = 0.172$), and RPE$_{L}$ ($F_{(4, 36)} = 0.595$, $p = 0.669$, $\eta^2 = 0.062$) between the CON, EXT, and MIX interventions during the DE fights as shown in Table 7.9.

Table 7.9. RPE$_{O}$, RPE$_{A}$, and RPE$_{L}$ between the CON, EXT and MIX interventions (mean ± SD (95% CI)).

	CON			EXT			MIX		
Variable	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3	DE 1	DE 2	DE 3
RPE$_{O}$	14 ± 2 (13, 15)	14 ± 1 (13, 15)	14 ± 2 (12, 15)	14 ± 2 (13, 15)	14 ± 2 (12, 15)	13 ± 2 (12, 15)	13 ± 2 (12, 15)	13 ± 2 (12, 15)	13 ± 2 (12, 15)
RPE$_{A}$	14 ± 2 (12, 15)	14 ± 2 (12, 15)	13 ± 2 (12, 15)	12 ± 2 (11, 13)	13 ± 1 (12, 14)	13 ± 2 (12, 15)	13 ± 2 (11, 14)	13 ± 2 (11, 14)	13 ± 2 (11, 14)
RPE$_{L}$	14 ± 2 (13, 15)	14 ± 2 (13, 15)	14 ± 2 (13, 16)	14 ± 2 (12, 15)	14 ± 2 (12, 15)	13 ± 2 (12, 15)	14 ± 1 (13, 15)	14 ± 2 (13, 15)	13 ± 2 (12, 15)

CON = Control, EXT = External, MIX = Mixed-Methods, DE = Direct Elimination, RPE$_{O}$ = overall ratings of perceived exertion, RPE$_{A}$ = arms ratings of perceived exertion, RPE$_{L}$ = legs ratings of perceived exertion

7.4.6 Effects of CON, EXT, and MIX interventions on cognitive function.

Table 7.10 shows the cognitive function test results between the cooling interventions pre DE 1 and post DE 3. There was no significant interaction for Corsi Block total score ($F_{(1.117, 10.005)} = 0.057$, $p = 0.944$, $\eta^2 = 0.006$), Stroop congruence accuracy ($F_{(2, 18)} = 0.310$, $p = 0.737$, $\eta^2 = 0.033$), Stroop congruence response time ($F_{(2, 18)} = 0.236$, $p = 0.792$, $\eta^2 = 0.026$), Stroop incongruence accuracy ($F_{(2, 18)} = 0.448$, $p = 0.646$, $\eta^2 = 0.047$), Stroop incongruence response time ($F_{(2, 18)} = 0.914$, $p = 0.419$, $\eta^2 = 0.092$), Stroop neutral accuracy ($F_{(2,\ 18)}$ = 0.364, *p* = 0.700, η^2 = 0.039), Stroop neutral response time ($F_{(2,\ 18)}$ = 0.511, *p* = 0.608, η^2 = 0.054), visual search field size 10 response time ($F_{(2,\ 18)}$ = 1.743, *p* = 0.203, η^2 = 0.162), visual search field size 20 response time ($F_{(2,\ 18)}$ = 0.230, *p* = 0.797, η^2 = 0.025) and visual search field size 30 response time ($F_{(2,\ 18)}$ = 0.672, *p* = 0.523, η^2 = 0.069) between CON, EXT and MIX interventions pre DE 1 and post DE 3.

Table 7.10. Cognitive function results pre DE 1 and post DE 3 between the CON, EXT and MIX interventions (mean ± SD (95% CI)).

	CON		EXT		MIX	
Variable	Pre DE 1	Post DE 3	Pre DE 1	Post DE 3	Pre DE 1	Post DE 3
Corsi Block Total Score	59 ± 23 (42, 76)	63 ± 24 (46, 80)	70 ± 25 (52, 87)	76 ± 23 (59, 92)	61 ± 32 (37, 84)	67 ± 30 (46, 88)
Stroop Congruence Accuracy	9.9 ± 0.3 (9.7, 10.1)	9.9 ± 0.3 (9,7, 10.1)	9.9 ± 0.3 (9,7, 10.1)	9.7 ± 0.5 (9.4, 10.0)	9.8 ± 0.4 (9.5, 10.1)	9.7 ± 0.7 (9.2, 10.2)
Stroop Congruence Response Time (ms)	674 ± 141 (573, 775)	662 ± 109 (584, 740)	636 ± 124 (547, 724)	644 ± 124 (555, 733)	626 ± 99 (555, 696)	624 ± 108 (545, 701)
Stroop Incongruence Accuracy	9.4 ± 0.8 (8.8, 10.0)	9.6 ± 0.5 (9.2, 10.0)	9.4 ± 0.8 (8.8, 10.0)	9.3 ± 0.5 (9.0, 9.6)	9.3 ± 0.7 (8.8, 9.8)	9.5 ± 0.7 (9.0, 10.0)
Stroop Incongruence Response Time (ms)	788 ± 218 (632, 943)	809 ± 133 (714, 904)	812 ± 141 (711, 913)	792 ± 196 (652, 932)	800 ± 169 (679, 921)	735 ± 158 (623, 848)

Stroop Neutral Accuracy	9.9 ± 0.3 (9,7, 10.1)	9.6 ± 0.5 (9.2, 10.0)	9.8 ± 0.4 (9.5, 10.1)	9.8 ± 0.6 (9.3, 10.3)	9.7 ± 0.7 (9.2, 10.2)	9.5 ± 0.5 (9.1, 9.9)
Stroop Neutral Response Time (ms)	728 ± 169 (607, 849)	694 ± 117 (610, 777)	674 ± 117 (590, 758)	628 ± 125 (539, 718)	663 ± 130 (570, 756)	660 ± 147 (555, 765)
Visual Search Field Size 10 Response Time (ms)	1934 ± 262 (1747, 2122)	1801 ± 323 (1569, 2032)	2033 ± 295 (1608, 2459)	1888 ± 436 (1576, 2199)	1817 ± 438 (1504, 2130)	1864 ± 365 (1603, 2125)
Visual Search Field Size 20 Response Time (ms)	2236 ± 476 (1896, 2576)	2103 ± 394 (1821, 2385)	2190 ± 468 (1956, 2525)	2128 ± 392 (1847, 2409)	2110 ± 542 (1722, 2498)	2068 ± 447 (1749, 2388)
Visual Search Field Size 30 Response Time (ms)	2493 ± 492 (2141, 2845)	2245 ± 488 (1896, 2595)	2341 ± 450 (2019, 2663)	2265 ± 418 (1966, 2564)	2253 ± 527 (1876, 2630)	2193 ± 473 (1854, 2431)

CON = Control, EXT = External, MIX = Mixed-Methods, DE = Direct Elimination

7.5 Discussion

The aims of this chapter were to assess the effects of different cooling interventions (EXT, and MIX) between DE fights on physiological responses, cognitive function and performance variables during fencing. It was hypothesised that the MIX would have a greater effect on physiological, performance, perceptual and cognitive function variables than the EXT condition. The key findings from this chapter were that the EXT and MIX interventions decreased mean skin temperature compared to the CON in DE 2 and DE 3. Furthermore, the cooling interventions tended to have an effect of decreasing thermal sensation pre DE 2 and DE 3, but with a larger increase in thermal sensation for the EXT intervention during DE 2 and DE 3. There were no statistically significant differences between the cooling interventions on cognitive function or performance.

A further aim of this chapter was to determine if MIX would have a greater benefit to physiological, performance, perceptual and cognitive function variables during fencing. There were no significant differences between the EXT and MIX cooling interventions for physiological, performance, perceptual or cognitive function measurements therefore *H5* was rejected. When considering individual responses there potentially could be a slightly better performance in terms of points difference for the MIX than EXT due to greater numbers of participants having a positive points difference in DE 2 (6 vs. 4) and DE 3 (7 vs. 4) for the MIX condition.

7.5.1 Effects of Cooling on Mean Skin Temperature during Fencing

There was a significantly lower T_{skin} in DE 2 and DE 3 in both the EXT and MIX interventions when compared to the CON which partially accepts *H1*. Furthermore, there was a lower T_{skin} recorded in the first minute of the intervention period in EXT and MIX than the CON. This could indicate the cooling interventions lower the rise in T_{skin} in the recovery period between fights, observed in chapter 5. The T_{skin} in DE 1 was similar between cooling interventions highlighting that the first DE fight which had no prior cooling intervention provided a similar thermal load for all the participants before receiving an intervention. Although, T_{skin} was lower in this chapter than reported in chapter 5 during a simulated fencing competition. Therefore, both cooling interventions in this study could be effective at lowering the greater thermal load of fencing competition, as highlighted in chapter 5 whereby hot T_{skin} (>35°C) which was linked to high RPE, and lower distance covered. However, despite a decrease in T_{skin} in this study there were no statistically significant recorded performance improvements between the EXT, MIX, and the CON condition i.e., distance covered, training load, points scored, points conceded or points difference, rejecting *H3*. Furthermore, there were no statistically significant differences for any associated physiological variables measured between EXT, MIX and the CON condition – HR_{av}, HR_{max}, blood lactate concentration, and T_{au} – rejecting *H2*. This was unexpected as a reduction in T_{skin} should result in lower cardiovascular strain through reduced skin blood flow requirements to dissipate heat which should lower heart rate (B. R. Ely et al., 2010; Sawka et al., 2012). However, the difference in T_{skin} of ~1°C between the CON and EXT and CON and MIX interventions may not be great enough to cause a reduction in heart rate.

Previous research by Eijvogels et al (2014) during 5km running performance showed similar results of lower T_{skin} than the control condition for external cooling using ECV. Average T_{skin} in this study and the study by Eijsvogels et al. (2014) were <34.5°C, which is also lower than those reported in chapter 5. However, there was no difference in performance or core temperature between the cooling and control conditions (Eijsvogels et al., 2014). The researchers suggested that the ambient conditions being moderate could have explained the lack of performance improvement (Eijsvogels et al., 2014) whereas the majority of cooling intervention studies use ambient temperatures of 30°C or higher. However, it was expected that cooling in this chapter may have a benefit to fencing performance through alleviating the high T_{skin} and the micro-climate created by the fencing protective equipment as shown in chapter 5. Furthermore, the lower skin temperature (~1°C) in the cooling conditions compared to CON in this chapter and Eijsvogels et al (2014) may not be a large enough to have any further physiological effects and performance improvements. Cooling interventions may also be more beneficial in improving performance when mean skin temperatures in non-cooling conditions are classified as hot (>35°C), as shown in chapter 5 and in previous literature (Hasegawa et al., 2006; Ihsan et al., 2010; Lee et al., 2008; Lynch et al., 2018; Naito & Ogaki, 2017). Moreover, there could have been a cooling effect of the CON trial drink temperature which was lower than body temperature and due to the fencers removing the fencing jacket between fights to standardise clothing layers between the different trials. This could have lowered skin temperature enough in the recovery period and reduced thermal sensation back to a comfortable level to not impact performance as shown in Figure 7.14. Future research should consider the effects of different fluid temperatures on fencing performance. Previous research has shown positive effects of cold water ingestion on endurance performance with greater time to exhaustion (Lee et al., 2008; Mündel et al., 2006) and distance covered in a cycling time trial (Byrne et al., 2011).

7.5.2 Effects of Cooling on Core Temperature during Fencing

There were no statistically significant differences for deep body temperature estimates (T_{au} and T_{gast} as shown in Figure 7.8 and Appendix D Figure D.1, respectively). However, it is unclear on the effectiveness of the EXT and MIX interventions as there were only 5 and 6 complete sets of data for T_{au} and T_{gast}. From data in Figure 7.8 there did seem to be a decreased T_{au} pre and post DE 2 and DE 3 in MIX when compared to the EXT and CON conditions by ~0.3°C indicating that the MIX may cause a slightly lower internal body temperature. A significant difference of ~0.2-0.4°C has been shown during exercise in previous studies using cold water as a cooling intervention to improve cycling performance (Byrne et al., 2011; Lee et al., 2008, 2013; Mündel et al., 2006) Unfortunately, due to issues with the core temperature turning on whilst being activated, participants were given the core temperature pill immediately at the start of the testing. This only allowed the pill ~1 hour to transit through the body prior to the start of DE 1, which has been shown to record similar core temperature readings to T_{re} or pills taken at 3, 6 and 12 hours prior to exercise (Notley et al., 2021). Therefore, this was deemed an appropriate transit time for the pills during the testing. However, the T_{gast} measurements in this study were likely to be affected by the temperature of the ingested water which has been shown previously to be affected up to 3 hours post pill ingestion (Roxane et al., 2018). This is shown by the large range of T_{gast} measurements during each cooling condition pre and post each DE fight as shown in Appendix D Appendix Figure D.2, as well as post fight T_{gast} temperatures not reaching similar readings as reported in chapter 4 and 5 (~37.8°C in this chapter vs. ~38.5°C in chapter 4 and 5). Furthermore, the measurement of T_{au} could have underestimated T_{core} due to being influenced by the external environmental conditions and reflecting the carotid artery temperature and, therefore, not deep body temperature (Ganio et al., 2009; Lim et al., 2008; Moran & Mendal, 2002)

7.5.3 Effects of Cooling on Mask Temperature during Fencing

There were no significant differences determined between cooling interventions for T_{mask}. Despite this, there is a potentially cooler micro-climate within the protective clothing due to reduced mean skin temperature from cooling as shown by a significant correlation between T_{skin} and T_{mask} for all DE fights together and for DE 2 and DE 3 after cooling has been applied as shown in Figure 7.10 and Figure 7.11. This cooler micro-climate may not be large enough to have any physiological or performance benefits. This chapter only studied 3 DE fights not a full set of up to 8 DE fights, therefore, cooling for longer may potentially have more beneficial effects by reducing the hot micro-climate and T_{mask} towards ambient temperature.

7.5.4 Effects of Cooling on Physiological Responses during Fencing

Similar HR_{av} and HR_{max} were reported in this chapter compared to chapter 4 and 5 showing a similar physiological response in this fencing protocol to simulated competitions. There were no significant differences between the cooling interventions for HR_{av} and HR_{max} indicating that despite a significantly lower T_{skin} there was no reduction in cardiovascular strain with cooling. However, there could potentially be an individual response to cooling on the heart rate response during the DE fights between the MIX and the CON trial as shown in Appendix G. Average and maximum heart rate tended to decrease on average by ~4.5% in DE 2 and ~6% in DE 3 in the MIX condition compared to the CON, with HR_{av} and HR_{max} ~85% and ~95% of HR_{APM} for all DE fights in the CON conditions and HR_{av} and HR_{max} were ~78% and ~88% of HR_{APM} by DE 3 in the MIX condition. Differences in HR_{av} and HR_{max} for the EXT condition compared to the CON were ~2-3% for DE 2 and DE 3. Had the cooling intervention been applied for a full set of DE fights there could have been a significant decrease in HR_{av} and HR_{max} in both the cooling conditions that could have lowered cardiovascular strain of fencing. As shown in chapter 5 HR_{av} and HR_{max} did not differ across the 7 DE fights and were above 86% and 94%, respectively. Therefore, a lower heart rate response due to cooling across a full set of DE fights could lower the cardiovascular strain of fencing through decreased T_{skin} and increasing the core to skin temperature gradient which could cause a lower skin blood flow requirements to dissipate heat (Sawka et al., 2012). Future research should explore the effects of cooling across a full DE phase to see if there are any physiological effects as fencers fatigue to improve fencing performance in latter DE rounds.

7.5.5 Effects of Cooling on Perceptual Responses during Fencing

There were some significant effects of the cooling interventions on thermal sensation ratings which partially accepts *H4*. However, there were no significant differences for thermal comfort or differentiated RPE between cooling interventions. There was a similar rate of increase in thermal sensation in the CON and MIX interventions pre to post fight, however, there was a significantly greater rate of increase in thermal sensation pre to post fight in the EXT only intervention. There were lower ratings of thermal sensation recorded pre DE 2 and pre DE 3 in the MIX and EXT intervention (Figure 7.14 and Appendix E Figure E.1) and also post DE 2 and DE 3 in the MIX intervention when compared to the CON (Figure 7.14 and Appendix E Figure E.2). These potential differences in thermal sensation indicate that there could be a perceptual benefit of the EXT and MIX interventions with participants starting each DE fight feeling cooler and finishing cooler in the MIX intervention. Despite a significantly greater rate of increase in thermal sensation in the EXT intervention the post-fight thermal sensation was similar to the CON intervention (Figure 7.14). The lower thermal sensation due to cooling could be linked to the lower T_{skin} and could be important for fencers to maintain motivation and performance levels by feeling cooler. It has been shown that mean skin temperature can predict thermal sensation ratings (Lan et al., 2019; Liu et al., 2021).

7.5.6 Effects of Cooling on Fencing Performance

There were no significant differences for points difference, points scored or points conceded between the cooling interventions. However, as fencing style can be individual with attacking or defensive styles as discussed in chapter 2.1. When individual responses are considered within this chapter there may have been a limited performance benefit present within the different cooling interventions, as shown by Figure 7.15 and Appendix F Figure F.1. There were more participants with a positive points difference in DE 2 and DE 3 in the MIX condition compared to the EXT and CON conditions (DE 2: MIX = 6, EXT = 4, CON = 4; DE 3: MIX = 7, EXT = 4, CON = 4; Appendix F). The mean points difference also increased from DE 2 to DE 3 from 1.5 to 3 points (Figure 7.13) in the MIX. This could be important in a standard DE fight during competition, whereby it is first to 15 points, so an ability to score more points with the MIX approach could be advantageous for fencers to get to 15 points earlier. Future research should consider if MIX maintains a positive points difference and if there are benefits to EXT only cooling over a full set of DE fights. Furthermore, as shown in Appendix F individual athletes may have a preference to a particular cooling intervention with some participants having a positive points difference in the CON, EXT, or MIX conditions. Therefore, fencers should determine which cooling intervention is most effective in training prior to use in competition. This could be achieved through simulating DE fights with a standard rest period between fights for cooling to be applied and measuring points scored and conceded (to calculate points difference) and perceptual measurements i.e., thermal sensation and thermal comfort. The large variation in points scored and conceded will have affected the lack of significant differences determined due to the volume of exercise being standardised to a full 3 x 3-minute DE fight instead of first to 15 points. Therefore, depending on the tactical nature of each fight and the different fencing styles (attacking vs. defensive) more points were scored in some fights than others and could have created large points differences.

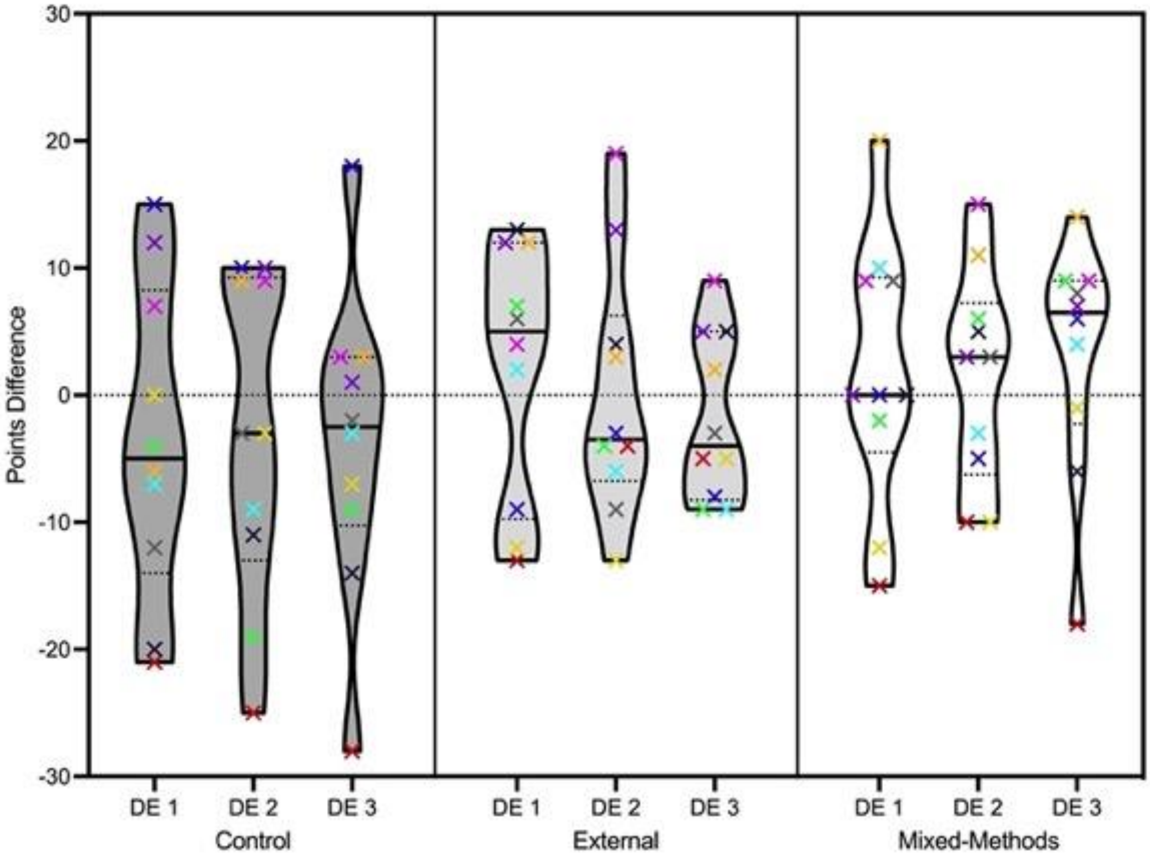


Figure 7.15. Points difference distribution during DE fights for CON, EXT, and MIX interventions. Solid line = median, dotted line = quartiles. DE = Direct Elimination. Individual participants represented by a different colour.

