Short-term heat training: Practically relevant strategies for enhancing team sports performance

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Abstract

Repeated exposure to hot and humid conditions is traditionally employed for facilitating physiological and thermoregulatory adaptations that can negate impaired exercise performance in hot conditions. Despite the popularity and interest surrounding heat training, there is currently little practical information for coaches and support staff on how to best implement heat training in a team sport environment. Heat training has the potential to offer accelerated conditioning, rapid physiological and thermal adaptations and the potential to offer performance benefits in temperate environmental conditions. However, the logistical challenges associated with team sports often make implementation of such interventions challenging. The aims of the first experimental study were to enhance endurance running and thermal tolerance using short-term heat training during the pre-season and to evaluate the utility of a novel mixed-mode heat raining intervention in state-level Australian football players. Subsequently, the second study assessed the impact of repeated sprint interval training, with and without brief passive heat exposure on player conditioning and running capacity and its suitability to be integrated with sports-specific training during the competitive season. Therefore, the purpose of this research is to provide coaches and performance staff with pragmatic heat training programs that can be easily applied in the daily training environment without compromising sport-specific objectives.

A short-term, intermittent day laboratory-based heat training program was implemented during the pre-season in state-level Australian football players to quantify the degree of fitness benefits and thermal tolerance. Eleven state-level male Australian football players from the same team completed 6 x 60 min sessions (5 min warm up; 5 x 8 min efforts alternating running and cycling; 3 min passive recovery between sets) in HEAT (35°C, 50% RH) and TEMP (temperate; 18°C, 50% Relative Humidity; RH) conditions over 12 days in a counterbalanced crossover design. The crossover design involved two x 12-day training blocks either side of a 4-week washout period ensuring all players completed both HEAT and TEMP training interventions. Running performance pre and post HEAT and TEMP interventions were assessed via the Yo-Yo Intermittent Recovery Test (Level 1), and thermal adaptation using a submaximal (4 x 4 min) treadmill heat stress test (HST) in 35°C, 50% RH. Yo-Yo running distance improved by 9, ±9% in HEAT (standardised mean, ±90% confidence limits) and 13, ±6% in TEMP, however the difference in the mean change between conditions was unclear (0.24, ±0.64 standardised mean, ±90% confidence limits). Regardless of the intervention

conditions, there was an order and subsequent training effect indicated by a large 476 ± 168 m increase in running distance between the first and final of the four Yo-Yo tests performed across the study. There was little evidence of thermal adaptation indicated by trivial to small reductions in heart rate, blood lactate, RPE and thermal sensation after both interventions. Differences in mean core and skin temperature between baseline and post-intervention HSTs were unclear. The substantial training effect together with limited thermal adaptation implies that at this point in the season, laboratory-based heat training did not provide additional performance benefits above those obtained by training in temperate conditions.

Repeated sprint cycling training with and without brief passive heat exposure was undertaken to evaluate the effects of general conditioning and running capacity in the heat during rounds 16 – 22 of a 22-round state-level Australian football season. Thirty male players in a pre-post parallel group experimental design were assigned to either: Passive + Active Heat (PAH; n=10), Active Heat (AH; n=10) or Temperate (TEMP; n=10) to complete 6 x 40 min repeat effort cycling training sessions (5 min warm up; 6 x 5 x 10 s sprints; 30 s active recovery between sprints and 2 min passive recovery between each set) over 12 days in 35°C (PAH and AH) or 18°C (TEMP) and 50% RH. Players in PAH were exposed to passive heat (seated) for 20 min prior to commencing exercise. Physiological adaptation and running capacity were assessed via a treadmill submaximal HST followed by a time-to-exhaustion test (run capacity) in 35°C, 50% RH. Running capacity increased by 26 ± 8% PAH (0.88, ±0.23; standardised mean, ±90% confidence limits), 29 ± 12% AH (1.23, ±0.45) and 10 ± 11% TEMP (0.45, ±0.48) compared with baseline. There were greater improvements in running capacity for the PAH (0.52, ±0.42; standardised mean, ±90% confidence limits) and AH (0.35, ±0.57) conditions compared to TEMP. However, the difference between AH and TEMP was unclear. Physiological measures assessed during the HSTs were trivial and small, but uncertain following the two heat training interventions. Thus, remained relatively unchanged between baseline and post-intervention testing. In contrast, there were small to moderate reductions in RPE and thermal sensation within AH and also in both AH and PAH compared to TEMP, respectively. When acquiring specific heat adaptation is not a direct priority, 6 x 40 min repeated effort cycling sessions, with and without passive heat exposure are more effective in enhancing running capacity compared to temperate ambient conditions alone in team sport players without interfering with sports-specific training during the season.

Modern-day team sports present several challenges that restrict the implementation of traditional heat training practices in a real-world context. When aiming to improve performance in temperate conditions and achieving thermal adaptation is not a direct priority, short duration ($\leq$60 min) sessions undertaken intermittently can offer positive conditioning/training effects in a relatively short time frame in both the pre-season and during the season. Similarly, the perceived benefits of undertaking heat training may complement increased training load and underlying physiological/thermal adaptations in facilitating performance benefits in state-level team sport players. Heat training sessions performed every other day to sport-specific training were well tolerated by the players, and can be implemented without disrupting field-based skills sessions or compromising football-specific goals.

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Table of Contents

List of Figures

List of Tables

List of Abbreviations

AH	Active heat (Chapter 4)
CL	Confidence limits
CON	Control (Chapter 4)
CV	Coefficient of variation
ES	Effect size
HIIT	High intensity interval training
HR	Heart rate
HR_{max}	Heart rate maximum
HST	Heat stress test
PAH	Passive + active heat (Chapter 4)
PO	Power output
RH	Relative humidity
RPE	Rating of perceived exertion
RPM	Revolutions per minute
SD	Standard deviation
T_c	Core temperature
T_{cmax}	Core temperate maximum
TEMP	Temperate (Chapter 3)
TS	Thermal sensation
T_{sk}	Skin temperature
T_{skmax}	Skin temperature maximum
T_{tymp}	Tympanic temperature

List of Abbreviations

v	Versus
VO_{2max}	Maximal oxygen uptake
VO_{2peak}	Peak oxygen uptake
WBGT	Wet blub globe temperature

List of Conference Presentations

Gale, R.M., Etxebarria, N., and Pyne, D.B. (September 2016). Effect of short-term heat training on intermittent running performance in temperate conditions in team sport players. *Science of Sport, Exercise and Physical Activity in the Tropics*. Townsville, Australia.

Pyne, D.B., **Gale, R.M.,** Etxebarria, N., and Pumpa, K.L. (July 2019). Combined passive and active heat exposure to enhance running performance in winter-based team sports. *European College of Sports Science, 24th Annual Congress*. Prague, Czech Republic.

Chapter 1: Introduction

Team sports are multifaceted and their competitive success relies on the interaction between physical, technical and tactical performance.[1] As game demands and pressure increase, more elements compete for players' time. Hence, coaches, conditioning staff and sports science advisors seek time efficient innovative methods for enhancing and/or maintaining physical performance and player fitness. The challenge is meeting these goals without compromising sport-specific priorities. With the potential to enable relatively rapid physiological, perceptual and performance benefits, repeated exposure to hot environments is used to elicit heat acclimation (artificial exposure) or acclimatisation (natural exposure).[2] Enhanced physiological capacity has the potential to offer performance benefits in cool as well as hot environmental conditions.[3,4]

Heat-based training has become increasingly popular among field-based team sports. However, questions remain on the systematic prescription and scheduling of heat training programs in a real-world context. Given that the physiological and perceptual adaptations to heat training are similar to those achieved through long-term, regular exercise training but in a shorter time frame, heat training offers potential for time poor and logistically challenged team sports. Despite the appeal, traditional heat training programs are often not practically suited to the modern-day team. Evidence-based guidelines that acknowledge traditional heat training strategies but apply them in a pragmatic sense relative to team sports would benefit coaches and support staff.

While there is no single heat training program that facilitates optimal adaptation,[5] current recommendations advocate 60–90 min of heat exposure per day for 10–14 days (consecutively) in environmental conditions that closely replicate or exceed those that will be experienced during training and/or competitions to ensure athletes are fully acclimated.[6,7] However, given that 75–80% of the physiological adaptations occur in the first 4–7 days of exposure,[8] attention has shifted to investigating short-term heat training (≤7 days) in highly trained athletes[9-11] and team sport players.[12-14] In well-trained female team sport players, as few as four sessions across 10 days improved high-intensity intermittent running by 33%.[14] Notably, daily heat exposure will facilitate the most rapid and complete physiological and thermoregulatory response[5], however, this is arguably not the most practical in a team sport environment when teams are often required to train twice a day.

Alternating days of heat training and sports-specific training presents a more realistic alternative for teams to be able to engage heat training. Although the magnitude of physiological and thermal adaptation may be limited during intermittent exposure,[15] the extent of these adaptations is essentially dependent on the exercise intensity, frequency, duration and number of heat exposures.[16] Equally important is the program's effectiveness to sufficiently elevate core and skin temperature and elicit profuse sweating.[7] While temperature and relative humidity values range between studies, generally maintaining a Wet Bulb Globe Temperature (WBGT; combined measure of temperature and relatively humidity) of ≥30°C is sufficient to generate physiological and thermoregulatory adaptations.[17] Despite the ongoing interest from coaches, support staff and athletes, the manipulation and customisation of these key variables pertaining to heat training remains relatively unexplored in an applied, real-world team sport setting.