7.5.7 Effects of Cooling on Cognitive Function during Fencing

There were no significant differences reported in cognitive function between the CON, EXT and MIX interventions which partially rejects *H4*. It is possible that the increase in T_{core} during the fencing protocol may not have been high enough to reduce cognitive function. For example, it has been previously shown T_{core} >38.5°C impairs cognitive function for complex tasks such as the visual search task in this study (Gaoua et al., 2011; Maroni et al., 2020; Schmit et al., 2017). Furthermore, it has also been determined that increases in core temperature ~38.0°C can improve cognitive function (Bandelow et al., 2010; Lee et al., 2014; Simmons et al., 2008) due to increased arousal (Maroni et al., 2020). Therefore, the moderate T_{core} (T_{au} ~37.6°C and T_{gast} ~37.8°C) in this chapter could explain the lack of significant difference determined for cognitive function. Additionally, it has been proposed that hot T_{skin} (~36.0°C) could decrease cognitive function (Gaoua et al., 2012), as the T_{skin} in the current study (~34.0°C) did not reach those seen in chapter 5 (>35.0°C) a decline in cognitive function may not have been present in the current no-cooling trial. Therefore, cooling was not likely to improve cognitive function as shown by the non-statistically significant results in this chapter. There are also mixed research results on the effects of cooling and cognitive function with Lee et al. (2014) and Bandelow et al. (2010) reporting positive effects of cooling but only for complex tasks, whereas research by Simmons et al. (2008) and this chapter have shown no benefit of cooling on cognitive function. As the T_{core} and T_{skin} did not reach similar levels (>38.5°C and >35°C, respectively) to chapter 4 and 5 future research should examine the effects of these cooling interventions on cognitive function in fencers where T_{core} is >38.5°C and T_{skin} is >35°C. Decrements in cognitive function, especially reaction time and responding to complex visual information, could be detrimental for fencing performance as this has been shown to be important for fencing performance (Balkó et al., 2017; Roi & Bianchedi, 2008). The protocol in this study used three DE fights which may not have been enough fights to cause a sufficient increase in fatigue and thermal discomfort for a deterioration in cognitive function whereas declines may appear in later DE fights in actual competition (where up to 7 DE fights can be competed in).

7.5.8 Limitations and Future Directions

A potential limitation of this chapter was the issues with the core temperature pills not switching on when activating and therefore timing of ingestion prior to DE 1 was only ~1 hour. Therefore, the temperature of the water ingested likely affected the T_{gast} readings and caused large ranges in the data (Roxane et al., 2018). Furthermore, the collection of T_{au} could have potentially underestimated T_{core} (Ganio et al., 2009), and T_{core} recordings did not reach similar levels to chapter 4 and 5. Moreover, the cooling interventions may have not had a powerful enough cooling effect to produce physiological responses to impact upon performance. However, the aim of this study was to investigate practical cooling interventions within fencing. Additionally, the timing of the cooling intervention was only 10 minutes between fights which is the minimum a fencer would experience in competition. Therefore, increased cooling time, in longer breaks between fights, using these interventions and added boluses of cold-water ingestion could cause a greater decrease in T_{skin}, T_{core}, HR, T_{mask}, RPE, thermal sensation and thermal comfort and have positive effects on performance as seen previously (Byrne et al., 2011; Lee et al., 2008; Mündel et al., 2006). Future research should explore cooling within fencing where greater rest periods between fights are allowed to examine any benefits on physiological and thermoregulatory responses and performance. With fencers training and competing in full protective clothing they could have benefits of heat acclimatisation from continually placing the body under heat stress. Therefore, longer, or stronger cooling methods may be required to have a physiological and performance impact. Future research should determine the level of heat acclimatisation in fencing athletes to determine if they are well adapted to performing under heat stress, and whether cooling interventions need to be more aggressive to have a benefit. To ensure physiological, cognitive and performance differences were not due to hydration levels an equivalent volume of water was given to the participants in the CON and EXT interventions as the MIX intervention. The temperature of this water (~21.8°C) being cooler than the body may have also caused a cooling effect as shown by the decreasing skin temperatures and pre fight thermal sensation in both the CON and EXT. Furthermore, the fencers removed the fencing jacket in all conditions which may have also caused an increase in evaporative cooling.

To standardise the exercise duration for each DE fight the protocol required fencers to work for a full DE fight instead of first to 15 points. This was not reflective of a true DE fight therefore future research could determine if cooling is beneficial in a true DE fight. Furthermore, due to this study taking place in a training environment with a limit on time available, only three DE fights were completed by the participants in this chapter, whereas in a competition fencers could fight up to 7 DE fights. Therefore, cooling throughout a full set of DE fights may have physiological, cognitive and performance benefits when athletes fatigue. This chapter was conducted in a training environment whereas laboratory research would have allowed for more controlled and standardised testing, in particular the environmental conditions (Mendel & Cheatham, 2008). Initially, this study was designed to be conducted in a laboratory, however it was not possible to find sufficient numbers of fencers that were willing to come into the laboratory so, therefore, the testing was undertaken in a real world training environment. Future research could, therefore, assess the effects of cooling in laboratory environments to standardise and control the research. This chapter also focussed on cooling with epée which may not transfer to foil and sabre due to different work to rest ratios, therefore suitable cooling interventions and the thermoregulatory demands for foil and sabre may need determining. Finally, the thermoregulatory response and cardiovascular strain exhibited during this chapter were lower than chapter 4 and 5 as shown through T_{skin}, HR, and T_{core} responses. This could have been due to the training environment and protocol only using 3 DE fights causing a lower catecholamine response (Hoch et al., 1988; Viru et al., 2010). Research could, also, be undertaken in competitive fencing environments to ensure ecological validity and to ensure that fencers are achieving a true physiological and thermoregulatory response in a fight as seen in chapter 5.

7.5.9 Conclusions

This chapter has shown practical, quick, and simple cooling methods (EXT and MIX) for epée fencers to lower T_{skin} and thermal sensation. The EXT and MIX interventions could reduce the rise in T_{skin} between fights observed in chapter 5, due to lower T_{skin} in the first minute of the intervention period. When considering fencing performance there was no statistically significant difference for points difference across the interventions. However, when individual fencing styles are considered there seems to be an individual response as to which intervention is effective for performance, with 7/10 participants having a greater points difference in DE 3 in the MIX compared to 4/10 for the EXT and CON cooling conditions. Therefore, fencers should determine which is the best cooling method to use in training before use at competition. It was unclear if the cooling interventions lowered T_{gast} due to the timing of ingestion and the water temperature potentially influencing the T_{gast} readings. There were no significant differences between cooling interventions determined for any other physiological, or performance variables measured in this study. There were no significant differences for cognitive function measurements between cooling interventions. It must be noted there was only 3 DE fights whereas competition could have up to 7 DE fights, therefore, the protocol used may not have increased body temperature to the same levels as competition. Future, research should determine if cooling over a full set of DE fights in fencers causes physiological, cognitive and performance benefits within fencing.

This thesis has determined the physiological and thermoregulatory responses of able-bodied epée fencing, the following chapter will explore the physiological and thermoregulatory responses of wheelchair fencing.

Chapter 8

8 Study 5 – Physiological and Thermoregulatory Demands of Wheelchair Epée Fencing

8.1 Abstract

Wheelchair fencing competition structure is similar to able-bodied fencing and fencers also compete in similar protective clothing. This study aims to determine the physiological and thermoregulatory responses of wheelchair epée fencing. Four wheelchair fencers (2 category A and 2 category B including world ranked number 1 category A and B fencers) were recruited and competed in 4 Poule and 4 DE fights during training. Three participants also completed an incremental peak oxygen uptake test using an arm crank ergometer. During the Poule and DE fights T_{gast}, T_{skin}, T_{mask}, HR, thermal sensation and differentiated RPE were collected. Work to rest ratio and fight duration was determined for all fights, and for 8 DE fights from the 2019 World Championships and 2016 Rio Paralympics. The key finding from this study was coaches and athletes need to ensure the intensity of training fights mirrors competition especially when mixing category A and B fencers through appropriate fight durations and work to rest ratios. There was an individual thermoregulatory response for each participant for T_{gast} and T_{skin}, with T_{skin} >32°C (warm) throughout and approaching hot towards the end of DE 4 for participant 1. Wheelchair fencing athletes could benefit from face or head cooling due to increases in T_{mask} during DE fights (range 0.34-3.04°C). Finally, competition data should be obtained as despite participant 1 (RPE_O ~11) and 3 (RPE_O ~13) being relatively comfortable throughout there were increases in thermoregulatory variables measured that could be greater at competition and, therefore, cause a decrement in performance.

8.2 Introduction

Wheelchair epée fencing comprises of the same rules and competition format as able bodied epée with the exceptions that the wheelchairs are fixed and thus do not move and points can only be scored from the waist upwards (International Wheelchair and Amputee Sports Federation, 2020c). Wheelchair fencing is classified into three categories: A, B and C, with only A and B competed in at the Paralympic Games. Fencers in category A are classified as having good trunk control, and category B fencers have impairments of the trunk or fencing arm (International Wheelchair and Amputee Sports Federation, 2020b). Participant numbers are generally low in wheelchair fencing. At the Rio Olympic games 2016 there were 12 and 10 athletes that participated in category A and B epée, respectively, whereas at the Tokyo Olympic games 2020 there were 14 athletes that participated in category A and B epée (International Paralympic Committee, 2021) with medals in each individual category and team event to be won. However, greater numbers of participants were evident at the 2019 World Championships with 46 in category A and 35 in category B (International Wheelchair and Amputee Sports Federation, 2020a). Thus, small athlete numbers and the uniqueness of wheelchair fencing has likely contributed to there being limited research assessing the physiological and thermoregulatory demands of wheelchair epée fencing (Bernardi et al., 2010; Iglesias et al., 2019). Those studies that have investigated wheelchair fencing have focussed primarily on heart rate and oxygen consumption responses.

Previous research by Bernardi et al. (2010) determined physiological demands and characteristics of wheelchair fencing. Participants were a mix of category A and B fencers (paraplegia n=4, poliomyelitis n=1, transtibial amputee n=1). During incremental arm cranking exercise peak oxygen uptake ($\dot{V}O_{2peak}$) was recorded as 2.40 ± 0.67 $L.min^{-1}$ (34.4 ± 5.8 $ml,kg^{-1}.min^{-1}$) with peak heart rates recorded as 182 ± 5 $beats.min^{-1}$. During simulated fencing in a laboratory average heart rate and $\dot{V}O_2$ were recorded as 153 ± 10 $beats.min^{-1}$ and 25.0 ± 3.6 $ml.kg^{-1}.min^{-1}$, respectively, with maximal values for heart rate and $\dot{V}O_2$ of 172 ± 14 $beats.min^{-1}$ and 31.3 ± 3.9 $ml.kg^{-1}.min^{-1}$, respectively. However, grouping these athletes together with different impairments and wheelchair fencing categories could have masked the physiological responses of these participants. For example, differences in muscle mass recruitment and loss of sympathetic cardiac innervation in higher level spinal cord injury (SCI) lesions resulting in large standard deviations for heart rate responses were evident. Furthermore, the simulated fencing undertaken was unclear as to whether the fights were similar to a competition in structure or if the 30-45 “attacks” were completed in multiple sets during the 3 x 3 minute bouts to create a full DE. It is also unclear how many fights each fencer completed in the testing which makes drawing conclusions for practical applications difficult.

Research by Iglesias et al. (2019) compared seated and standing epée fencing in able bodied fencers during a single Poule and DE fight in each mode of fencing. Average $\dot{V}O_2$ during seated fencing was similar to the study by Bernardi et al. (2010) of 24.7 ± 5.6 $ml.kg^{-1}.min^{-1}$ however mean heart rate was lower at 137 ± 14 $beats.min^{-1}$. This could be due to able-bodied participants having active muscle mass in the legs to stabilise the upper body, whereas SCI fencers are unlikely to have sufficient muscle mass to do this. Therefore, heart rate would be higher in the SCI fencers due to having to work harder to meet the oxygen demands of the active muscle during wheelchair fencing. This study did not use wheelchair fencing athletes; however, the able-bodied athletes were accustomed to wheelchair fencing. Although the able-bodied participants technique may still differ as a result of being able to use their legs more than the trunk, as wheelchair fencers have been shown to use their trunk muscle primarily when competing (Borysiuk et al., 2020). One potential issue with wheelchair fencing is due to low participation numbers the physiological responses during training could be significantly lower than competition if there are mismatches in function between fencers or different categories competing against each other. However, previous research by Bernardi et al. (2010) and Iglesias et al. (2019) has provided absolute not relative exercise intensities in wheelchair fencing. Relative percentages of an athlete’s maximum heart rate and $\dot{V}O_{2peak}$ could be useful for coaches to determine more accurate individual exercise intensities.

There is no previous research reported for wheelchair fencing assessing the thermoregulatory responses of wheelchair fencing performance. Wheelchair fencers wear protective clothing similar to able-bodied fencing with an added lame apron in epée which covers the non-target area of the lower body. These aprons could cause further decreased heat dissipation and subsequently increased thermal load especially for participants with spinal cord injuries (SCI) which impacts upon the body's ability to regulate temperature during exercise (Price & Campbell, 1999, 2003). Participants with SCI tend to have warmer aural temperatures and skin temperature sites (forehead, forearm, upper arm) especially during recovery from exercise when compared to able-bodied participants (Price & Campbell, 1999). Furthermore, participants with SCI have also been shown to have greater heat storage in the lower body during exercise and recovery when compared to able-bodied participants (Price & Campbell, 1999). During 60 minutes of exercise in hot conditions participants with SCI tend to show an increase in aural and skin temperature throughout exercise without plateauing (Price & Campbell, 2003). As shown in chapter 4 and 5 in able bodied fencers there were high T_{gast}, T_{skin}, T_{mask}, thermal sensation, RPE, and heart rate responses were recorded during simulated fencing competition. There was also an increase in T_{skin} during the recovery between fights adding to the thermal load experienced by the participants. Therefore, due to the added protective clothing and potential thermoregulatory concerns (especially in SCI) it is of importance to determine the thermoregulatory and perceptual demands of wheelchair fencing.

Due to low participant numbers in wheelchair fencing this study used an individualised approach. The aim of this study was to determine the physiological and thermoregulatory responses to wheelchair epée during Poule and DE fights during a training session. A second aim was to determine physiological characteristics of wheelchair fencers during incremental exercise testing to enable training intensities to be more specifically determined. Finally, as this study recruited the world ranked #1 in wheelchair epée for both category A and B, this enabled elite wheelchair fencing athlete profiling as would occur in typical elite athlete support scenarios.

8.3 Methods

8.3.1 Participants

Four male well-trained wheelchair epée fencers volunteered to take part in this study. The participants recruited were classified as either category A fencers (n = 2, Ehlers-Danlos Syndrome/undiagnosed neuromuscular disorder, and Klippel-Trenaunay Syndrome) or category B fencers (n = 2; spinal cord injury (SCI) T4, T5-T6) according to the International Wheelchair and Amputee Sports Federation (International Wheelchair and Amputee Sports Federation, 2020b). All participants competed at international standard (including world #1 for both categories at the time of testing), had previous wheelchair epée fencing training history and trained regularly in wheelchair fencing. All participants had attended the 2019 Wheelchair Fencing World Championships. All participants completed preliminary questionnaires as described in chapter 3.2. Seated height was measured to the nearest 0.1cm using a portable stadiometer (Seca 213, Birmingham, UK). The participants were measured seated in their competition wheelchair, and then requested to take an inhalation of breath and instructed to have the head in the Frankfort Plane (Winter et al., 2007). Table 8.1 shows the characteristics of the four participants.

Table 8.1. Participant characteristics for the four participants.

Variable	Participant 1	Participant 2	Participant 3	Participant 4
Wheelchair Epée Category	A	A	B	B
Age (years)	23	26	20	32
Seated Height (cm)	155	149	144	149
Fencing (Hours per Week)	25	20	13.5	8

Strength and Conditioning (Hours per Week)	3	4	3	3
Previous Fencing Experience (years)	7	1	8.5	7
Disability	Ehlers-Danlos Syndrome/undiagnosed neuromuscular disorder	Klippel-Tranaunay Syndrome	SCI T4	SCI T5-T6

8.3.2 Procedures

Participants were required to compete in four Poule and four DE fights in a round-robin format during a training session in an established fencing training centre. Poule and DE fights in wheelchair epée are identical to able-bodied fencing. All testing was performed in the participant’s own International Fencing Federation approved equipment and competition wheelchair, however due to the training environment participants did not wear the apron worn normally worn in competition. Each participant’s competition wheelchair was fixed to the piste as per normal competition conditions (Figure 8.1). A fifth wheelchair fencer was also involved in the testing session to make up the remaining fights, but no data was collected. Environmental conditions were monitored every 30 minutes during the session as described in chapter 3.4. Throughout the session average WBGT was 15.7 ± 0.9°C, black bulb temperature was 21.7 ± 0.9°C, ambient temperature 21.6 ± 1.4°C and humidity 37.6

± 2.3%. Participant 1, 3 and 4 also attend a laboratory testing session to determine $\dot{V}O_{2peak}$.

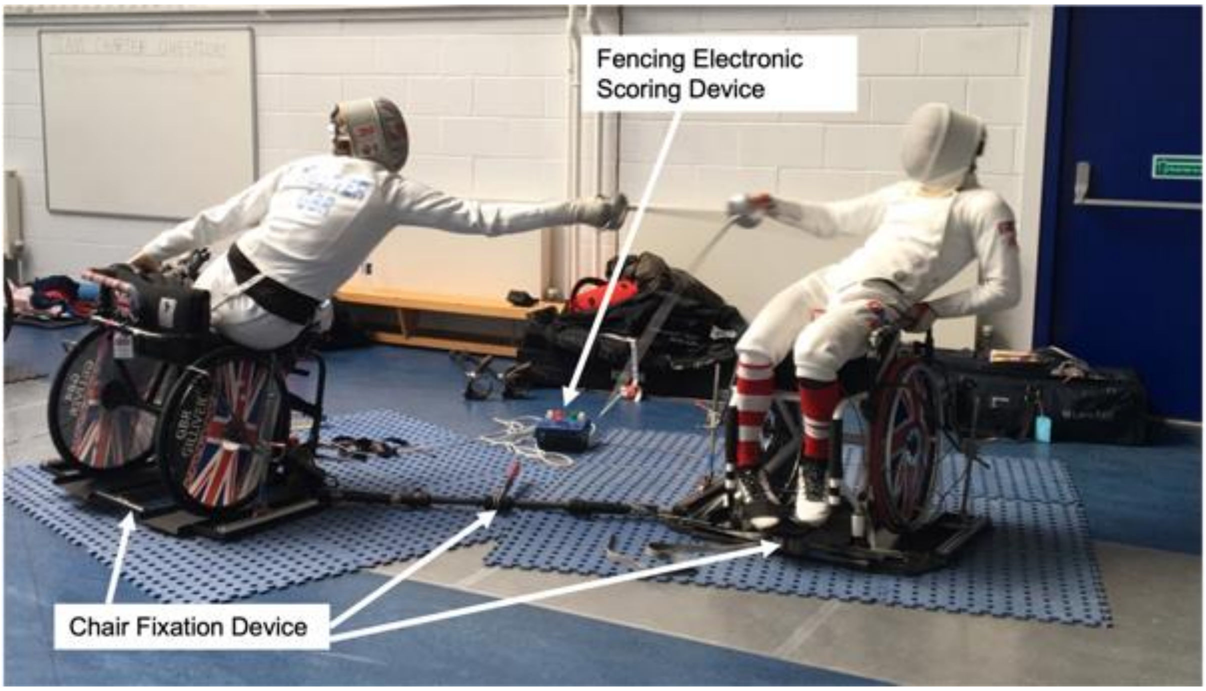


Figure 8.1. Wheelchair epée fencing fight set up during the testing. Within wheelchair epée the target area is anywhere on the upper body apart from the head.

8.3.3 Peak Oxygen Consumption

Participants 1, 3 and 4 attended a separate laboratory session to determine $\dot{V}O_{2peak}$ using an arm crank ergometer (ACE; Lode Angio, Lode, Groningen, The Netherlands). Prior to testing all participants were required to void bladder to reduce risk of autonomic dysreflexia due to hypertension (Goosey-Tolfrey, 2006) in the SCI participants. Upon arrival participants were fitted with a heart rate monitor (Polar T31-Coded, Polar, Finland, Kempele) and transferred to a standardised chair for the testing (Figure 8.2). A 20µL resting capillary blood sample was collected from the ear lobe with procedures described in chapter 3.6.1 to determine resting blood lactate concentration. Participants were then fitted with a face mask for expired gas to be collected. Expired gas was sampled continuously during the testing using a portable breath-by-breath gas analysis system (Metamax 3B, CORTEX Biophysik GmbH, Leipzig, Germany). Values for $\dot{V}O_2$, $\dot{V}CO_2$, RER, and minute ventilation ($\dot{V}E$) were calculated and exported to an excel spreadsheet.

The Metamax 3B gas analysis system was calibrated as per manufacturer instructions using Metasoft software (Metasoft, CORTEX Biophysik GmbH, Leipzig, Germany). Initially a room pressure calibration was completed. Then the room air calibration procedure was carried out. Following this the reference gas calibration was carried out whereby gas concentrations were 5% carbon dioxide, 10% oxygen, and Nitrogen for balance. Finally, the turbine calibration was complete with the turbine being connected to a 3-litre volume calibration syringe (Hans Rudolph, Shawnee, Kansas State, USA).

Participants were required to complete a 5-minute warm-up on the ACE between 0-30W. The use of an electronically braked ACE ensured the same power output could be achieved despite slight changes in crank rate during each stage of the $\dot{V}O_{2peak}$ test (Price, Bottoms, Smith, & Nicholettos, 2011). Participants then completed an incremental test to volitional exhaustion for $\dot{V}O_{2peak}$ starting at between 0-30W and increasing by 10W every 2 minutes at a cadence of 70-80 revs.min^{-1} (Smith, Price, & Doherty, 2001). Participants were given three warnings if cadence dropped below 65 revs.min^{-1}, being verbally encouraged to increase cadence, and the test was terminated after the 4th drop in cadence or if the participant reached volitional exhaustion. Participants were given verbal encouragement throughout the test and had access to a fan if required. Immediately on cessation of exercise a capillary blood sample was collected to determine blood lactate concentration at $\dot{V}O_{2peak}$. Peak oxygen uptake was determined as the final 30 second average oxygen consumption data of the final stage recorded. Maximum heart rate was recorded as the greatest 5 second average during the test, which was the final stage for all participants.

Figure 8.2. Lode Angio arm crank ergometer set up used for the incremental exercise tests.

8.3.4 Gastrointestinal Temperature

Gastrointestinal temperature was measured as described in chapter 3.7.1. Participant 4 had a contraindication to using the T_{gast} pill, therefore had no T_{gast} measurements collected. Gastrointestinal temperature was recorded pre and post all Poule and DE fights.

8.3.5 Skin Temperature Measurements

Mean skin temperature was measured and calculated as described in chapter 3.8, except thermochrons were set to record every 10 seconds during testing. An additional thermochron was placed on the back between the left and right scapula. Mean skin temperature was calculated for the following time points for all Poule and DE fights: first and last minute of each fight, mean for each fight, and 5th minute of recovery between fights.

8.3.6 Mask Temperature Measurements

Fencing T_{mask} was determined by placing an iButton thermochron (as described in chapter 3.8) inside the top of the mask so it did not disturb the vision of the participants. The iButton was programmed as described in chapter 3.8. Mask temperature was measured during the first minute, last minute and average for each Poule and DE fights. The change in mask temperature was calculated by subtracting the first minute temperature from the last minute temperature for each fight.

8.3.7 Core to Skin Temperature Gradient

Core to skin temperature gradient was calculated by subtracting T_{skin} during the last minute of the fight from post fight T_{gast} for all Poule and DE fights.

8.3.8 Heart Rate Monitoring

Heart rate was recorded as described in chapter 3.9. Maximum heart rate was determined for participant 1, 3 and 4 from the $\dot{V}O_{2max}$ testing session and relative heart rates recorded during Poule and DE fights were calculated based on this. Participant 2 was unable to attend the $\dot{V}O_{2max}$ testing session so had maximum heart rate determined as their age predicted maximum. Both absolute heart rate (beats.min^{-1}) and relative heart rate (% HR_{max} or % HR_{APM}), HR_{av}, and HR_{max} were recorded for all Poule and DE fights.

8.3.9 Work to Rest Ratio

Work to rest ratios for all Poule and DE fights were calculated as described in chapter 3.11. Work to rest ratios for DE rounds were also calculated as described in chapter 3.11 from competition video obtained for participant 1 and 3 from the 2016 Rio Paralympic Games (participant 1), 2019 World Championships (participant 1 and 3), and the 2016 category A Paralympc final. There were no Poule fights available for analysis. This was used to compare work to rest ratio data from competition in category A and B fights to the training fights completed in this chapter.

8.3.10 Blood Lactate Concentration

Capillary blood lactate analysis was collected and analysed as described in chapter 3.6.1. Capillary blood samples were collected at baseline, post Poule, and post DE. Capillary blood samples at baseline were collected after a minimum of 10 minutes rest. Post fight capillary blood samples were collected within 3 minutes of the fight terminating.

8.3.11 Ratings of Perceived Exertion

Differentiated ratings of perceived exertion were recorded as described in chapter 3.12. Differentiated RPE (RPE_O and RPE_A) was collected immediately post fight for all Poule and DE fights.

8.3.12 Thermal Sensation

Thermal sensation was recorded as described in chapter 3.13. Thermal sensation was recorded immediately post fight for all Poule and DE fights.

8.3.13 Statistical Analysis

Data are presented as mean ± standard deviation for each participant for Poule and DE fights. Due to differences in functionality and disabilities of the participants individual data is presented for each participant. As the study is observational and participant numbers being low there was no statistical analysis undertaken.

8.4 Results

8.4.1 Peak Oxygen Consumption

The results from the incremental arm crank ergometry test are shown in Table 8.2. Peak oxygen consumption was lower in participants in category B compared to category A.

Table 8.2. Peak responses from the incremental arm crank ergometry test.

Variable	Participant 1	Participant 3	Participant 4
$\dot{V}O_{2peak}$ (L.min^{-1})	2.50	2.07	1.76
$\dot{V}CO_{2peak}$ (L.min^{-1})	2.78	2.36	2.08
$\dot{V}E_{peak}$ (L.min^{-1})	92.6	85.3	73.8
RER at $\dot{V}O_{2peak}$	1.12	1.14	1.18
HR_{max} (beat.min^{-1})	182	176	197
RPE_O at $\dot{V}O_{2peak}$	14	17	16
RPE_A at $\dot{V}O_{2peak}$	20	16	16
Pre-test blood lactate concentration (mmol.L^{-1})	1.00	1.64	1.62
Post-test blood lactate concentration (mmol.L^{-1})	6.95	6.63	10.97

$\dot{V}O_{2peak}$ = peak oxygen consumption, HR_{max} = maximum heart rate, RER = respiratory exchange ratio, RPE_O = overall ratings of perceived exertion, RPE_A = arms ratings of perceived exertion

8.4.2 Poule and DE fight performance characteristics

The fight performance characteristics of the Poule and DE fights are shown in Table 8.3 and Table 8.4. Participant 1 won all their Poule and DE fights, participant 2 won one Poule and one DE fight and lost the remaining fights, participant 3 won three Poule and three DE fights and lost the remaining fights, and participant 4 lost all Poule and DE fights.

Table 8.3. Poule fight duration (mins:secs) and score (first number = column participant score, second number = row participant score).

Vs.	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Participant 1					
Participant 2	0:31 (5-0)				
Participant 3	1:41 (5-1)	1:29 (3-5)			
Participant 4	0:52 (5-0)	2:24 (5-1)	1:03 (5-1)		
Participant 5	0:49 (5-0)	2:51 (3-5)	1:10 (5-2)	1:48 (2-5)	

Table 8.4. Direct Elimination fight duration (mins:secs) and score (first number = column participant score, second number = row participant score).

Vs.	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Participant 1					
Participant 2	3:49 (15-5)				
Participant 3	6:25 (15-6)	7:08 (13-15)			
Participant 4	2:19 (15-0)	6:45 (15-2)	5:51 (15-5)		
Participant 5	4:15 (15-5)	5:01 (11-15)	3:49 (15-10)	18:14 (2-15)	

8.4.3 Thermoregulatory Responses during Training Session

Figure 8.3 shows the T_{gast} response across the Poule and DE rounds. There was a general increase in T_{gast} from P1 to DE 4 (~1°C) for participant 1. Participant 2 showed a greater increase in T_{gast} to participant 1 throughout the Poule and DE (~1.5°C), however T_{gast} decreased pre P2, DE 1 and DE 3. Participant 3 had an initial increase in T_{gast} pre P1 to post P1 (~0.8°C), then T_{gast} remained between 37.8-38.0°C for all remaining pre and post fight time points.

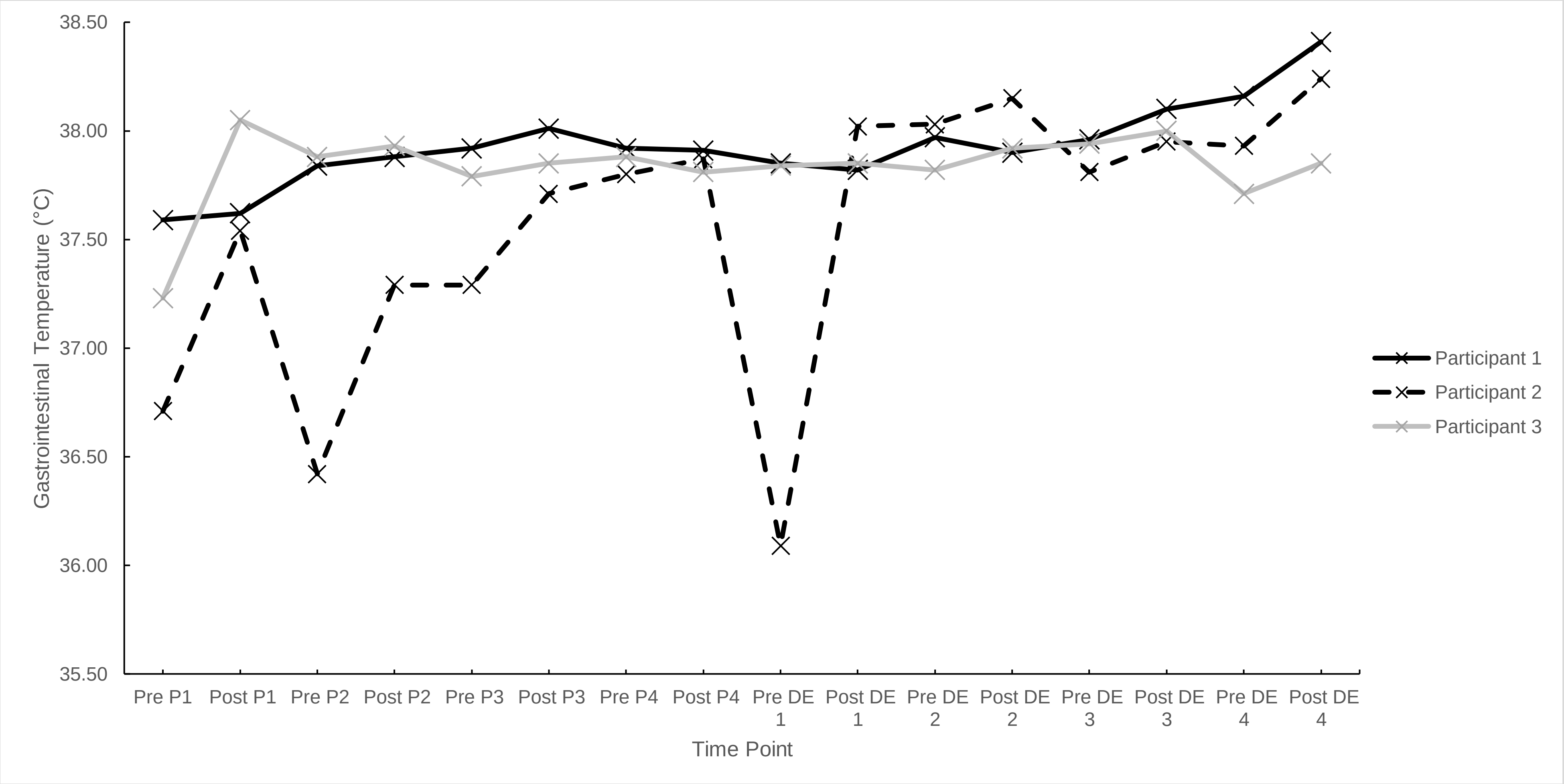


Figure 8.3. Gastrointestinal temperature (°C) response during Poule and DE fights for Participants 1, 2 and 3.

P = Poule, DE = Direct Elimination.

Figure 8.4 and Figure 8.5 show the skin temperature responses during Poule and DE fights for the four participants. All participants had T_{skin} throughout the fights classified as warm by Sawka et al. (2012). Both category A fencers had greater T_{skin} than both category B fencers. Participant 1 had an increase in T_{skin} throughout from P1 to DE 4 approaching hot T_{skin} (34.95°C for DE 4) with last minute skin temperature in DE 4 of 35.14°C. Participant 2 had a similar T_{skin} increase throughout Poule fights before decreasing in the DE fights and plateaued ~34.0-34.3°C. Both category B fencers had a similar T_{skin} (~32-32.5°C) throughout Poule and DE fights. Fifth minute recovery T_{skin} post fight between Poule and DE fights increased from the last minute of the fight for participant 1, 3 and 4. However, participant 2 had a small increase in T_{skin} during Poule rounds but had a decrease in T_{skin} during DE rounds at the 5th minute of recovery. Figure 8.6 shows calf skin temperature during Poule and DE fights for the four participants. Calf skin temperature was similar throughout all Poule and DE fights for participant 3 and 4 with SCI. Calf skin temperature increased throughout all Poule and DE fights for participant 1 and 2. Mask temperature during Poule rounds was relatively stable, however during DE fights there was an increase in T_{mask} from DE 1 to DE 4 for all participants (Figure 8.7). All participants had greater back temperature recorded in DE than Poule fights (Figure 8.8), with Participant 1, 2 and 3 having average back temperatures classified as hot during DE fights (Sawka et al., 2012).

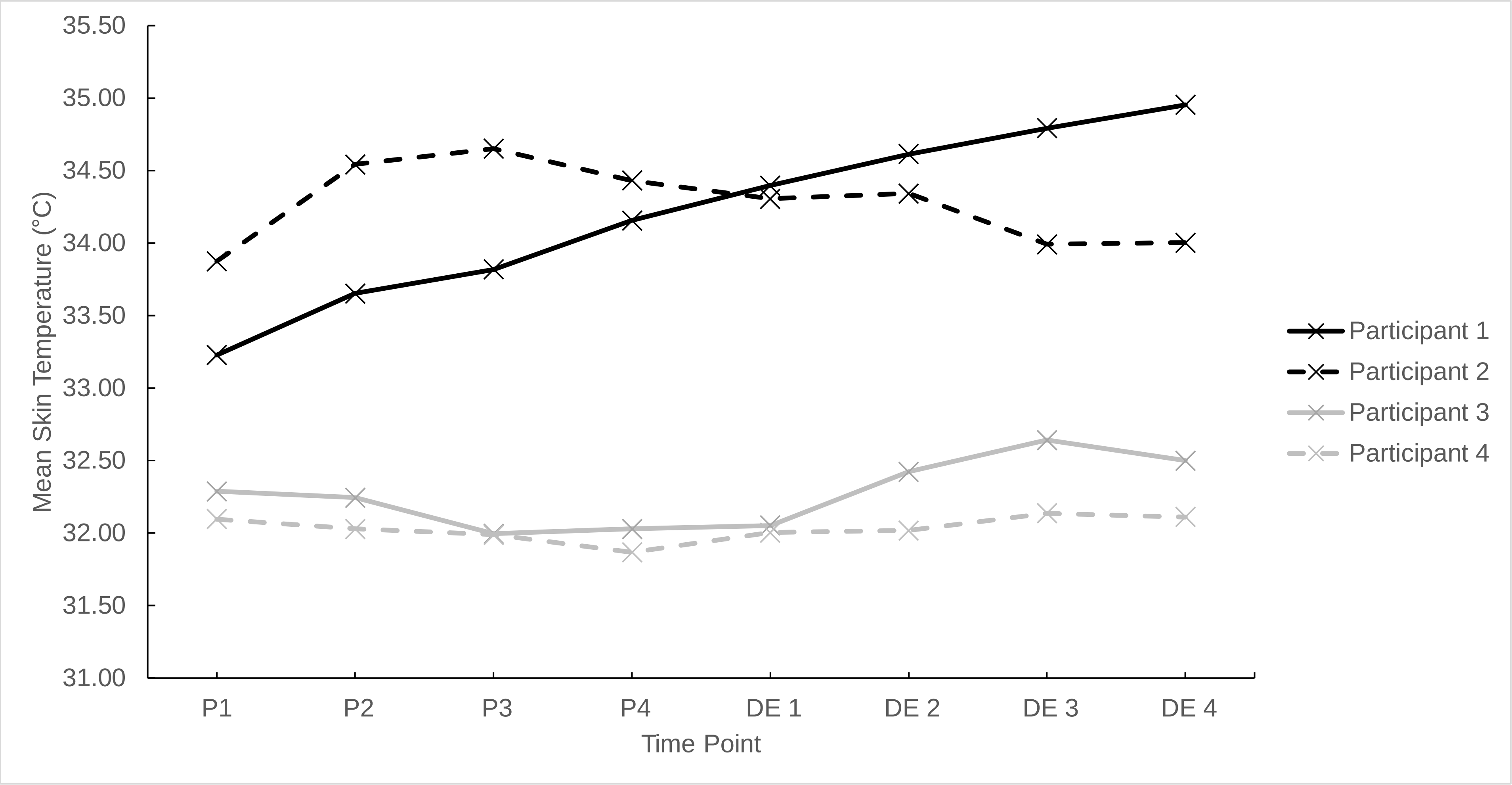


Figure 8.4. Mean skin temperature (°C) response during Poule and DE fights for the four participants.