Teams traveling to conduct heat training camps where field-based technical and tactical sessions can be maintained in hot conditions have also become popular.[18-20] Despite the two-fold benefit of maintaining sports-specific training and facilitating heat adaptation, these camps are costly and logistically demanding. In addition to traditional methods being impractical, there is a clear need to provide teams with more relevant laboratory-based heat training programs. Programs that do not require travel, have little financial impact and can be easily implemented with multiple players simultaneously during the season are warranted. Heat training has the potential to offer teams a competitive edge over their opponents come game day.

There is a wealth of scientific information pertaining to traditional heat training methods, mechanisms responsible for the physiological and thermoregulatory responses and subsequent performance improvements. On the contrary, there is little information on how heat training can be applied in a team sport environment. Team sports involve a large number of players and given their weekly competition schedules often involving domestic and/or international travel present several logistical challenges. A compromise between traditional methods and what is practically achievable is required to modernise heat training for team sports.

Statement of the Problem

Traditional heat acclimation and acclimatisation research has focused narrowly on athletes engaging heat training to sustain/enhance performance during training and competition in hot environmental conditions.[6] However, given the well-established benefits, heat training may have the potential to offer more than just an avenue to negate impaired performance in hot conditions. More recently, the potential for heat training to enhance performance in cooler conditions has become an area of interest.[3] Although team sport coaches, athletes and support staff are encouraged by its potential, there is little practical information on how heat training can be applied in a team sport setting. In reality, current (traditional) recommendations and strategies are often not practically feasible within the daily training environment as higher (sports-specific) priorities take precedence. To date there have only been two studies that have investigated the use of laboratory-based heat training in a real-world setting in combination with pre-season[12] and in-season training and games.[13] Hence, coaches and support staff seek further information on how this training methodology can be applied pragmatically in the real world for the modern day team. Given the rapid physiological responses (i.e. a reduction in resting and exercise heart rate, core and skin temperature, enhanced sweat response) and potential performance benefits, exploring heat training as a conditioning method offers a practical alternative without compromising sports-specific priorities. Currently, there is little information pertaining to heat training as a conditioning method for when thermal adaptation is not the explicit priority.

Aims

The aims of the experimental studies in this thesis were to manipulate traditional heat training (exercise intensity, frequency, duration and number of heat exposures) to evaluate whether pragmatic, real-world heat training programs could be easily applied for field-based team sport players. The work presented in this thesis addresses topical and applied research questions that have been carefully formulated in response to interest and demand from the sports industry. Thus, traditional hypothesises testing and statistical significance analysis has not been applied in this thesis. Instead a more modern and relevant (to the current research) method involving point estimation of effects (difference between treatments and changes over time) and precision of estimation using confidence limits[21] has been adopted. The research questions are clearly articulated in the following aims and analytical techniques detailed and applied within the methods section of Chapter's 3 and 4, respectively. The specific aims of each study were to:

1. Investigate a short-term, intermittent day laboratory-based heat training program to enhance endurance running performance and thermal tolerance in state-level Australian football players during the pre-season.

2. Evaluate the utility of a mixed-mode training method involving stationary cycling and treadmill running on subsequent physiological/thermal adaptation and endurance running performance in warm conditions.

3. Assess the impact of repeat sprint cycling training in the heat on player conditioning and running capacity when integrated with sports-specific training and games during the competitive season.

4. Explore the potential of combined passive and active heat exposure for facilitating physiological/thermal adaptation and improving running capacity in state-level team sport players.

Significance of the Thesis

The outcomes of this thesis should provide coaches and performance staff with practically relevant heat training programs that can be easily integrated with sport-specific training and games throughout the season. The first study was designed to provide teams with a laboratory-based option for heat training during the pre-season that doesn't require travel or expensive training camps. The second study was designed to supplement in-season fitness and conditioning when technical and tactical sessions often take precedence. The uniqueness of the two studies is that they were undertaken in a real-world context to ensure the practical relevance.

The studies in this thesis will be some of the first to explore the use of heat-based training as a conditioning method as opposed to specifically aiming to facilitate heat acclimation. This thesis will also highlight different features that should be considered by coaching and support staff prior to deciding to engage heat training. These discussions should consider how manipulation of key training variables may differ depending on the purpose of heat training, rationale for engaging heat training, and the timing of the season that heat training is undertaken. The outcomes of this thesis should provide coaches and performance staff with the confidence in knowing that heat training should benefit field-based team sport players.