P = Poule, DE = Direct Elimination

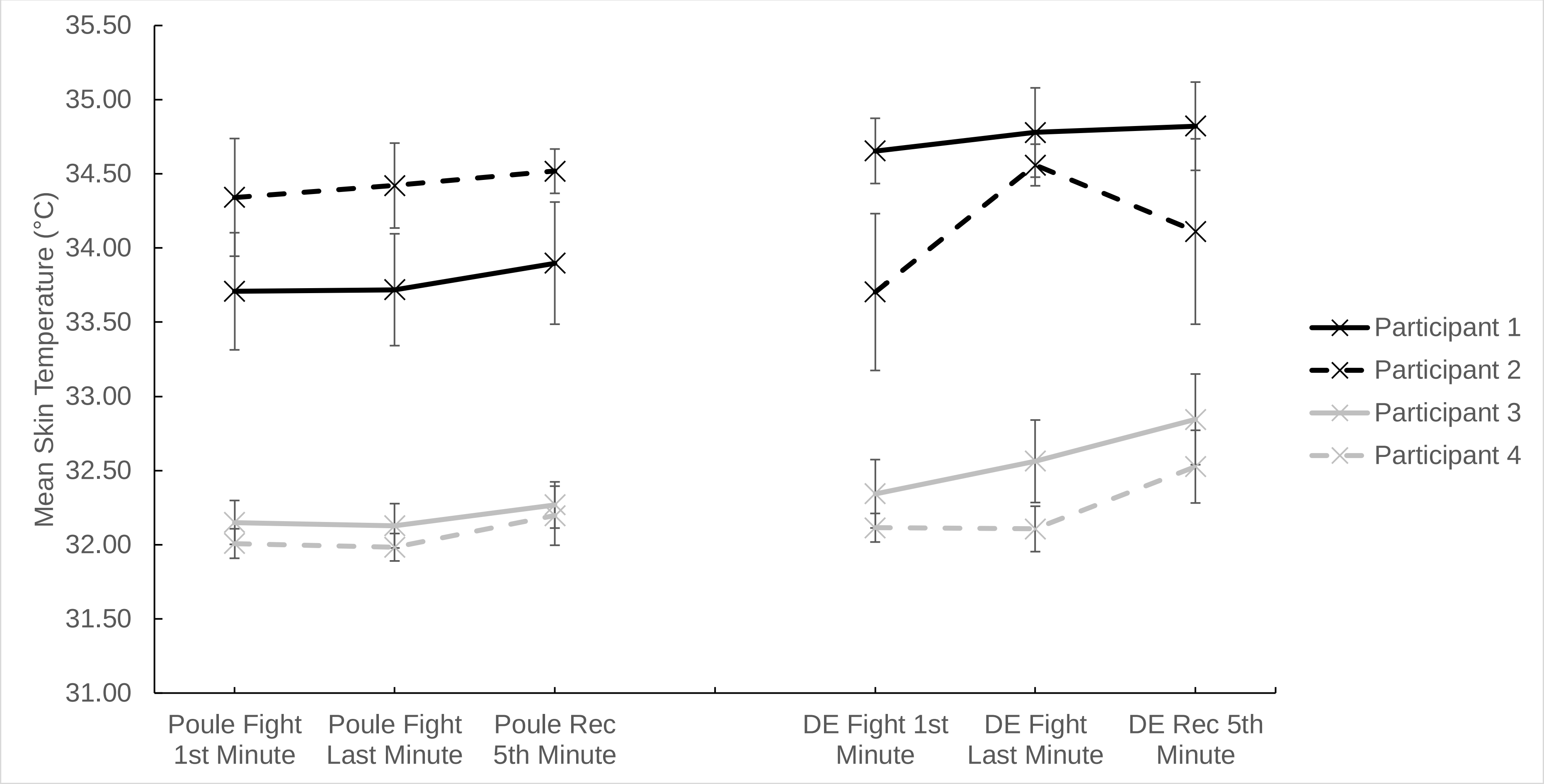


Figure 8.5. Mean skin temperature (°C) during the first minute of the fight, last minute of the fight, and fifth minute of recovery between fights for Poule and DE fights of the four participants (mean ± SD).

DE = Direct Elimination, Rec 5th minute = 5th minute of recovery.

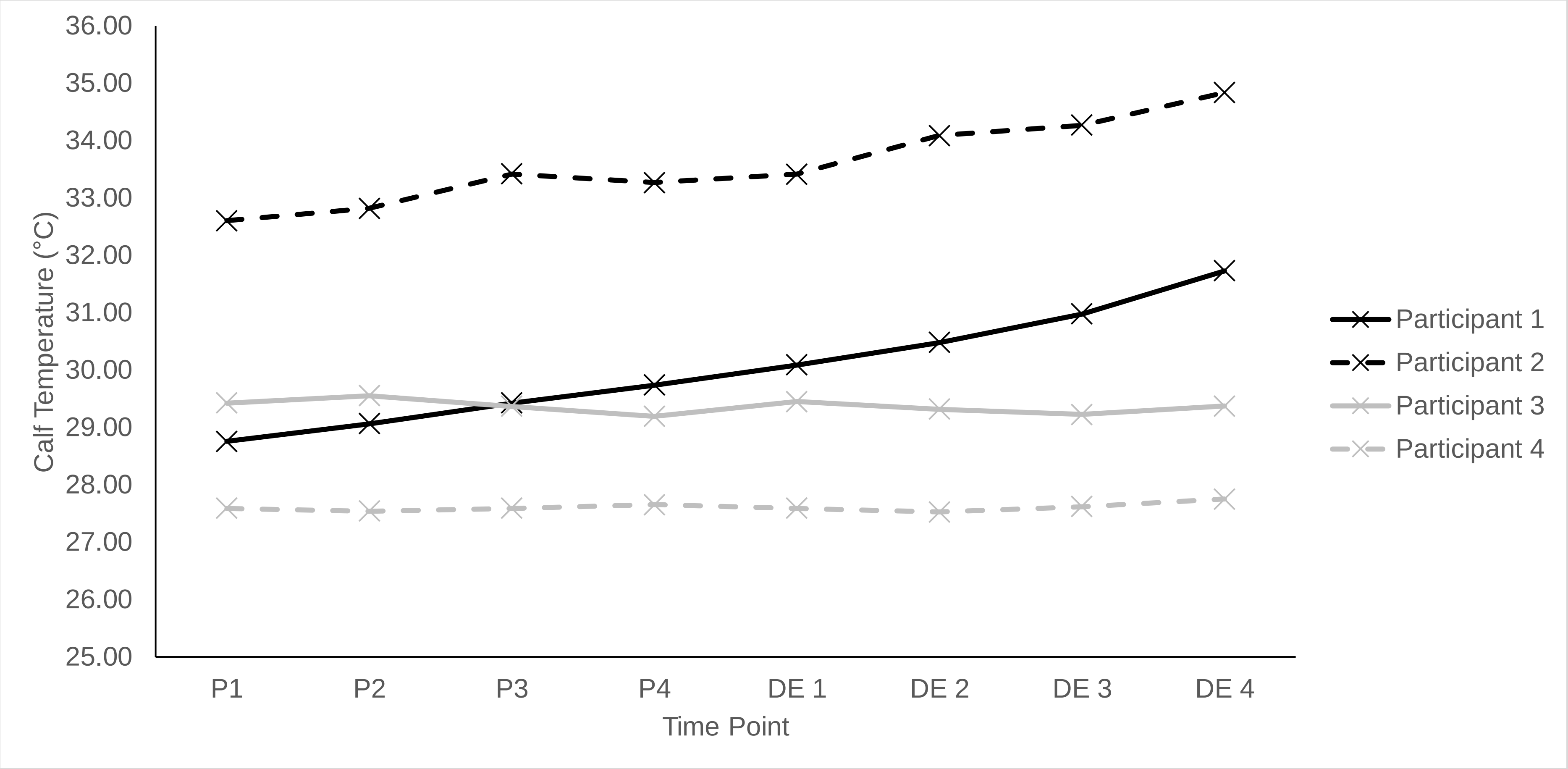


Figure 8.6. Calf skin temperature (°C) recorded during Poule and DE fights for the four participants.

P = Poule, DE = Direct Elimination.

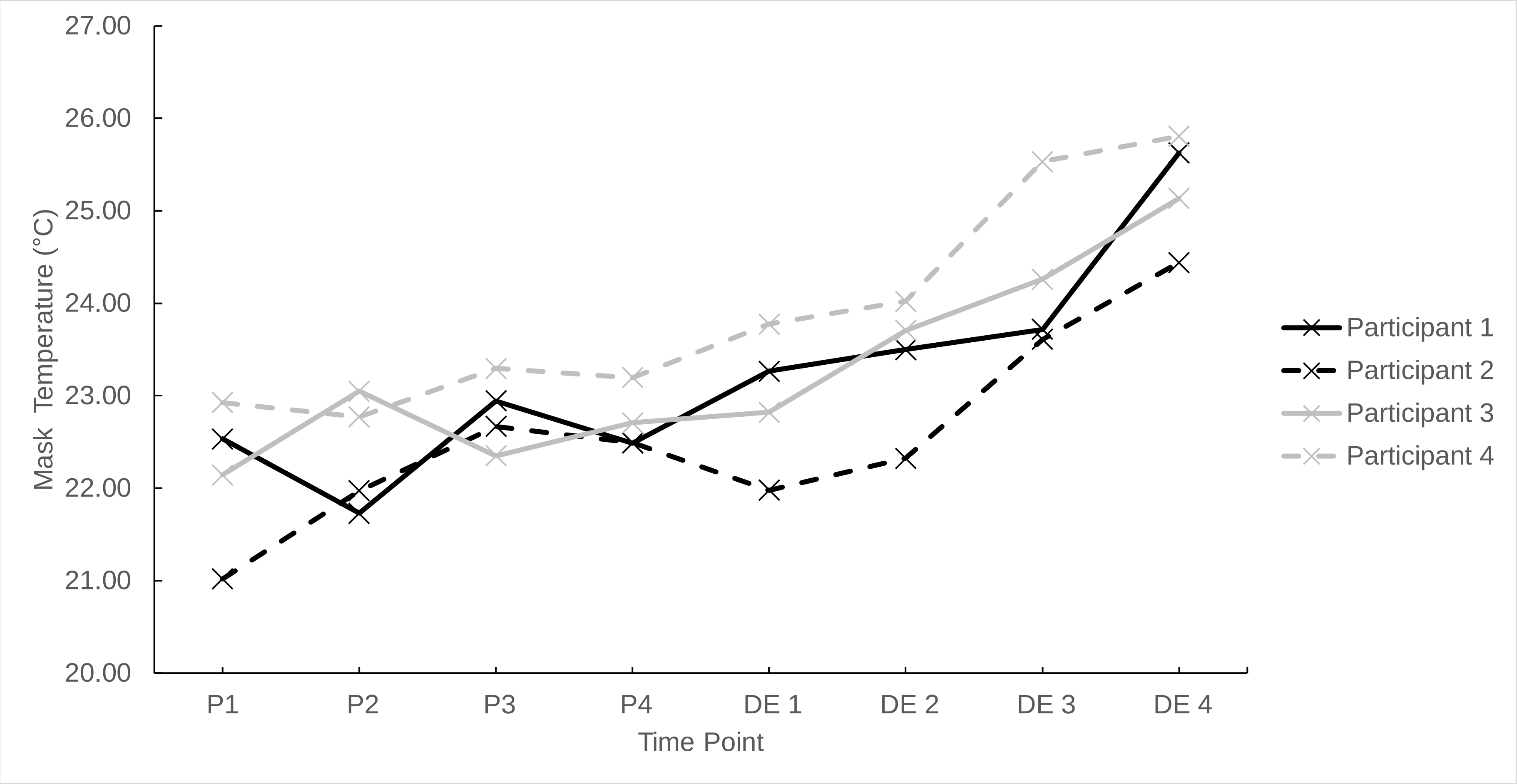


Figure 8.7. Mean T_{mask} (°C) recorded during Poule and DE fights for the four participants.

P = Poule, DE = Direct Elimination.

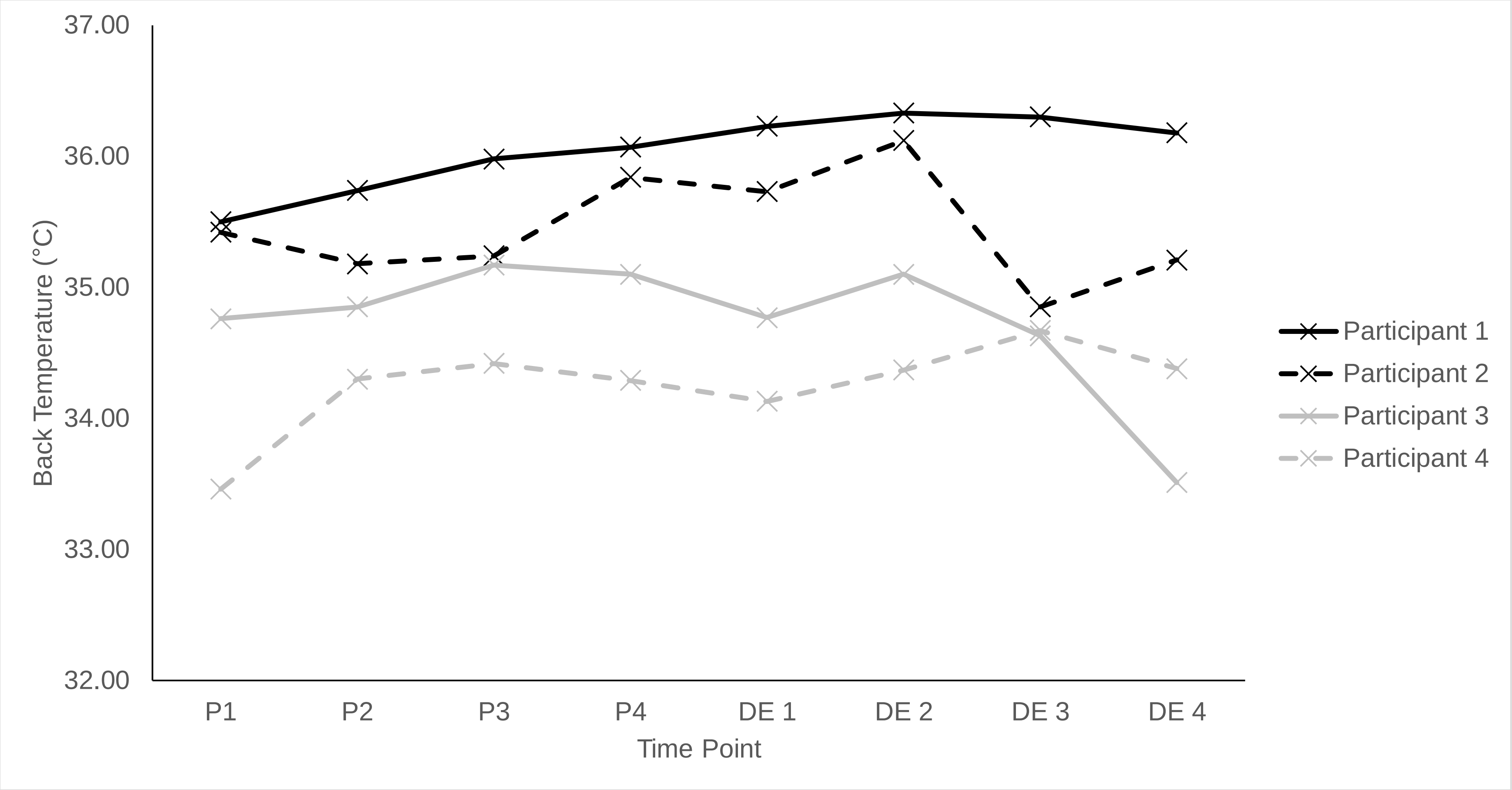


Figure 8.8. Back skin temperature (°C) recorded during Poule and DE fights for the four participants.

P = Poule, DE = Direct Elimination.

Table 8.5 shows other thermoregulatory variables recorded during Poule and DE fights. There were small increases in T_{mask} during Poule fights for participants 2 and 3 with no change for participants 1 and 4. However, during DE fights there were increases in T_{mask} for all participants recorded. There were greater thermal sensation ratings reported in DE than Poule fights for all participants with participant 2, 3 and 4 reporting ‘hot’ ratings. There was a lower core to skin temperature gradient in DE than Poule fights for participant 1 and 3 but a greater gradient for participant 2 in DE than Poule fights.

Table 8.5. Thermoregulatory variables during Poule and DE fights for the four participants (mean ± SD).

	T_{mask} difference first to last minute of fight (°C)		Core to skin temperature gradient (°C)		Thermal Sensation	
Fight Type	Poule	DE	Poule	DE	Poule	DE
Participant 1	0.06 ± 0.12	0.89 ± 0.41	4.14 ± 0.27	3.28 ± 0.09	4 ± 1	5 ± 1
Participant 2	0.18 ± 0.22	1.50 ± 0.51	3.18 ± 0.36	3.53 ± 0.11	5 ± 1	6 ± 1
Participant 3	0.29 ± 0.09	2.33 ± 0.62	5.78 ± 0.08	5.34 ± 0.22	5 ± 1	6 ± 1
Participant 4	0.09 ± 0.06	0.97 ± 0.55	[redacted]	[redacted]	5 ± 1	6 ± 1

DE = Direct Elimination

8.4.4 Physiological and Perceptual Responses during Training Session

There was a similar heart rate response during Poule and DE fights for participant 2, 3 and 4 for both HR_{av} and HR_{max}, however, participant 1 had a greater HR_{av} and HR_{max} during DE than Poule fights (Table 8.6).

Table 8.6. Heart rate responses during Poule and DE fights for the four participants (mean ± SD). Note HR_{APM} for participant 2.

	Absolute Average HR (beats.min^{-1})		Relative Average HR (% HR_{max} or % HR_{APM})		Absolute Maximal HR (beats.min^{-1})		Relative Maximal HR (% HR_{max} or HR_{APM}	
Fight Type	Poule	DE	Poule	DE	Poule	DE	Poule	DE
Participant 1	138 ± 2	154 ± 13	76 ± 1	84 ± 7	151 ± 4	165 ± 12	83 ± 2	90 ± 7
Participant 2	148 ± 7	146 ± 5	76 ± 3	75 ± 2	154 ± 8	158 ± 6	79 ± 4	81 ± 4
Participant 3	115 ± 4	110 ± 6	65 ± 2	62 ± 3	124 ± 5	123 ± 5	70 ± 3	70 ± 3
Participant 4	142 ± 4	137 ± 7	72 ± 2	69 ± 4	150 ± 6	151 ± 8	76 ± 3	77 ± 4

HR = heart rate, HR_{max} = maximum heart rate from VO_{2peak} testing, HR_{APM} = age predicted maximum heart rate, DE = Direct Elimination

Figure 8.9 shows the blood lactate concentration for each participant. Blood lactate concentration for participants 1, 2 and 3 did not increase from baseline to the end of the Poule fights, with participant 2 and 3 not increasing post DE from baseline. Participant 1 had an increase in blood lactate concentration post Poule to post DE. Participant 4 had an increase in blood lactate concentration from baseline to post Poule and then a further increase to post DE.

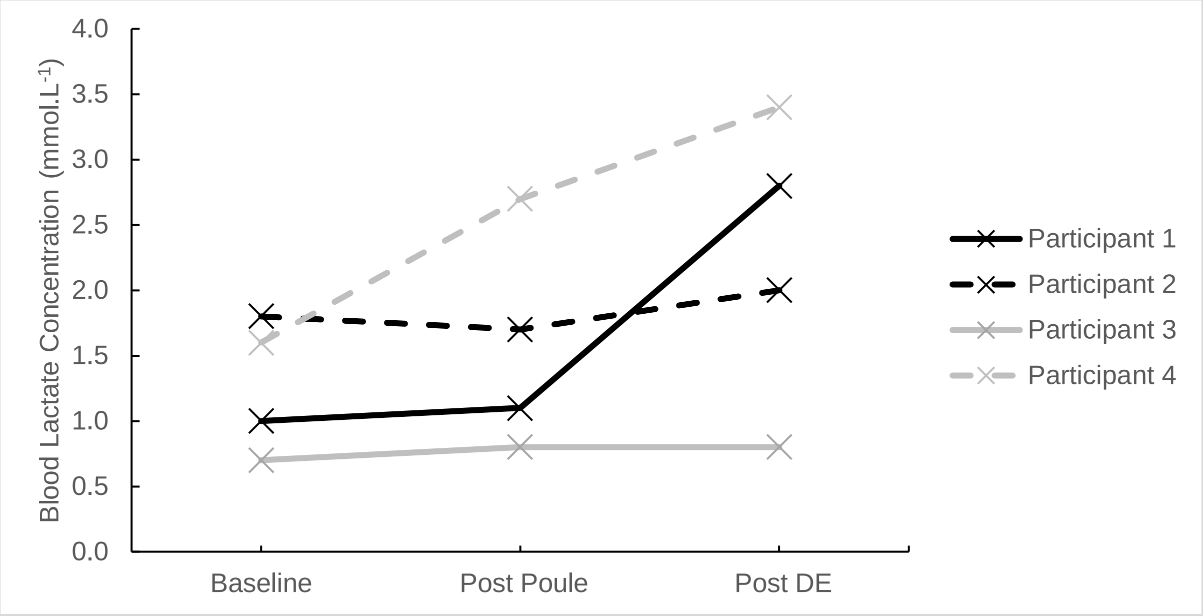


Figure 8.9. Blood lactate concentration (mmol.L^{-1}) at baseline, post Poule and post DE for the four participants. DE = Direct Elimination.

There were slightly greater RPE$_O$ and RPE$_A$ recorded for participant 2, 3 and 4 in DE than Poule fights, however there were similar RPE$_O$ and RPE$_A$ for participant 1 (Table 8.7). Participants 1 and 3 had low ratings of perceived exertion recorded.

Table 8.7. Ratings of Perceived Exertion during Poule and DE fights for the four participants (mean ± SD).

	RPE$_O$		RPE$_A$	
Fight Type	Poule	DE	Poule	DE
Participant 1	10 ± 0	11 ± 2	7 ± 0	7 ± 1
Participant 2	13 ± 2	15 ± 2	14 ± 2	15 ± 2
Participant 3	12 ± 1	13 ± 1	11 ± 1	13 ± 1
Participant 4	14 ± 1	15 ± 1	18 ± 1	19 ± 0

RPE$_O$ = overall ratings of perceived exertion, RPE$_A$ = arms ratings of perceived exertion, DE = Direct Elimination

8.4.5 Comparison of Work to Rest Ratio and Fight Duration between this Study and Wheelchair Fencing Competition

The DE work to rest ratios in this study were similar to those recorded in competition for category A fencers, however DE work to rest ratios in this study were greater than those recorded for category B fencers at competition (Figure 8.10). Figure 8.11 shows the comparison of DE fight duration during this study and those recorded during competition. Average fight duration for the DE fights in this study were greater than those recorded for category B fights and lower than those recorded for category A fights. The fight duration for all category A vs. category A fights in this study were lower than those recorded during competition. The fight duration for the category B vs. category B fight in this study was greater than those recorded during competition. There is a wider variation in DE fights for category A than category B during competition.

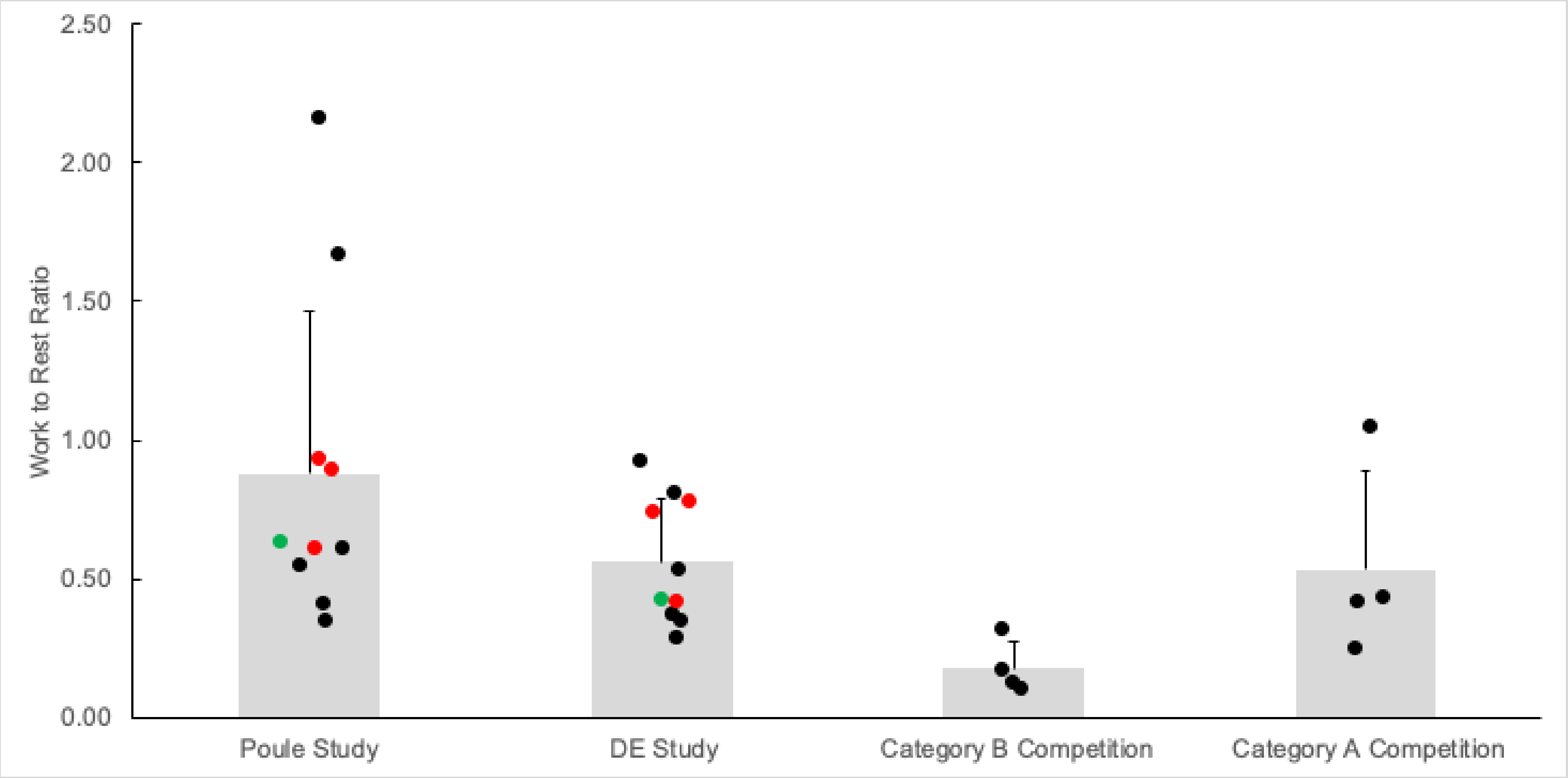


Figure 8.10. Work to rest ratios during Poule and DE fights in this chapter and work to rest ratios for category A and B DE fights during competition (mean ± SD).

Dots represent individual fights. For Poule study and DE study bar: Red dots indicate category A vs. category A fight, green dots indicate category B vs. category B fight, black dots indicate category A vs. category B fight. DE = Direct Elimination

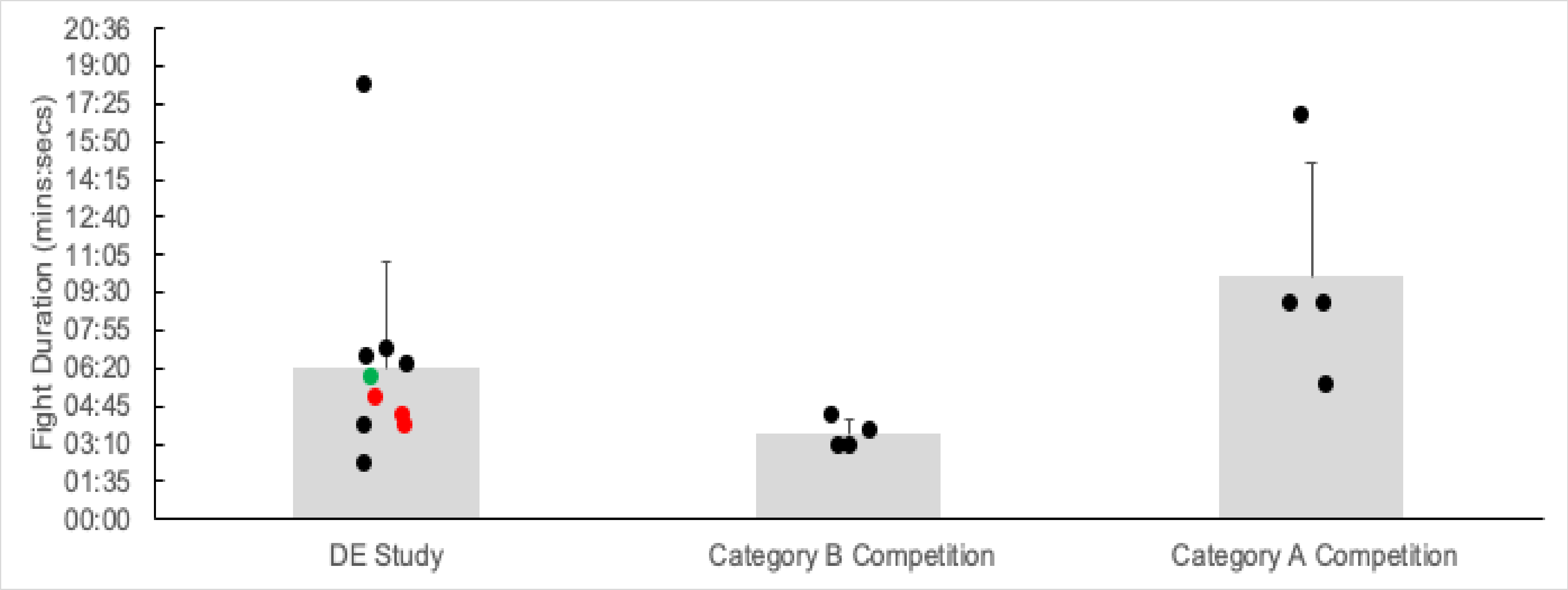


Figure 8.11. Fight duration (mins:secs) during DE fights in this chapter and fight duration (mins: secs) for category A and B DE fights during competition (mean ± SD).

Dots represent individual fights. For DE study bar: Red dots indicate category A vs. category A fight, green dots indicate category B vs. category B fight, black dots indicate category A vs. category B fight. DE = Direct Elimination.

8.5 Discussion

The aims of this study were to profile the physiological and thermoregulatory responses of wheelchair epée fencing during a training session, and to determine physiological characteristics of wheelchair fencing athletes during incremental exercise testing. Furthermore, as this study recruited the world ranked #1 in wheelchair epée for both category A and B, this enabled elite wheelchair fencing athlete profiling as would occur in typical elite athlete support scenarios.

8.5.1 Incremental Maximal Oxygen Uptake Testing

This study adds to the study by Bernardi et al. (2010) who showed a mixture of category A and B fencers had $\dot{V}O_{2peak}$ of 2.4 ± 0.67 L.min^{-1} with HR$_{max}$ recorded as 182 ± 5. The participants $\dot{V}O_{2peak}$ recorded in this study of 2.50, 2.07 and 1.76 L.min^{-1} were similar to those reported by Bernardi et al. (2010). Similarly, HR$_{max}$ of 182, 176 and 197 beats.min^{-1} was similar to those reported by Bernardi et al. (2010). Due to differences in disabilities amongst wheelchair athletes it could be preferential to report individual results instead of group average data especially when mixing different categories of wheelchair fencers. For example, in this study participant 3 and 4 both have a SCI at T4 and T5-6, respectively, however, their maximum heart rates achieved during the incremental $\dot{V}O_{2peak}$ test were different by 23 beats. This shows the impact of SCI on the maximal physiological responses to exercise of the participants. Further, despite a lower maximum heart rate during the incremental $\dot{V}O_{2peak}$ test participant 3 had a greater $\dot{V}O_{2peak}$ recorded than participant 4. This could be due to differences in training volume with participant 3 training more than participant 4 and, therefore, having greater cardiovascular fitness.

8.5.2 Physiological and Thermoregulatory Responses during the Training Session

The key finding from this study highlighted a need to ensure the intensity of wheelchair fencing fights during training is at a similar level to competition. This was shown through a mismatch of work to rest ratios especially for category B fencers, which was consistently higher when compared to fights from competition. Furthermore, average fight duration during the training session was different to competition fight duration for both category A and B fencers as shown in Figure 8.11. Fight duration for category A fights during competition was more varied compared to category B fights. Due to wheelchair fencing training sessions incorporating both category A and B fencers who will have to compete against each other during the session, coaches should ensure that fights meet the demands for each category. Instead of competing in a traditional fight to a certain number of points coaches could use duration or timed intervals using work to rest ratios and fight durations specific for each category of fencer if category A is competing against category B. Category A fencers could also require variations in fight durations during training incorporating some longer fights (~15 minutes). This could be important for the category A participant that was ranked number 1 in the world, as this participant would have more skill and functionality than other participants in the training session so would need to experience longer fights to prepare for competition. Furthermore, Poule fights during wheelchair fencing competition need to be analysed for work to rest ratio and fight duration to enable comparison to training session data to inform training intensity.

During the training session low HR_{av} and HR_{max} were recorded for participants 2, 3 and 4, which were lower than those reported previously in wheelchair fencing (HR_{av} ~81% HR_{APM}, and ~92% HR_{APM}) by Bernardi et al. (2010). However, HR_{av} and HR_{max} was similar to those reported (HR_{av} ~71% HR_{APM} and HR_{max} ~78% HR_{APM}) in seated fencing by Iglesias et al. (2019). Participant 1 had similar HR_{av} and HR_{max} to those reported by Bernardo et al. (2010). Therefore, the HR response recorded in this study may not be a true representation of competition HR intensity. Future research should determine HR responses to wheelchair fencing during actual competition. This would allow coaches to determine training intensity wheelchair fencers should aim to compete at during simulated fights in training. Wearing of heart rate monitors during training is a simple method athletes could use and would ensure wheelchair fencers are training at an appropriate intensity.

The thermoregulatory response for the wheelchair fencing athletes during the training session varied depending on the category of fencer. Category A participants tended to show gradual increases in T_{gast} from P1 to DE 4 during the training session. Category A fencers also had an increasing skin temperature (especially participant 1) during the session which was approaching hot during DE 4 as classified by Sawka et al. (2012). Whereas T_{gast} for the category B fencer had an initial increase in T_{gast} which then remained stable throughout the remainder of the training session. There was also a similar T_{skin} for category B fencers throughout the session which was classed as warm by Sawka et al. (2012). Similar T_{gast} and T_{skin} responses during intermittent exercise have been shown in SCI participants (Griggs, Leicht, Price, & Goosey-Tolfrey, 2015). Calf skin temperature showed a continuous increase for both category A fencers but remained stable for category B fencers during the training session (Figure 8.6). This was unexpected for category B fencers as it has been reported that calf temperature during upper body exercise increases in SCI participants due to vasodilation and heat transferred to the lower body (Price, 2006).

There were some similarities between category A and B fencers in terms of the thermoregulatory response there was an increase in T_{skin} in the 5th minute of recovery between fights from the T_{skin} recorded during the fight. Back temperature recorded in this study was greater than 34°C for all participants during all Poule and DE fights, with both category A fencers' back temperature greater than 36°C during DE fights. Furthermore, there was an increase in T_{mask} especially in the DE for all participants, which was ~3-4°C greater than the ambient temperature. This could indicate the protective clothing is creating a hot micro-climate as the body is unable to dissipate heat effectively. Between fights participants should consider cooling methods to attenuate the increase in T_{skin} in the recovery between fights and to lower the thermal load produced during a fight (Griggs, Price, & Goosey-Tolfrey, 2014). Due to increasing mask temperatures research should be conducted to determine how this could impact cognitive performance in wheelchair fencers. Wheelchair fencers could, also, benefit from face or head cooling between bouts or fights to lower the heat that is transferred to the head during fencing which has been shown to lower thermal strain and maintain performance in wheelchair rugby (Griggs, Havenith, et al., 2015). Furthermore, face and head cooling has also been shown to help manage T_{core}, T_{skin} and have perceptual benefits in able-bodied and Paralympic athletes (Cao, Lei, Wang, Yang, & Mündel, 2022; Pritchett, Broad, Scaramella, & Baumann, 2020).

Perceptually the participants in this study may be unable to perceive heat effectively when factoring in the thermoregulatory responses during a fight, especially during DE fights. This finding has also been shown in SCI wheelchair rugby players possibly due to a smaller area of the body being sensate (Griggs, Havenith, Price, et al., 2017). Participant 1 was rating either comfortable or warm despite a rising T_{gast}, T_{skin} and T_{mask}. This could be related to the participant comfortably winning all their fights and therefore perceiving performance as more comfortable. The participants with SCI may have been over rating their perceptual ratings as they were rating the fights as hot despite T_{gast} <38°C, and T_{skin} <33°C. There may have been some influence of the increasing T_{mask} during the DE that was impacting the thermal sensation felt by these participants, as well as SCI lesion level impacting the amount of the body that is sensate. Participant 1 and 3 reported low differentiated RPE during the fights in this study, therefore it is possible that during competition especially in final rounds this could be reported as higher due greater physiological responses (HR, T_{gast}, T_{skin}). Coaches should determine RPE and HR at competition to assist with training intensity to fully prepare these participants for competition.

8.5.3 Limitations

A limitation of this study is that it was conducted in a training environment and not competition, which may not show a true physiological response to wheelchair fencing. Therefore, it is important to determine the physiological and thermoregulatory responses during actual competition. For example, participant 1 comfortably won all their fights in this study, therefore there could be a greater physiological and thermoregulatory response encountered during competition against opponents of a similar standard. This could cause increased perception of thermal sensation, RPE, and there could be much greater T_{gast}, T_{skin} and T_{mask} during competition. Moreover, there could be a potential negative influence on cognitive performance during wheelchair fencing if T_{gast} and T_{skin} increase above 39.0°C and 35.0°C during competitive fights, respectively (Gaoua et al., 2012; Schmit et al., 2017). Previous research has shown T_{gast} can increase to ~39.0°C in wheelchair rugby athletes (Griggs, Havenith, Paulson, Price, & Goosey-Tolfrey, 2017; Griggs, Havenith, Price, et al., 2017). However, further research is warranted to test these hypothetical responses. Additionally, this study only comprised of 4 Poule and 4 DE fights actual competition could have more rounds depending on participant numbers so competition research should be conducted in future research.

8.5.4 Conclusions

Despite the limitations of this study being in a training environment this is the first study to show the thermoregulatory responses during wheelchair fencing. This study also highlights the need for coaches and athletes to collect actual competition data to ensure the intensity of training fights mirrors competition through recording heart rate, RPE, fight duration, and work to rest ratio. Coaches should ensure each category fencer competes at an appropriate work to rest ratio for their category. Furthermore, use of heart rate monitors during training could ensure fencers are competing at the correct intensity. Thermoregulatory (T_{gast} and T_{skin}) and cardiovascular responses seem to be individual, especially for category A fencers, therefore individual data should be reported in the literature rather than mean group data where variability may be greater than able-bodied participants due to physiological differences between the different category fencers and disabilities. Despite this all participants had an increase in T_{mask} during the DE fights so potential face or head cooling could have physiological and perceptual benefits during competition between fights or bouts and warrants investigation.

Chapter 9

9 General Discussion

This thesis set out to develop a further understanding of the physiological and thermoregulatory demands of fencing, and to determine if there were any effects of cooling on the physiological responses and performance during fencing. This thesis focussed on epée fencing due to the greater work to rest ratios than foil and sabre (Aquili et al., 2013; Roi & Bianchedi, 2008) potentially causing a greater physiological demand. There is limited research assessing the physiological demands of fencing across a competition with the majority of studies focussing on simulated or lab based protocols (Bottoms et al., 2011, 2013; Iglesias et al., 2019; Milia et al., 2013) or being older potentially out-dated research (Iglesias & Rodríguez, 1995, 1999, 2000; Li et al., 1999). There has also been no previous research assessing the thermoregulatory demands of fencing, which is surprising due to the long competition days and the requirement for wearing thick protective clothing which could create a hot micro-climate and impact thermoregulation and performance (Bishop et al., 2000; Pascoe, Bellingar, et al., 1994; Pascoe, Shanley, et al., 1994). An additional aim in this thesis was to assess the physiological and thermoregulatory responses of wheelchair fencing using an individualised approach. There has only been two studies assessing the physiological responses of wheelchair fencing (Bernardi et al., 2010; Iglesias et al., 2019). The study by Iglesias et al. (2019) used able-bodied participants to assess wheelchair fencing this may not show the true physiological response of wheelchair fencing where there is a loss of function in the legs.

Four studies were conducted in this thesis: 1) the physiological demands of epée fencing, 2) the thermoregulatory demands of epée fencing, 3) the effects of EXT and MIX cooling on the physiological responses, cognitive function, and performance variables in epée fencing, 4) the physiological and thermoregulatory demands of wheelchair epée fencing. The main findings, contribution to knowledge, limitations, practical applications, and future research will be discussed in this section

9.1 Main Findings

The main findings for each study are presented below. Chapter 4, 5 and 8 were observational studies thus did not have any hypotheses. Chapter 6 was a validation study comparing the competition protocol from this thesis to the National Championships. Chapter 7 tested several hypotheses and acceptance or rejection are discussed with the main findings.