Thesis Outline

This thesis contains six chapters. Experimental Chapters 3 and 4 are presented in scientific manuscript format as per the journal specifications to which they have been submitted to prior to the thesis submission. Chapters 3 and 4 are presented with a corresponding Abstract, Introduction, Methods, Results and Discussion sections. There is some common methodology employed in the experimental studies. All references are located at the end of the thesis to assist the flow.

- **Chapter 1: Introduction**
  - The first chapter of this thesis briefly highlights the background rationale for undertaking this research, the statement of the problem, the aims of each experimental study, significance of the thesis and the thesis outline.
- **Chapter 2: Literature Review**
  - This chapter provides a review of the classical adaptations and traditional induction strategies pertaining to heat training. It details the challenges associated with team sports undertaking conventional heat training strategies, and discusses how the principles of traditional heat training can be pragmatically applied to team sports.
- **Chapter 3: Mixed-mode heat training: A pragmatic alternative to a traditional heat-based intervention for enhancing aerobic capacity in team sports**
  - This experimental study explores the utility of an intermittent day, mixed-mode laboratory-based heat training program on enhancing endurance running and thermal tolerance during a state-level pre-season in Australian football players.
- **Chapter 4: Cycling-based repeat sprint training in the heat enhances running performance in team sport players**
  - This study investigates the efficacy of integrating a repeat sprint cycling program with and without passive heat exposure in combination with sport-specific field

training and competitive games during a state-level Australian Rules football season.

- **Chapter 5: General Discussion**
  - This chapter reviews the outcomes of the experimental studies and how they contribute to our understanding of applying heat training in a real-world context. The chapter highlights the impact of the current research in the real world and the considerations coaches and performance staff should acknowledge prior to employing heat training throughout the season.
- **Chapter 6: Conclusions and Practical Applications**
  - The final chapter summarises the main findings of the thesis, presents a practical schematic for coaches and performance staff on heat training, and discusses the limitations and delimitations of the experimental studies, practical applications and considerations for future research.

Chapter 2: Literature Review

Introduction

Team sport training and performance is the result of a complex interplay of technical, tactical, physical and psychological constructs.[1] These constructs highlight the importance of strength, power, anaerobic and aerobic fitness qualities and their subsequent influence on speed, agility, work rate, recovery and injury prevention, ultimately setting the foundation for team success.[22,23] As the physical calibre and skill level of elite athletes increase, naturally so too does the competitiveness of the game. Over a 7-year monitoring period, significant increases in running speed, time spent sprinting, number of sprint efforts per minute, game speed and decreases in overall time on the field were observed in senior Australian football rules players but not in players at the Under 18 level.[24] Player running speed was the only measure to improve significantly at the Under 18 level, highlighting the rapid evolution in game intensity and player demands at an elite senior level.[24] Thus, advancements in scientific research have transformed how coaches and performance staff prepare athletes for competition. Similarly, with player load monitoring at the forefront of high-performance sport, coaching staff seek innovative methods for increasing and/or maintaining player fitness/conditioning throughout the season.

Given the potential to offer relatively rapid physiological, perceptual and performance benefits, the interest in heat-based training among team sports has grown in recent years. *Heat acclimatisation* (exposure to naturally hot environments) or *heat acclimation* (exposure to artificially hot environments i.e. laboratory/indoors) is the product of repeated heat exposures over a specified time course (i.e. 7 days). These terms relate to the different approaches used to signify the process for facilitating thermal adaptation. For the purpose of this review the empirical term, *heat training* will be used as a general descriptor for undertaking exercise in hot conditions. Our current understanding and knowledge pertaining to heat training (in natural or artificial environments) is mostly centred on enhancing aerobic performance in endurance sport athletes. Thus, applying traditional heat training strategies in the context of the modern-day team without disrupting sports-specific training objectives is complex and often a barrier for implementation.[5]

The logistical complexities of team sports are unique, and the large player numbers in addition to their requirements to train collectively warrant investigation for more pragmatic heat strategies that can be easily applied in a real-world setting. This review will discuss the traditional fundamentals of *heat acclimation* training and how they inform the design of more practically relevant heat training programs for the modern-day team. The primary aim of this review is to discuss how manipulating key training variables (duration, frequency, intensity and number of heat exposures) can provide team sports with practical alternatives to traditional heat acclimation methods. The review will focus on the following topics and key concepts to explore the utility of heat-based training as an advanced conditioning and rehabilitation method for team sports: Relevance of heat training in team sports, fundamentals and adaptations to heat (acclimation) training, traditional heat training strategies and alternative methods of heat exposure and developing pragmatic heat training strategies for team sports.

Characteristics and challenges associated with team sports

Operational and logistical challenges associated with team sports include the requirement to train simultaneously, large player and staff numbers, financial implications of maintaining such large numbers, and regular travel commitments for games and competition. Depending on the sport, teams often maintain a playing roster of anywhere between 12–30+ players, not including development listed players. These large numbers and the team's general requirement to train simultaneously present key challenges to implementing novel training interventions such as heat-training, where facility space and equipment could be limited. Successful match play in team sports involves tactical decisions and the execution of a technical skills that require specific movement patterns for execution.[1] This sequence of events is often initiated by a single player, whereby other players of the team read and anticipate the game play to progress into the team's offensive/forward zone and score. The effectiveness of this process is highly dependent on the readiness to perform of each individual in the team, and a variety of situational influences such as travel, new playing environment, ambient temperatures, win/loss ratio, and strength of the opposition.[1] To further complicate things, team sport athletes are usually required to perform consistently over several months in league style competitions, yet also be at their peak for major regional, national or international competitions.[25] For example, during the 10 month in-season phase of a professional European Soccer league, players completed 4–8 matches and 16–20 training sessions per month.[26] Similarly, the pre-season and in-season phases of the professional Australian Football League can extend across a 41 week period.[27]

The annual preparation of team sports is usually segmented into three phases throughout the year, namely the pre-season, competitive season and the off-season. During the pre-season phase, training focuses on building fitness following the off-season (where no structured team training is typically prescribed) and is combined with on-field technical and tactical sessions. Recovery sessions such as hydrotherapy, yoga and massage are scheduled to complement physical training and facilitate optimal physiological adaptations.[28,29] Subsequently, in-season training focuses on maintaining physiological adaptations developed during the pre-season[29] as technical and tactical skill development takes precedence to ensure game readiness. In-season microcycles (6–7 days) are typically manipulated based on time between games, travel requirements, competitiveness of the next opponent, injury and minutes of match play in the previous game.[25] During the competitive season, recovery from the previous game and player readiness for the forthcoming game are emphasised. This pattern of demands presents a challenging scenario whereby the opportunity to add additional sessions, or specific training interventions such as heat-based training to the annual training plan is often difficult.

Relevance of heat training in team sports

Environmental stressors, and more specifically, the menacing combination of extreme high temperature and high humidity pose a great physiological challenge for team sports players during training and competition. Many international team sport events such as the Summer Olympic Games, FIFA World Cup and various annual World Cups and World Championships are held in the summer months when environmental temperatures are high.[18,30] Similarly, it is not uncommon for teams to travel from their place of residence in cooler climates to attend international or national events in warmer environments. When moving from one extreme temperature to another (i.e. cool/dry to hot and humid), players voluntarily modify their activity patterns during match play in hot environments to sustain physiological parameters essential to match performance.[1,31,32] However, heat-induced performance decrements were observed during football (soccer) match play in ~43°C compared to ~21°C by 6% in total running distance and 16% in high-intensity running.[33]Whereas, professional Australian football players can maintain high-intensity efforts during match play in hot conditions by reducing low-intensity activity and ultimately their total distance covered.[34] While heat training is a key consideration for preparing teams for pinnacle events in the summer months, its logistical implementation in combination with sports-specific training remains a challenge.

With the increasing competitiveness and time demands associated with elite sport, coaches, athletes and performance staff continuously seek time-efficient methods to improve physical performance.[12] The rapid physiological adaptations[7] and ergogenic potential to improve performance in temperate conditions[3] has generated interest in short-term heat training and heat training camps for team sports. A total of 47 out of 52 data sets involving short, medium and long-term heat training protocols analysed in a recent meta-analysis reported a ≥1% performance improvement in hot conditions with mean improvements ranging from ~7–23% for each study's respective exercise performance or capacity tests/trial.[35] Although participants were well trained cyclists, a 5% increase in VO_{2max} and power output at lactate threshold and a 6% increase in time trial performance indicates the ergogenic potential of heat-training to offer performance benefits in cool (13°C) conditions.[4] This performance transfer from heat to temperate and cool conditions would be of particular interest for winter based team sports. Typically in-season training loads and intensities decrease compared to pre-season to compensate for the increased game load.[29,36,37] Thus, exploring the ergogenic potential of heat-training could provide supplementary physiological load when the main training focus is on technical and tactical elements.[18]