9.1.1 Chapter 4

i. There is an increased cardiovascular demand of DE fights compared to Poule fights as shown through significantly greater HR_{max}, RPE_{O}, RPE_{A}, RPE_{L} and tendency for a greater T_{gast}. Furthermore, ~80% of a Poule and DE fight are spent above 80% HR_{APM}. There was a similar HR_{av} and percentage of time spent in different heart rate zones between Poule and DE fights.

ii. Epée fencing is reliant on alactic and aerobic energy systems, with a heavier reliance on the aerobic system as a DE progress into later rounds, as shown by a decreasing blood lactate concentration from P1 to DE 7.

iii. Using average fight time and average energy expended epée fencers could expend ~1500kcal during a competition (not including rest periods between fights). Therefore, fencers should ensure they are adequately fuelled during competition to improve/maintain performance.

iv. This is the first research to assess fencing movement data using a tri-axial accelerometer-based athlete tracking system. Distance covered in epée can be varied and depend on the style of each fencer in both Poule (283 ± 93m) and DE (833 ± 261m) fights. Fencers can achieve average peak speed of 3.4 ± 0.7 $m.s^{-1}$ in Poule and 3.9 ± 0.8 $m.s^{-1}$ in DE fights. There is a greater mechanical load exhibited in DE than Poule fights with significant greater peak speeds achieved and accelerations in zone 2, with decreased accelerations in zone 1.

9.1.2 Chapter 5

i. There was a moderate increase in T_{gast}, T_{skin}, T_{mask} and thermal sensation in Poule fights. Gastrointestinal temperature was ~38°C post Poule fights. Mean skin temperature was ~34.5°C during Poule fights and rose in the recovery to ~34.8-35.0°C. Mask temperature rose during the Poule fights with P5-P7 greater than P1 and P2. Average change in T_{mask} in Poule fights was ~0.3-0.4°C. Average thermal sensation was rated as warm to hot in Poule fights.

ii. There was a greater increase in T_{gast}, T_{skin}, T_{mask} and thermal sensation in DE fights. Gastrointestinal temperature was consistently greater than 38°C pre-fight and 38.5°C post fight. Mean skin temperature was consistently greater than 34.5°C and was greater than 35°C in earlier DE rounds. There was also an increase in T_{skin} within the recovery period post fight, peaking at >36°C. Mask temperature consistently rose in the DE fights and was significantly greater in DE 7 than DE 1, DE 4 and DE 5 and could indicate the protective clothing creating a hot microclimate. Average change in T_{mask} during a DE fight was 1.10 ± 0.56°C. Thermal sensation was rated by fencers as very hot during DE fights.

iii. Core to skin temperature gradient ranged from 1.08°C to 4.84°C in the DE rounds.

iv. There was a significant difference for distance covered and distance covered per minute in the DE rounds. There was a tendency for decreased distance covered and distance covered per minute from DE 1 to DE 7.

v. There was a significant correlation between T_{skin} and thermal sensation suggesting perceptual ratings of thermal sensation could be associated with T_{skin}.

9.1.3 Chapter 6

i. There were similar movement data recorded for both Poule and DE fights during the epée simulated competition protocol used this thesis and the

National Championship as shown by fight duration, average speed, distance covered, and distance covered per minute.

ii. There was a significantly lower HR_{av} for Poule and DE fights during the epée competition protocol used this thesis and the National Championship. However, the majority of HR_{av} recorded were within 2 standard deviations of the National Championship mean data. There was a similar HR_{max} for Poule and DE fights during the simulated competition protocol used this thesis and the National Championship.

iii. The simulated competition protocol used in this thesis was a better representation of epée fencing performance than previous research by Bottoms et al. (2013).

9.1.4 Chapter 7

i. There was a significantly lower T_{skin} in the EXT and MIX cooling conditions compared to the CON condition in DE 2 and DE 3, however there were no differences between cooling interventions and CON for T_{core} or T_{mask}. *H1* partially accepted.

ii. There were no significant differences for HR_{av} and HR_{max} between EXT or MIX cooling compared to the CON condition. *H2* rejected.

iii. There were no significant differences for points scored, points conceded, points difference or movement data between EXT or MIX compared to the CON condition. *H3* rejected. When individual fencing styles are considered there potentially is a performance benefit of MIX compared to the EXT and CON conditions with greater numbers of participants have a positive points difference in the MIX in DE 2 (6 vs. 4 vs. 4) and DE 3 (7 vs. 4 vs. 4).

iv. There was a significantly lower thermal sensation pre-fight for EXT and MIX compared to the CON condition. There was a significantly lower thermal sensation post fight in MIX compared to the CON condition. There was a significantly greater rate of increase in thermal sensation in the EXT condition than the MIX and CON condition, however post fight thermal sensation was similar between the EXT and CON condition. There were no significant differences for RPE, thermal comfort or cognitive function measurements between cooling conditions. *H4* partially accepted

v. There were no significant differences for physiological, performance, perceptual or cognitive function variables between MIX and EXT interventions. *H5* rejected.

9.1.5 Chapter 8

i. Due to differences in function within wheelchair fencing maximal values recorded during VO_{2peak} testing should be reported as individual results and not group mean data.

ii. There is a need to meet the demands of wheelchair fencing competition in training fights, as there was a mismatch in work to rest ratios and fight durations when training was compared to a competition. Furthermore, low heart rate responses were recorded during wheelchair fencing. As wheelchair fencing training sessions will have category A and B fencers against each other, due to limited numbers of wheelchair fencers, coaches should ensure fights meet the demands for each fencer through timed intervals to match work to rest ratios and fight durations. Wearing heart rate monitors could be a simple method to ensure training intensity mirrors competition.

iii. There was an individual thermoregulatory response for the wheelchair fencers. Category A fencers tended to have a gradual increase in T_{gast} and T_{skin} from P1 to DE 4, with T_{skin} approaching hot >35°C. Category B fencers tended to have an initial rise then stable T_{gast} and T_{skin} throughout Poule and DE fights. There was also an increase in T_{skin} in the recovery between fights.

iv. There was an increase in T_{mask} for all wheelchair fencers, especially in the DE fights, with T_{mask} ~3-4°C greater than the ambient temperature. The protective clothing worn by wheelchair fencers could be producing a hot micro-climate.

v. Wheelchair fencers may be unable to perceive heat effectively. Category B fencers were rating thermal sensation as hot despite low T_{gast} (<38°C) and T_{skin}

(<33°C). Participant 1 also rated thermal sensation as comfortable/warm despite rising T_{gast}, T_{skin} and T_{mask}.

9.2 Contribution to Knowledge

9.2.1 Physiological Demands of Epée Fencing

This thesis aimed to add to the literature of the physiological demands of epée fencing and to assess the physiological responses across a whole competition for multiple participants. This allowed a deeper understanding of the demands of fencing by allowing participant numbers "reaching the final" to be 8 compared to a maximum of 2 in an actual competition. As discussed in chapter 2.1 fencing athletes are required to compete in fencing competitions that last 9-11 hours, the physiological demands of fencing across a full competition are not well understood. This thesis showed epée fencing produces a high cardiovascular strain. Chapter 4 and 5 showed during Poule and DE fights mean HR_{av} to be ~86% with mean HR_{max} to ~96%. Furthermore, time spent above 80% HR_{APM} was ~76% and ~82% for Poule and DE fights. Differentiated RPE showed greater RPE for DE fights compared to Poule fights, most likely due to greater work completed due to longer fight durations in DE fights. Energy expenditure was shown to be ~13 kcal.min^{-1} for both Poule and DE fights and over a long competition could produce a high energy expenditure. Epée fencing is reliant on PCr and aerobic energy systems as shown by relatively low blood lactate concentrations, with a heavier reliance on aerobic energy systems as the DE progresses with blood lactate concentration decreasing from DE 1-7 as shown in chapter 4. The physiological responses in this thesis were similar to those shown previously (Bottoms et al., 2011, 2013; Iglesias & Rodríguez, 1995, 1999), however there were greater HR and RPE recorded in this thesis than those by Bottoms et al. (2013) possibly due to the more competitive nature of the competition protocol in this thesis producing a greater catecholamine response (Hoch et al., 1988; Viru et al., 2010). Further, this thesis supports the importance of the PCr energy systems in fencing (Bottoms et al., 2011; Turner et al., 2014) and further supports the importance of the aerobic system within epée (Bottoms et al., 2011) which has been ignored or dismissed as unimportant previously (Turner et al., 2014, 2017).

This thesis was the first to use an accelerometer-based system to determine movement data of fencing performance. In chapter 4 there was a varied distance covered by fencers during Poule (120-670m) and DE (435-1652m) fights, however average distance covered was similar to those reported by Roi & Bianchedi (2008). There were differences in movement intensities between Poule and DE fights with a greater percentage of accelerations in zone 2 with corresponding lower percentage of accelerations in zone 1 in DE than Poule fights. This indicates DE fights could have a greater demand on the body through greater numbers of accelerations in higher acceleration zones than Poule fights. There was also a greater peak speed achieved in DE than Poule fights further highlighting the increased intensity of DE fights compared to Poule fights. The work to rest ratios calculated in chapter 5 for Poule (~1.7-2.9:1) and DE (~1.5-1.9:1) fights were greater than those previously reported in male epée of 1:1 (Aquili et al., 2013; Bottoms et al., 2013). Despite fencing being relatively short in duration there is a high mechanical load accumulated over a competition which could impact performance in later DE rounds where the medals are decided. It is also important for coaches to match the intensity of training sessions to competition to allow fencers to be prepared for the high intensity nature of competition.

9.2.2 Thermoregulatory Demands of Epée Fencing

There has been no previous research assessing the thermoregulatory demands of fencing. As discussed in chapter 2.4 and 2.5 fencing performance could be impacted by thermoregulatory challenges due to the thick whole-body protective clothing requirements. The whole-body protective clothing could cause an increase in body temperature due to creating a hot micro-climate and an inability to dissipate heat through evaporative and convection mechanisms. The aim of chapter 5 was to determine the thermoregulatory demands of epée fencing across a competition with Poule and DE fights analysed separately.

During Poule fights there was a moderate increase in T_{gast}, T_{skin}, T_{mask} and thermal sensation, whereas during DE fights there was a greater increase in T_{gast}, T_{skin}, T_{mask} and thermal sensation. Gastrointestinal temperature tended to increase and stay at a similar level. During Poule fights T_{gast} post fight was consistently >38°C with prefight T_{gast} slowly rising throughout the Poule and staying above >38°C from P6 onwards.

During DE fights T_{gast} post fight was consistently greater than 38.5°C with some participants above 39°C, with pre fight T_{gast} remaining consistently above 38°C. Mean skin temperature during both Poule and DE fights was consistently above >34.5°C, further during the early DE rounds T_{skin} was >35°C. An unexpected finding was that T_{skin} continued to rise into the recovery between fights with T_{skin} ~34.8-35.0°C in Poule fights and ~35.5°C in DE fights with peak values >36°C. The hot T_{skin} in DE rounds also caused a narrow core to skin temperature gradient which could have caused high cardiovascular strain through increased blood flow to the skin to dissipate heat (Sawka et al., 2012). The protective clothing may have caused a hot micro-climate as shown through increasing T_{mask} through the Poule and DE rounds which was hotter than the ambient conditions, even with participants removing the mask between fights. Mask temperature also increased from the first to last minute of each fight which could have impeded heat loss from the head (Rasch et al., 1991). Perceptually, fencers were also feeling hot with average thermal sensation in Poule fights rated as warm to hot and in DE fights as very hot. There was a significant correlation between T_{skin} and thermal sensation suggesting perceptual ratings of thermal sensation could be associated with T_{skin}. Due to the high core and skin temperatures particularly in earlier DE rounds there could have been a performance decrement with less distance covered and distance covered per minute despite similar work to rest ratios. Distance covered was positively correlated with change in T_{gast}, T_{skin}, and thermal sensation and negative correlation to core to skin temperature gradient. This indicates there could have been a tactical shift in later DE rounds to a more static fencing style to produce less body heat through lower muscle activity.

The high thermoregulatory demands of epée fencing, as shown in chapter 5, fencers indicate fencers may benefit from cooling interventions. Cooling interventions could lower the cardiovascular strain of fencing, perceptual responses and body heat produced (particularly T_{skin} and thermal sensation). These findings along with similar T_{gast} recorded in chapter 4 guided the thesis towards a cooling intervention to lower the thermoregulatory demands of epée and to determine if there were any performance benefits (chapter 7). Cooling interventions should aim to be practical for the fencers and could be implemented multiple times over a long competition day.

9.2.3 Effectiveness of External and Mixed-Method Cooling for Epée Fencing

Based upon the results of chapter 4 and 5 a cooling intervention study was designed for chapter 7. The aims of chapter 7 were to assess the effects of EXT (using an ECV), and MIX (ECV and cold-water ingestion) cooling during the recovery period between DE fights on the physiological responses, cognitive function, and performance variables during epée fencing. A secondary aim was to determine if MIX cooling would provide greater physiological and performance benefits than EXT. Due to the length of a fencing competition practical cooling methods that could be employed by fencers were used. As previously discussed in chapter 2.7 there are various cooling methods athletes can use, this thesis chose the use of evaporative cooling vests that can be submerged in water and cold-water ingestion as these can be easily and repeatedly used by fencers at a competition.

There were some effects of the cooling interventions on the thermoregulatory responses of epée fencing. There was a significantly lower T_{skin} in both the EXT and MIX conditions compared to the CON condition in DE 2 and DE 3. The EXT and MIX interventions could lower the rise in T_{skin} between fights as seen in chapter 5, due to lower T_{skin} in the first minute of the intervention period. Furthermore, there was a lower thermal sensation pre-fight in both the EXT and MIX conditions and post-fight in the MIX condition compared to the CON condition. There were no significant differences for T_{core} or T_{mask}, however due to issues with the core temperature pills and the cold water influencing the readings it is unclear whether there was an effect of cooling on T_{core}. There were no significant differences between cooling interventions for any other physiological, perceptual, cognitive function or performance measurements. The cooling interventions may not have provided a strong enough cooling power to have any further significant effects. Furthermore, the T_{core} and T_{skin} did not reach the same levels as those in chapter 5, therefore the thermoregulatory demand may have been slightly lower in the intervention chapter. The cooling intervention was only applied between the fights of two DE fights, therefore there may be more beneficial effects of cooling in later DE rounds as fencers' fatigue. There were no significant differences for any variable measured between the EXT and MIX indicating there was not a greater physiological or performance benefit of the MIX intervention.

Despite no significant differences for points difference, when accounting for individual fencing style there could have been an individual response. In the MIX intervention there were 6/10 and 7/10 participants that had a positive points difference in DE 2 and DE 3, respectively, compared to 4/10 and 4/10 in both the EXT and CON interventions for DE 2 and DE 3. Within DE fights having a positive points difference is important to ensure a fencer is in a winning position and does not get knocked out of the competition. Therefore, there could potentially be a preference as to which cooling intervention is beneficial for a fencer's performance. Fencers should determine which is the best cooling intervention in training before use at a competition.

9.2.4 Wheelchair Fencing

As previously discussed in chapter 8 there is limited research in the physiological demands of wheelchair fencing (Bernardi et al., 2010; Iglesias et al., 2019), with no previous research discussing the thermoregulatory demands. Participants with SCI could be at greater risk of complications due to increased body temperature (Griggs, Havenith, Price, et al., 2017; Price, 2006; Price & Campbell, 1997). The addition of thick protective clothing within wheelchair fencing could further raise body temperature due to an inability to dissipate heat effectively and create a hot micro-climate. The aims of chapter 8 were to profile the physiological and thermoregulatory responses of wheelchair epée fencing during Poule and DE fights in a training session, and to determine physiological characteristics of wheelchair fencing athletes during incremental maximal oxygen uptake testing. Finally, as this study recruited the world ranked #1 in wheelchair epée for both category A and B, this enabled elite wheelchair fencing athlete profiling as would occur in typical elite athlete support scenarios.

Maximal oxygen consumption and heart rate values recorded during $\dot{V}O_{2peak}$ testing were similar to those reported by Bernardi et al. (2010). It was highlighted that within wheelchair fencing due to low participant numbers and differences in disabilities individual results should be reported instead of mean data, as in Bernardi et al. (2010). This was shown by the two participants with SCI (T4 and T5/6) having a difference of 23 beats.min^{-1} for HR$_{max}$ and differences in $\dot{V}O_{2peak}$ values recorded.

Physiologically there was a mismatch in the intensity of the fights in the training session compared to fights at competition for work to rest ratio and fight duration. Furthermore, low heart rate responses were recorded in this chapter and were lower than those reported by Bernardi et al. (2010). Future research should determine the heart rate response to wheelchair fencing during competition. This could be due to wheelchair fencing training mixing category A and B fencers together due to low athlete numbers. Coaches could use duration or timed intervals instead of traditional fights to a set number of points with a focus on each category fencer during the fights to ensure the demands match competition. Further, category A fencers could require different fight durations to match longer fights seen in competition. Additionally, wearing heart rate monitors is a simple method athletes can use during training to monitor training intensity and attempt to mirror competition fight intensity.

There were individual differences in the thermoregulatory responses during the fights in the training session. Category A fencers tended to have a gradual increase in T_{gast} and T_{skin} from P1 to DE 4. However, the category B fencer had an initial increase in T_{gast} and T_{skin} which remained stable throughout the remainder of the training session. Similar to able-bodied fencers in chapter 5 there was an increase in T_{skin} in the recovery between fights. There was also an increase in T_{mask}, especially within DE fights, that was 3-4°C greater than the ambient temperature indicating the protective clothing creating a hot micro-climate. There seemed to be an inability of participants to perceive (as shown by thermal sensation) the rising thermal load of wheelchair epée fencing, potentially due to increases in T_{mask} and SCI lesion level for the category B fencers. The two number 1 ranked fencers also reported low RPE during the fights which at competition could be higher due to more challenging opponents and pressure of later DE rounds.

Further research is required within wheelchair fencing to gain a deeper understanding of the physiological and thermoregulatory demands of the sport. Competition data is required to ensure training can meet the demands of competition. Due to differences in skill level between wheelchair fencers it is important to ensure each fencer is training at an intensity to prepare them for competition. Further, research should also attempt to determine effective cooling strategies within wheelchair fencing to lower the increasing thermoregulatory responses as a competition progresses.

9.3 Limitations

There were limitations within each of the research studies within this thesis, as previously discussed in each chapter. The following section addresses the main limitations impacting the findings of this thesis.

Chapter 4 and 5 used high level fencers ranked within the top 35 and top 65 within the UK that represented a cohort similar to the national championships. However, for chapter 7 participants recruited were required to have a minimum of 2 years training experience within fencing so some of the participants were not as well trained as chapter 4 and 5, and there could have been differences in skill level between participants. To control for skill level between participants they were matched up based upon ability for each testing session as determined by the coach. Furthermore, testing took place at 2 fencing clubs (n = 7 and n = 3) therefore it can be assumed they all had a similar training volume and background which controls for different training programmes if fencers from different clubs were recruited. Due to participant availability some participants competed against a different fencer during the different intervention conditions, however they did fight the same fencer for all 3 DE fights in each session to control for different fencing styles. Due to the varying nature of tactics during fencing fights it may not be important to fight the same fencer for all conditions. Where two fencers did compete against each other during all 3 conditions during DE 1 (whereby there was no cooling applied) one participant scored 21, 19 and 11 points and the other participant score 11, 9 and 7 points, showing the variation in points scored despite fighting the same fencer.

Due to the round robin competition protocol used in chapters 4 and 5 participants could only be recruited in multiples of 8, and with fencing participation numbers being low recruiting more than 8 participants was not possible. Multiples of 8 were required to ensure fencers had the same amount of rest between fights (particularly in the DE rounds) to not disadvantage any participants by having less rest than others. Furthermore, multiples of 8 was the correct number for the round robin DE fights to simulate a true number of DE fights experienced in a competition.

For the cooling intervention study in chapter 7 the testing was carried out at 2 fencing clubs, which may have confounded some of the results due to the inability to control the environmental conditions in the sports halls. Due to the time available during the training sessions it was not possible to run a full set of DE fights which may have shown benefits of cooling on physiological, thermoregulatory, perceptual and performance responses when participants are more fatigued. The researcher did attempt to run the research study in a controlled laboratory environment, however due to a lack of willingness for fencers to come to the laboratory the research design was altered to take place in an applied setting. Ideally, to control for the environmental conditions the laboratory setting would have been preferential. Using an applied setting does have ecological validity as fencers train and compete in sports halls which will have varying environmental conditions.

There were some equipment issues that may have impacted upon the results within this thesis. Firstly, arbitrary heart rate, speed and acceleration zones were collected using the accelerometer-based athlete tracking system. Due to being the first study to use this system within fencing there are no fencing specific zones in the literature, this is an area future research should target. Furthermore, developers of athlete tracking systems could develop algorithms from the acceleration trace to determine fencing specific movements, such as lunges and fleches, to give a greater understanding of the movement demands of fencing. During chapter 4 there was a malfunction with the gas analysis system due to being struck during a fight therefore only 13/16 fights where gas analysis was to be collected were analysed in the DE rounds. Due to only having access to 2 gas analysis systems there was a limited number of fights that could have had expired gas collected. To ensure fencers were not disadvantaged whilst wearing the gas analysis system their opponent also had expired gas collected. The use of CorTemp pills limited the number of data points (pre and post fight) that could be collected when measuring T_{gast} as there were only 2 units available to read gastrointestinal temperature. Ideally, the researcher would have collected gastrointestinal temperature throughout the whole day (using the BodyCap system which the researcher did not have access to) to see how core temperature changed during the fights and into recovery. Furthermore, in chapter 7 there were issues with the CorTemp pills turning on so the researcher had to give them the pill at the start of testing so the pill was ingested ~1 hour before DE 1, which has been shown to not effect core temperature measurements (Notley et al., 2021). However, when participants ingested water this influenced the readings of core temperature (Roxane et al., 2018). When the researcher had determined the issue with the CorTemp pill it was decided to measure T_{au} alongside T_{gast} however as some participants had already been tested there were not full data sets for all participants for analysis of T_{gast} and T_{au}.

Finally, the results of this thesis are only applicable to epée fencing and may not transfer to foil and sabre due to the different work to rest ratios, protective clothing set ups, and fight durations of the different weapons (Aquili et al., 2013).

9.4 Practical Applications

The research carried out in this thesis has highlighted the following practical applications:

- This thesis developed a greater understanding of the physiological demands of epée fencing through using a round robin style competition to allow n = 8 reaching the final round. This protocol should be adopted within fencing research where feasible.
- This thesis has highlighted the importance of both the PCr and aerobic energy systems for epée fencing. These two energy systems should be targeted by coaches and sport science practitioners in training. There was a heavier reliance on the aerobic energy system as a competition progressed as shown by decreasing blood lactate concentration from P1 to DE 7.
- This thesis was the first research to quantify movement data of epée fencing performance using an accelerometer-based system, highlighting a high load across a full competition day.
- Coaches and sport science practitioners should be aware HR_{av} is >85% HR_{APM} for both Poule and DE fights and HR_{max} is >90% HR_{APM} and >95% HR_{APM} for Poule and DE fights, respectively, therefore training sessions should target these intensities to ensure fencers are prepared for competition.

- This thesis was the first to research the thermoregulatory demands of epée fencing. Coaches and sport science practitioners should be aware that T_{core} can consistently reach 38.5-39.0°C and T_{skin} can reach hot skin temperatures >35°C, which creates a narrow core to skin temperature. This increases cardiovascular strain through increased blood flow to the skin and high heart rates to dissipate heat. Furthermore, fencers perceptually rated DE fights as very hot. Therefore, appropriate cooling methods should be employed during a competition.
- Mean skin temperature was also shown to rise in the recovery between fights, so appropriate cooling strategies should be applied to lower T_{skin}, dissipate heat and cool fencers down.
- Coaches and sport science practitioners should be aware of potential tactical shifts to a more static style when fencers get hot as shown through decreasing distance covered, and distance covered per minute from DE 1 to DE 7. Therefore, fencers should ensure their performance levels are consistent across a competition and focus on recovery strategies between fights.
- Both the EXT and MIX cooling interventions lowered the thermoregulatory responses of epée through lower T_{skin}, lower pre fight thermal sensation and post fight thermal sensation (MIX condition only). However, there were no statistically significant performance benefits of either cooling intervention.
- Coaches and sport science practitioners should consider individual preferences for cooling as despite no significant group differences there potentially was an individual response to cooling. In the MIX intervention 6/10 in DE 2 and 7/10 in DE 3 participants had a positive points difference compared to 4/10 in DE 2 and 4/10 in DE 3 for both the EXT and CON interventions.
- Coaches and practitioners working with wheelchair fencers should aim to match the intensity of training fights to competition data. There was a mis-match in work to rest ratio and fight durations in this thesis, therefore, a duration or time interval approach may be better than a traditional number of points fight to ensure both category A and B fencers are prepared for competition.
- Wearing of heart rate monitors during training for wheelchair fencers could be a simple method to monitor training intensity.

- There was an individual physiological and thermoregulatory response during wheelchair fencing. Wheelchair fencers may be unable to perceive the heat load of wheelchair fencing. Coaches and sport science practitioners should monitor how each fencer responds during a fight to allow appropriate interventions to be applied.
- Fencing clothing manufacturers should consider how to design the thick protective clothing to facilitate heat loss, as the protective clothing could be creating a hot micro-climate as shown by hot T_{skin}, and T_{mask} being greater than the environment conditions and consistently rising throughout the fights in this thesis.
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9.5 Future Directions

The main findings from the research in this thesis has created a number of future research questions as discussed in the following section:

- Future research should determine if accelerometer-based systems can calculate different fencing movements e.g., lunges, fleche etc. using the accelerometer data to give more detail about the movement profile of fencing performance.
- Assessment of cognitive function tests should be undertaken in later DE rounds to see if fatigue is affecting fencing performance. Fencing specific tests could be developed to provide ecological validity.
- This thesis showed the benefits of cooling on T_{skin} during DE 2 and DE 3 with no performance effects. Cooling studies could be carried out over a full set of DE fights to determine if cooling in later DE rounds has any physiological or performance benefits.
- This thesis used EXT cooling using an evaporative cooling vest and MIX using an evaporative cooling vest and cold water. Future research could assess different cooling methods to see how this influence the physiological and thermoregulatory responses and performance variables in fencing. It should be noted cooling interventions should be practical and easy to employ at competition. Other practical interventions that could be utilised include: cold-water ingestion only, face cooling using water spray or fans, neck cooling using water spray or ice collars/wet towels, or other mixed-method approaches. Furthermore, the cooling intervention was only applied for 10 minutes between fights (which is the minimum time between fights

in fencing), therefore longer cooling interventions could be tested during long recovery periods between fights.

- Continually training and competing in thick protective clothing could provide fencing athletes with heat acclimatisation, therefore research should assess if fencing athletes are fully heat acclimatised, if there is a ceiling effect of heat acclimatisation, and whether they might benefit from heat acclimation protocols prior to competition.
- The cooling intervention in this thesis took place in an applied field-based setting, however laboratory-based testing could be undertaken to control the environmental conditions and to control the testing protocol to assess the effects of cooling on fencing performance.
- Competition research should be undertaken within wheelchair fencing to ascertain the true physiological, thermoregulatory, and perceptual responses of wheelchair fencing. This could then be used by coaches and sport science practitioners to develop training programmes to ensure athletes are prepared for competition.
- Due to the constant increasing body temperature and T_{mask} (particularly during DE fights) practical cooling interventions should be tested in wheelchair fencing.
- Finally, there is limited research in foil and sabre and future research could use similar protocols to assess the physiological, and thermoregulatory demands of these weapons. This could aid coaches and sport science practitioners with training programme design to prepare their athletes for competition and allow appropriate interventions to be applied to improve performance.
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9.6 Closing Statement

This thesis quantified the physiological and thermoregulatory demands of epée during simulated fencing competition, that produced similar responses actual competition. The use of the cooling interventions applied in this thesis were effective at lowering thermoregulatory responses of epée (T_{skin} and thermal sensation), although they had no performance benefits. However, potential ideas for future cooling strategies have been presented. Finally, this thesis highlighted that wheelchair fencing fights in training may not match the demands of competition and avenues for future research in wheelchair fencing have been discussed.

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Appendices

Appendix A

A Comparison of Lactate Pro 2 to Biosen C-Line

A.1 Methods

A.1.1 Procedures

One male participant completed an incremental exercise test on a motorised treadmill (Quasar 5.0, H/P/COSMOS Sports & Medical, Nussendorf-Traunstein, Germany). The treadmill was set at 1% gradient and each exercise stage was 3:30 minutes. The incremental exercise test commenced at 9 km.h^{-1} and increased by 1 km.h^{-1} at the end of each stage until 18 km.h^{-1}. Each stage consisted of 3 minutes running at a set speed and 30 seconds for capillary blood samples to be collected. Capillary blood samples were collected for Biosen C-line analysis as described in chapter 3.6.1 and for Lactate Pro 2 as described in chapter 3.6.2. Capillary blood samples were collected at rest (two samples) and each exercise stage from the same fingertip.

A.1.2 Statistical Analysis

Pearson's correlation coefficients were determined to examine relationships for blood lactate concentration between Lactate Pro 2 and Biosen C-Line. Significant ($p < 0.05$) correlation coefficients were determined to be small (r = 0.10-0.29), moderate (r = 0.30-0.49) or large (r > 0.50) (Cohen, 1988).

Absolute agreement intraclass correlation (ICC) analysis (Cicchetti, 1994; Shrout & Fleiss, 1979) was conducted to compare the reliability of blood lactate concentration between Lactate Pro 2 and Biosen C-Line. Interpretation of the ICC was as follows <0.40 poor, 0.40-0.59 fair, 0.60-0.74 good and 0.75-1.00 excellent (Cicchetti, 1994). Standard error of measurement (SEM) was also calculated as follows:

$$SEM = SD*\sqrt{(1-ICC)}$$

Data is presented as ICC (SEM).

A.2 Results

There was a significant Pearson correlation coefficient (r = 0.980, *p* < 0.05) determined for blood lactate concentration between Lactate Pro 2 and Biosen C-Line, as shown in Figure A.1. Excellent ICC was reported between Lactate Pro 2 and Biosen C-Line (0.988 (0.330)).

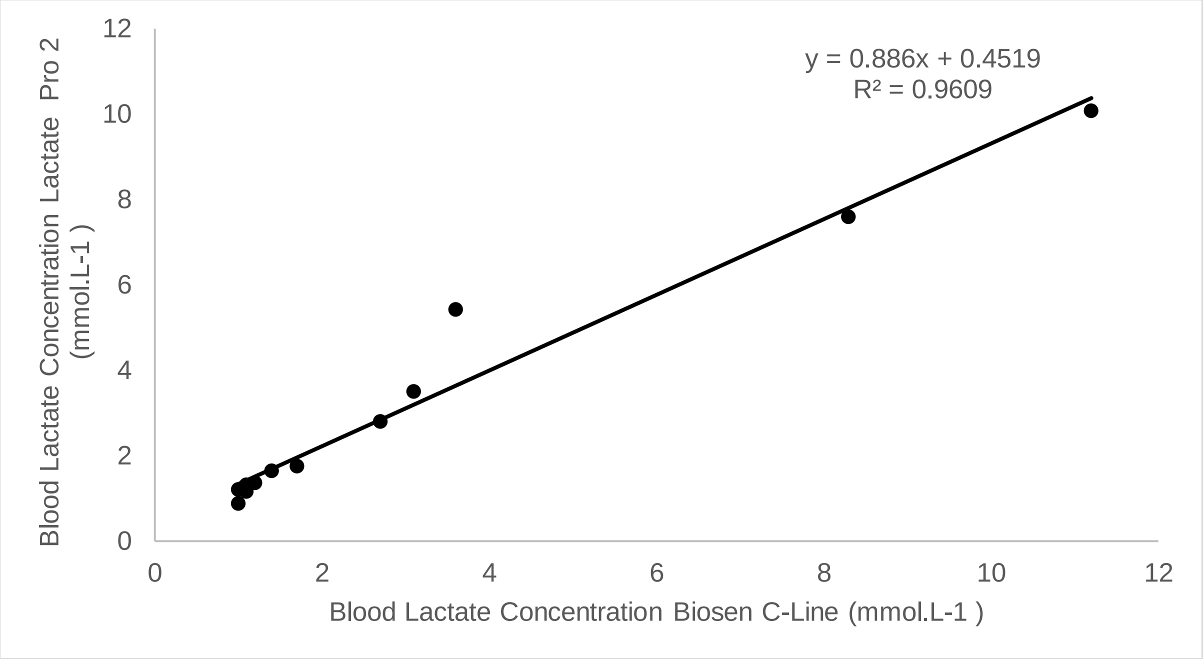

Figure A.1. Correlation for blood lactate concentration (mmol.L-1) between Lactate Pro 2 and Biosen C-Line.

Appendix B

B Validity and Reliability of Polar Team Pro Distance

B.1 Methods

B.1.1 Procedures

Two Polar Team Pro units (Polar Team Pro 2, Polar Electro, Kempele, Finland) were fitted at chest level to a male participant, using the recommended strap by the manufacturer. This was the placement of the device for all experimental studies and as recommended by the manufacturer. A 10m straight line was measured using a tape measure in the laboratory with cones set out at the start and end of the line. The participant completed 30 forwards and 30 backwards straight-line walking movements over the 10m line. The participant walked at ~1.1-1.4m.s^{-1} which is similar to the average speed of during a fencing fight as determined in chapter 4. Data was recorded as described in chapter 3.8 and analysed in the Polar online platform (teampro.polar.com, Polar Electro, Kempele, Finland).

B.1.2 Statistical Analysis

Data are presented as mean ± standard deviation. Data was exported from the Polar online platform and transferred into an Excel spreadsheet. Coefficient of variation (CV) was calculated for forwards and backwards movements for both Polar Team Pro units and calculated as follows:

$$CV = \frac{SD}{Mean} \times 100$$

B.2 Results

There was a lower CV for forwards movements (~5-6%) than backward movements (~10-12%) distance for the two Polar Team Pro devices as shown in Table B.1. There was consistency in both units for forwards and backwards movements in terms of CV. There was a slight overestimation of distance covered for backwards movements and slight underestimation of forwards movements. This could have been due to the Polar software rounding distance to the nearest meter.

Table B.1. Mean forward and backward distance (m) and CV for two Polar Team Pro Units

Unit	Mean Forward Distance (m)	CV Forward Distance (%)	Mean Backward Distance (m)	CV Backward Distance (%)
1	9.7 ± 0.6	6.0	10.8 ± 1.2	10.8
2	9.5 ± 0.5	5.2	10.6 ± 1.3	12.3

Appendix C

C Reliability of Evaporative Cooling Vest

C.1 Methods

C.1.1 Procedures

Six iButton thermochrons were programmed as described in chapter 3.8 and were programmed to record every 30 seconds. The iButtons were attached to the cooling panels on the ECV as used in chapter 7 (BodyCool Xtreme Evaporative PVA Cooling Vest, Inuteq, Deventer, The Netherlands). Figure C.1 shows the iButton location with one iButton attached on the inside panel of the vest, one on the back panel of the vest, and three on the front of the vest (upper right panel, lower right panel, upper left panel). The sixth iButton was used to measure ambient temperature. Different locations on the ECV were used to determine if the cooling was uniform across the vest. Vest temperature was measured on two separate occasions under similar ambient temperatures (Day 1: 20.37 ± 0.15°C Day 2: 20.25 ± 0.04°C) for 35 minutes. The ECV was hung on a hanger and was not touching any surfaces that could have influenced iButton temperature recordings.

Figure C.1. Location of iButton thermochrons during reliability testing of ECV. Black dot indicates iButton location. 1 = inside panel, 2 = upper right panel, 3 = lower right panel, 4 = upper left panel, and 5 = back panel.

C.1.2 Statistical Analysis

Mean ± SD vest temperature data for the 5 sites and ambient temperature were calculated. Average measures intraclass correlation (ICC) analysis (Cicchetti, 1994; Shrout & Fleiss, 1979) was conducted to compare the temperature on different areas on the cooling panels of the ECV and also to compare the reliability between measurement sites on different days in the same ambient temperature. Interpretation of the ICC was as follows <0.40 poor, 0.40-0.59 fair, 0.60-0.74 good and 0.75-1.00 excellent (Cicchetti, 1994). Standard error of measurement (SEM) was also calculated as follows:

$$SEM = SD*\sqrt{(1-ICC)}$$

Data is presented as ICC (SEM).

C.2 Results

Mean ECV temperature across all sites measured on day 1 was 18.34 ± 0.23°C and for day 2 was 18.44 ± 0.23°C. Excellent ICC were reported for the back panel, upper right panel, lower right panel, upper left panel and inside panel (Table C.1) showing excellent reliability across different days of each individual measurement site. Excellent ICC was also reported for all measurement sites on both day 1 and day 2 (Table C.1) showing excellent reliability of the different areas of the ECV and indicating similar cooling temperatures for all parts of the ECV.

Table C.1. Mean ± SD and reliability (ICC (SEM)) of the ECV temperature across all measurement sites and individual measurement sites.

Measurement Site	Back Panel Temperature (°C)	Upper Right Panel Temperature (°C)	Lower Right Panel Temperature(°C)	Upper Left Panel Temperature (°C)	Inside Panel Temperature(°C)	ICC (SEM)	Ambient Temperature (°C)
Day 1	18.25 ± 0.16	18.46 ± 0.19	18.44 ± 0.19	18.25 ± 0.19	18.34 ± 0.32	0.978 (0.154)	20.38 ± 0.15
Day 2	18.25 ± 0.15	18.50 ± 0.17	18.66 ± 0.20	18.46 ± 0.14	18.32 ± 0.20	0.993 (0.072)	20.26 ± 0.04
ICC (SEM)	0.976 (0.047)	0.980 (0.051)	0.991 (0.037)	0.956 (0.068)	0.940 (0.126)	[redacted]	[redacted]

ICC = Intraclass Correlation Coefficient, SEM = Standard Error of Measurement

Appendix D

D Gastrointestinal Temperature Using Core Temperature Pill during Chapter 7.

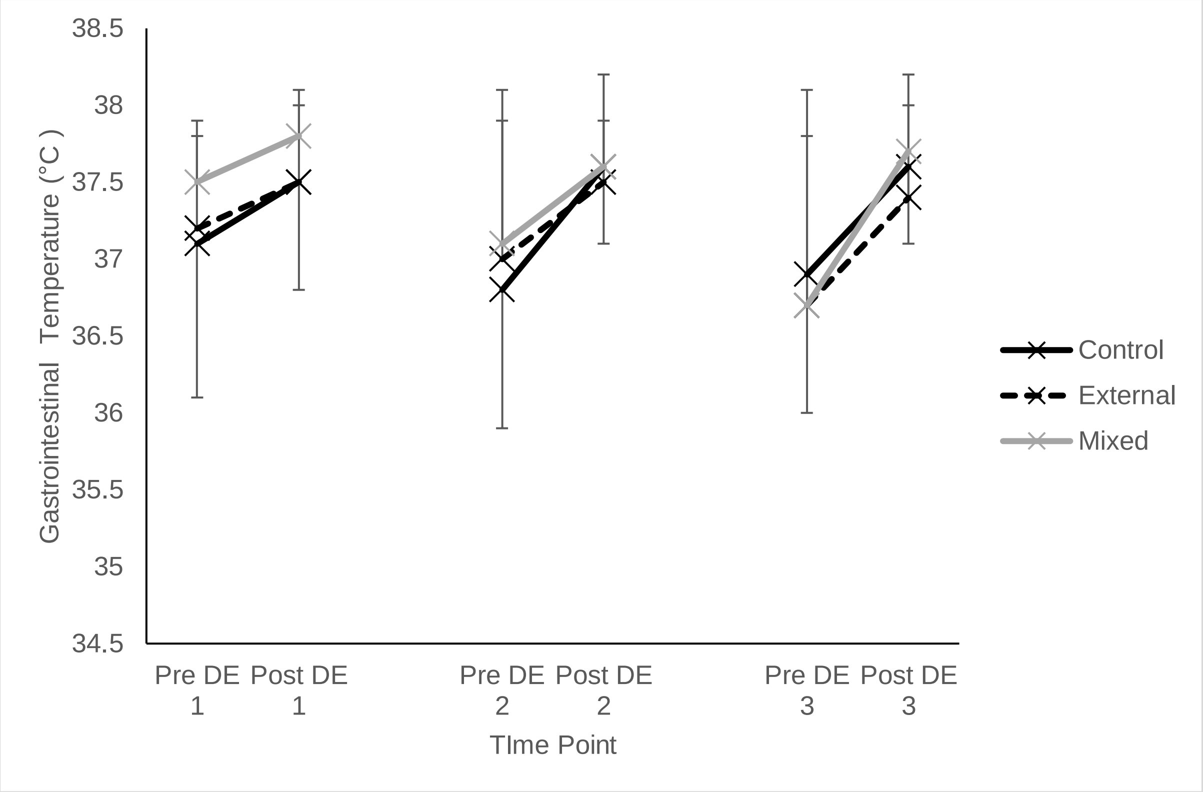

Figure D.1. Gastrointestinal temperature (°C) using core temperature pill during CON, EXT, and mixed cooling conditions (mean ± SD).