Specific to team sports, heat training has remined relatively unexplored up until the past decade. Over the years more and more teams, particularly professional football teams (Australian football, soccer, rugby) choose to travel to warmer locations to undertake pre-season training camps to accelerate player fitness. For example, following two weeks of football specific training outdoors in 29–33°C, elite Australian football players exhibited physiological adaptations characteristic of heat acclimation.[18,19] Reductions in exercise heart rate, skin temperature, and sweat sodium concentration, and increases in plasma volume were present following a two week training camp.[18] Additionally, distances covered during standardised training drills and the Yo-Yo Intermittent Recovery Test Level 2 were improved by 5% and 44% respectively.[18] Given the high physical calibre of players and variations between playing position, inter-individual responses to a novel training method such as heat training should be considered. Following an in-season soccer training camp in the heat, players who did not acclimatise fully to the heat reduced their running activity by up to ~6%, whereas players that responded positively were better able to maintain running activity during games in hot environments compared to those in temperate environments.[33] While these camps are effective for inducing thermal adaptation and performance improvements in football (soccer)[20,33] and Australian football[18] players, they are costly and logistically demanding. Taken together, these outcomes clearly point to the need to develop (and evaluate) more pragmatic laboratory-based heat training programs that can be undertaken locally without requiring travel or large financial burden.

Laboratory-based heat training interventions pertaining to team sports have typically been variable in nature involving a mix of physiological, perceptual and performance outcomes.[12-14,38,39] These interventions are less effective in maintaining sports-specific performance in relation to skills and tactics however, they offer more opportunity for teams to engage heat training locally throughout the season. Several medium[39,40] and short-term[14,41,42] laboratory-based heat training programs have shown performance improvements in team sport players. Ten x 60 min sessions (over 12 days) in ~33°C, 50% Relative Humidity (RH) of low-intensity cycling (50% VO_{2peak}) elicited a 2% increase in peak power output during a 40 min repeat sprint protocol after heat-training.[40] Similarly, absolute mean power (W), relative power output ($W.Kg^{-1}$), total work (kJ) and work per kilogram body mass ($kJ.Kg^{-1}$) scores were all substantially greater following 8 x 33–47 min high-intensity cycling sessions performed consecutively and intermittently (over 16 days) compared with baseline.[39] Despite the consecutive and intermittent sessions of heat exposure imparting a similar degree of adaptation, all power and work measures were improved for up to two weeks after the final training session was undertaken.[39] Furthermore, as few as four short running-based heat training sessions can elicit a 33% improvement in intermittent running performance despite sessions being spread over 10 days.[14] Similarly, four short cycling sessions in 30°C, 60% RH effectively enhanced perceptions of thermal comfort and sensation in club-level cricket players.[38] Depending on the phase of the season heat training is undertaken, practitioners should consider the likely benefits of employing heat training without compromising the quality of sports-specific training and/or causing excessive fatigue.[1]

It is typically recommended that heat-based training replicate the demands of team sports[30] allowing players to experience the impact of heat exposure in situations that best reflect their competitive environments.[6] A combination of high- and low-moderate intensity heat training could offer a wider range of performance benefits for sports with multiple performance determinants.[30] Five low-intensity heat acclimation sessions (90 min at 40% maximal aerobic power output) yielded a ~6% improvement in cycling endurance performance (20 km time trial) in the heat.[42] Similarly, five high-intensity (5 x 3 min at 70%, 3 min at 30% maximal aerobic power output) cycling sessions in the heat resulted in anaerobic performance improvements indicated by early sprint peak power output, countermovement jump and vertical jump, without influence on 20 km time trial performance.[42] Given the aerobic and anaerobic capacities required by team sports players, particularly Australian football players, a high-intensity 30–40 min training session should be an attractive in season conditioning option for coaches.

Given the rapid and positive physiological adaptations, heat exposure could be applied in a rehabilitation setting as a stimulus for imposing cardiovascular and thermoregulatory load when athletes are on restricted or modified training schedules. Despite similar improvements in intermittent running performance in heat (2.6%) and cool (2.2%) conditions following 5 x 50 min cycling sessions at 70% heart rate reserve, a heat trained group performed 30% less mechanical training load during the cycling training sessions.[12] This outcome indicates that heat training could also be a useful conditioning option for injured/rehabilitating athletes, or athletes seeking to increase running performance without wanting to increase additional running volume.[12] Whether used as a conditioning method for enhancing fitness and performance or player rehabilitation, opportunities for heat training should accommodate sports-specific training for team sports. Laboratory-based heat training has the potential to positively impact team sport performance. However, given the dynamic environment in which team sports operate, several questions on the pragmatic application of heat training remain speculative with limited evidence.

Fundamentals of heat training (acclimation)

Adverse environmental conditions and exercise interact to impose physiological and thermoregulatory strain resulting in unfavourable decrements in athletic performance compared with exercise in temperate conditions. When metabolic heat production surpasses the body’s ability to release heat, the heat dissipating mechanisms (evaporation, radiation, convection, conduction) can become compromised.[16] The concurrent increase in metabolic heat production and ambient environmental temperature during exercise can overload the athlete’s thermoregulatory and cardiovascular systems[43] causing performance to deteriorate and/or lead to heat illness in some cases. During these stressful encounters, the body is forced to meet thermoregulatory requirements without compromising cardiovascular and metabolic demands during exercise.[44] When exercise is performed repeatedly in a controlled hot and humid environment, chronic exposure initiates a number of physiological and thermoregulatory adaptations that alleviate the impact of heat stress on athletic performance.[6,7] In addition to the potential performance benefits, these distinct physiological responses have spiked the interest in exploring the use of heat-based training as an ergogenic aid for improving performance in cooler conditions[3,4,7] for team sports (i.e. for fitness and conditioning).