DE = Direct Elimination. N = 6 complete data set

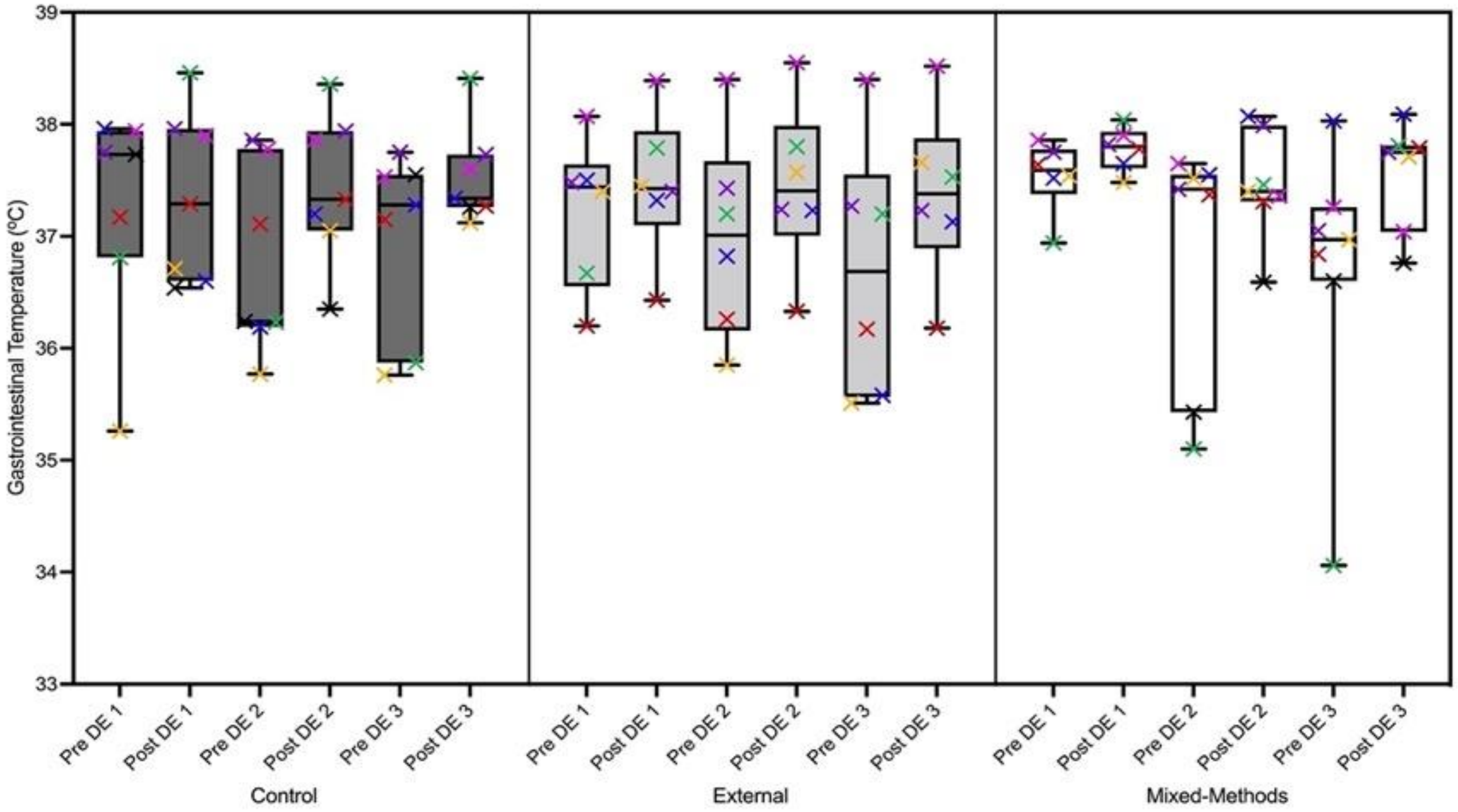

Figure D.2. Box plot and individual T_{gast} (°C) recordings for CON, EXT, and MIX interventions. (median ± range).

Individual participants represented by a different colour. DE = Direct Elimination

Appendix E

E Thermal Sensation between CON, EXT, and MIX Interventions

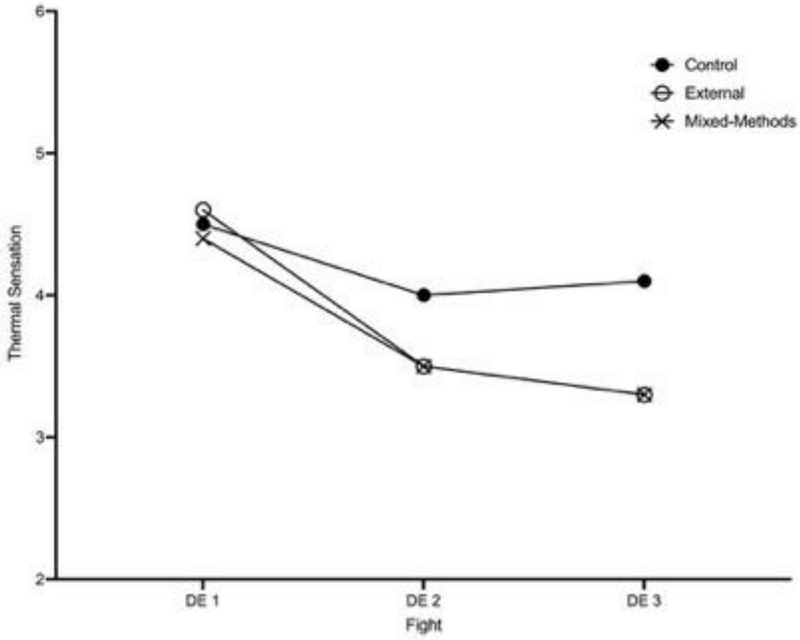

Figure E.1. Pre-fight thermal sensation ratings between CON, EXT, and MIX interventions (mean). DE = Direct Elimination

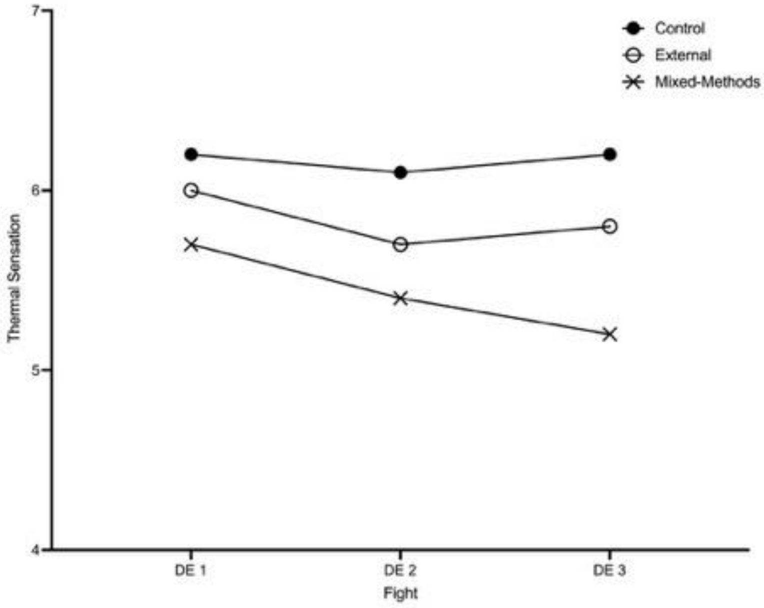

Figure E.2. Post-fight thermal sensation ratings between CON, EXT, and MIX interventions (mean). DE = Direct Elimination

Appendix F

F Individual Points Difference between CON, EXT, and MIX Interventions

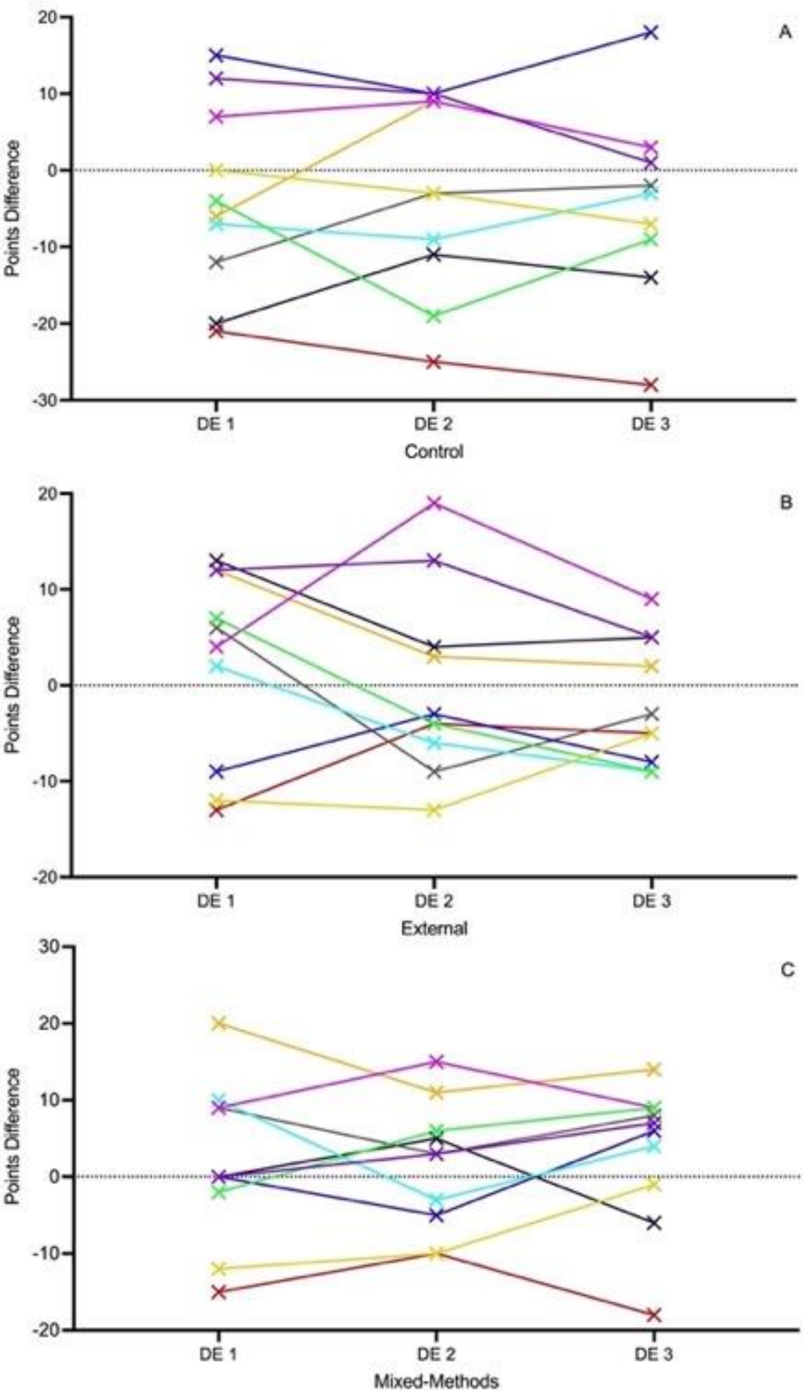

Figure F.1. Points difference for each individual participant during CON (A), EXT (B), and MIX (C) interventions. Each participant is shown by a different line colour.

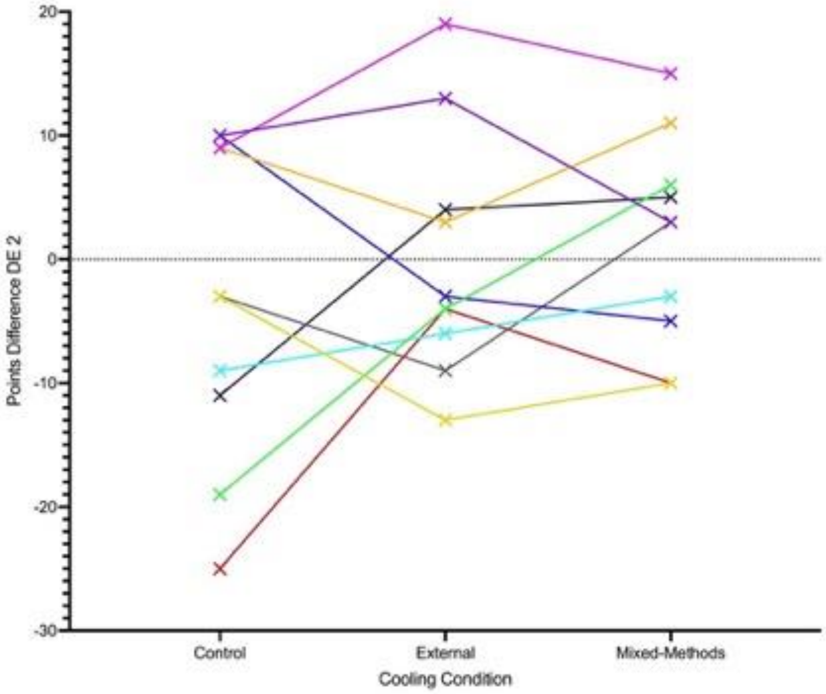

Figure F.2. Points difference for DE 2 between CON, EXT, and MIX interventions. Each participant is shown by a different line colour.

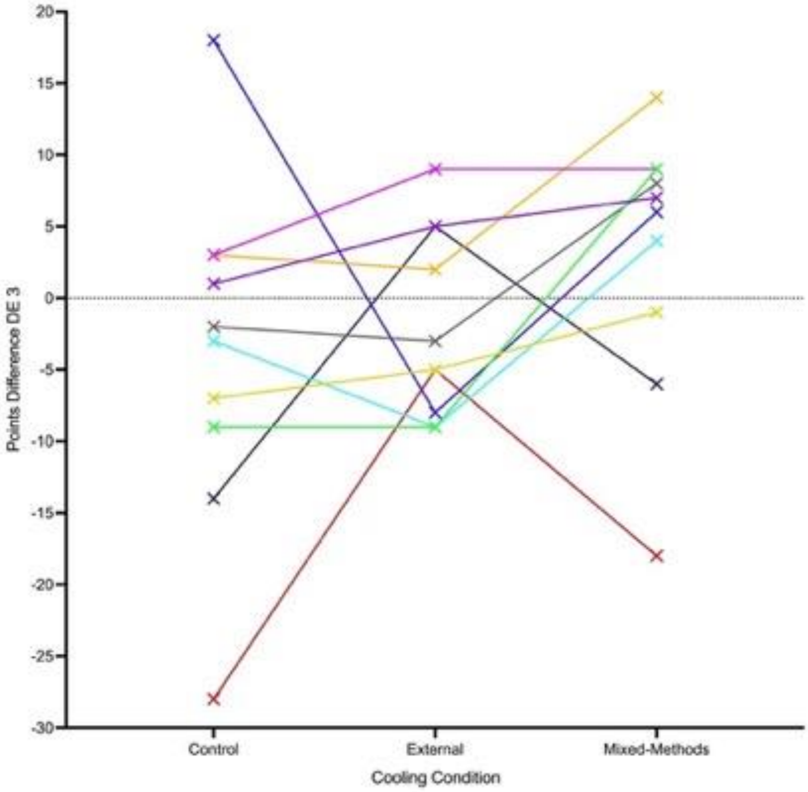

Figure F.3. Points difference in DE 3 between CON, EXT, and MIX interventions. Each participant is shown by a different line colour.

Appendix G

G Individual Responses for Average Heart Rate between Cooling Interventions

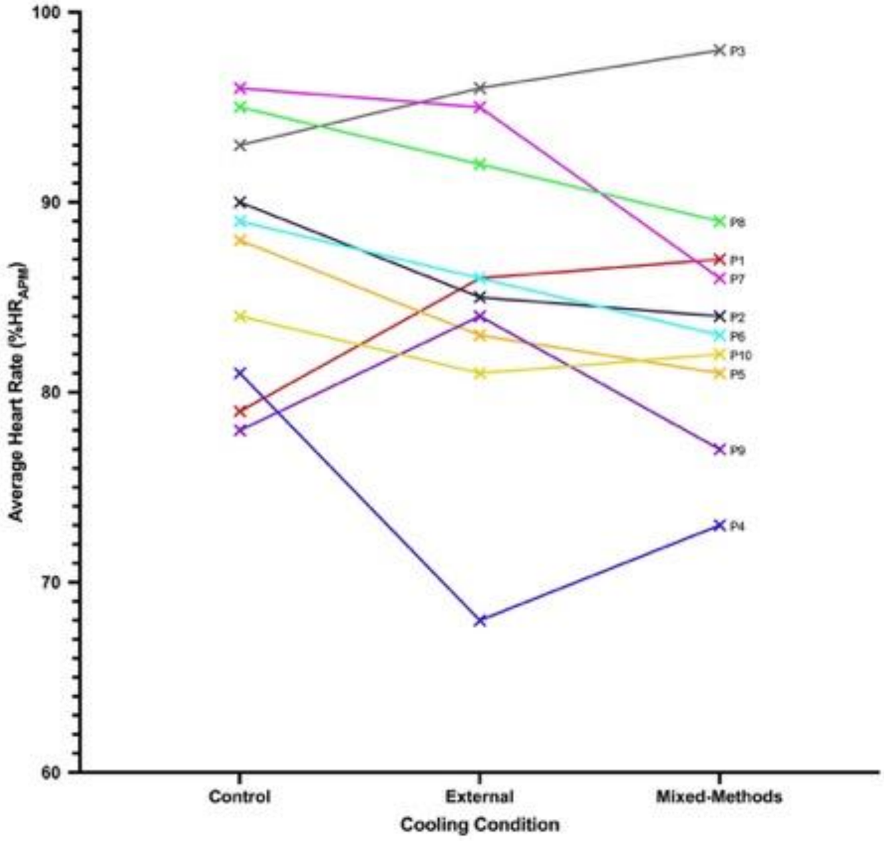

Figure G.1. Individual average heart rate (% HR$_{APM}$) during DE 1 between the CON, EXT, and MIX interventions. Each participant is shown by a different colour.

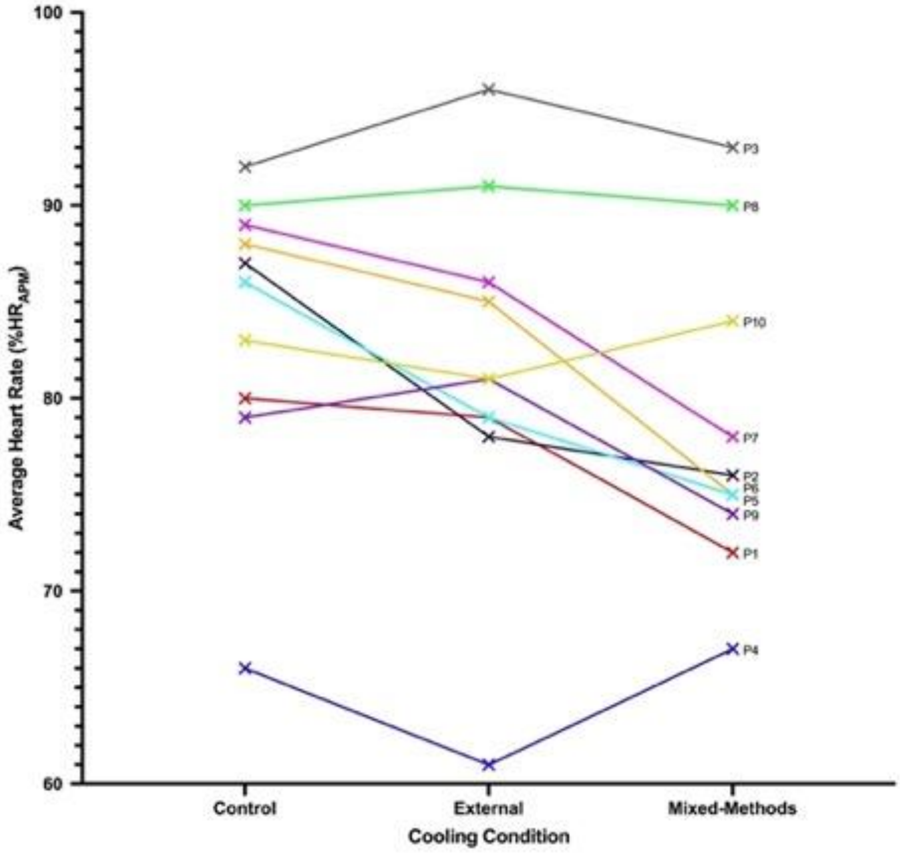

Figure G.2. Individual average heart rate (% HR$_{APM}$) during DE 3 between the CON, EXT, and MIX interventions. Each participant is shown by a different colour.