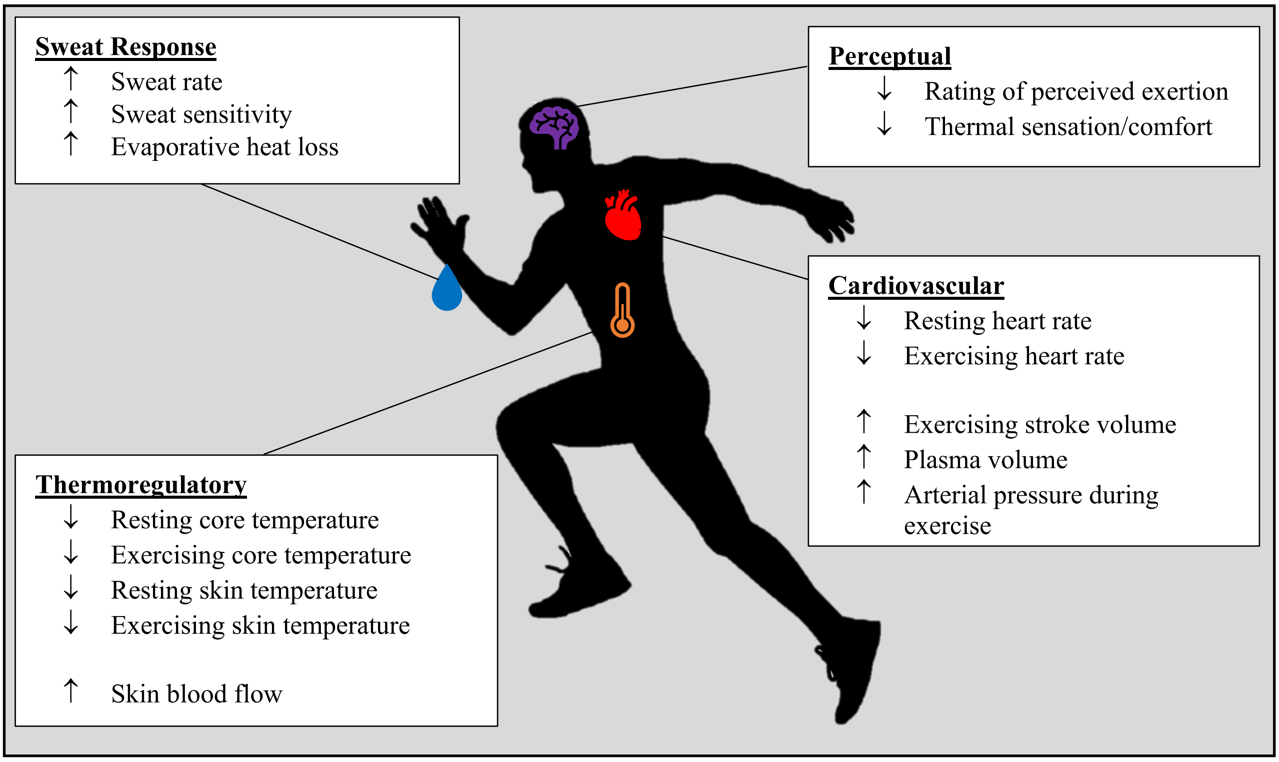
A long standing belief in the sports and scientific community asserts that medium to long term heat acclimation (>8 days) for up to 100 min per session[45] at low – moderate intensity (50 – 60% VO_{2max})[46] is more beneficial in facilitating heat adaptation than short-term protocols (<8 days).[17] However, advancements in scientific knowledge and practical consideration in elite settings have fostered the evolution of heat adaptation induction methods. In recent years, as few as four[14,38] or five[9,47,48] exposures have been shown to be equally as effective as medium-to-long term protocols in achieving full or partial heat acclimation status. Additionally, session duration has also decreased with a concurrent increase in exercise intensity in recent years. Despite more recent studies electing higher intensity interventions, an original heat acclimation study reported that 30 – 35 min of running ~75% VO_{2max} induced a similar degree of heat acclimation to walking or jogging at ~50% VO_{2max} for 60 min over 9 days.[46] Despite imparting a similar degree of adaptation, eight high-intensity cycling sessions conducted consecutively and intermittently (every second day) were equally effective in improving repeat sprint performance in the heat in well-trained team sport players.[39] Irrespective of whether heat training is undertaken in naturally or artificially hot environments, the magnitude for adaptation is primarily dependent on increasing core body temperature and eliciting a large sweat response.[49]

In recent years, new interventions such as passive heating (no exercise) via sauna exposure and hot water immersion have become popular as a practical alternative for imposing heat stress without increasing musculoskeletal load.[50-52] Characteristic physiological and thermoregulatory responses to heat training can be achieved via active, passive or a combination of active and passive exposure to hot and humid conditions.[17] Despite the diversity of these acclimation methods, facilitating heat adaptation and performance gains are ultimately dependent on the duration, frequency, intensity and number of heat exposure sessions.[16] Given the dynamic nature and logistical complexity of team sports, the use of traditional heat acclimation practices is challenging and often not practically relevant.

Adaptations to heat training

Adaptations associated with heat acclimation are commonly categorised as cardiovascular, thermoregulatory, metabolic and perceptual (Figure 2.1). Three key classical markers of heat acclimation are lower heart rate and core body temperature, and increased sweat rate.[16] When evaporative cooling becomes the body's primary method of dissipating heat, the increase in skin blood flow is often associated with reduced cardiac filling and stroke volume, which in turn increases heart rate to maintain adequate cardiac output.[53] Reductions in resting and exercising heart are the first of the adaptations to develop with these changes occurring rapidly within the first week of heat exposure and continuing more slowly thereafter.[7] There are reports of physiological adaptations and performance benefits persisting for up to 1 – 2 weeks following the final heat exposure.[39,54] This suggests that physiological adaptations may be lost as rapidly as they are gained if an adequate heat stimulus is not maintained to prevent decay.[55] Many of these adaptations mimic those typically developed through long-term habitual exercise training but in a much shorter time frame. Hence, highly-trained athletes often appear as though they are already acclimatised.[56] With the ability to facilitate positive physiological adaptations, heat training positions itself as an attractive conditioning method for team sports, however, it remains relatively unexplored from a fitness/conditioning perspective.

Figure 2.1. Physiological, thermoregulatory and perceptual adaptations to heat acclimation training.



Cardiovascular

During exercise in the heat, the primary role of the cardiovascular system is to simultaneously provide sufficient blood and oxygen to active muscles while maintaining adequate blood flow to the skin to support heat dissipation.[16] Improved cardiovascular stability following heat acclimation is essentially mediated by plasma volume expansion, redistribution of blood volume and enhanced skin cooling, increased venous tone from cutaneous and non-cutaneous vascular beds, and a reduction in core and skin temperature.[7] The expansion in plasma volume plays a particularly important role in alleviating cardiovascular strain, offering two distinct advantages: increased stroke volume and arterial pressure via increasing the vascular filling pressure,[57] and promoting heat transfer from the core to the skin.[58] A significant decrease in sympathetic nervous activity (assessed via plasma norepinephrine concentrations) on days 3 (~49%), 5 (~38%) and 8 (~36%) compared to day 1of an 8 day heat acclimation protocol was associated with the rapid reduction in heart rate within the first few days of acclimation.[59]

Thermoregulatory

Thermoregulatory responses to heat acclimation are ultimately driven by a reduction in core body temperature and enhanced sweat response. Humans are generally able to regulate core body temperature between 35–41°C with the goal of maintaining it around ~37°C.[16] Temperature regulation occurs through two parallel processes: behavioural (conscious and voluntary decision to alter body temperature), and physiological (increased metabolic heat production, redistribution of body heat and sweating) regulation.[58] During exercise in hot and humid environments, the body's ability to regulate core temperature is directly proportional to the dissipation of excess heat via evaporative cooling.[16] As ambient temperatures increase, the body becomes more reliant on evaporative cooling and sweating as its primary means of heat loss. Efficient evaporation of sweat from the skin surface is highly dependent on the temperature gradient between the skin and surrounding environment.[58] The wider the gradient, the greater the opportunity for sweat to evaporate from the skin resulting in body cooling.

The concomitant interaction between core temperature and sweat response occurs at both a central and peripheral level. Centrally, the onset threshold for sweating is triggered by a reduction in core temperature as adaptations progress (i.e. sweating begins earlier at a lower core temperature).[16] At the peripheral level, the reduced threshold for sweating occurs at the sweat glands and is manifested by increased sweat rates and sensitivity (i.e. number of active glands and secretion per gland).[7] The enhanced sweat response allows for greater evaporative cooling to prevent excess heat storage and high core and skin temperatures during exercise. Lowered skin temperature associated with acclimation decreases skin blood flow, allowing for redistribution back to the core and into central circulation.[60] This effect is however reliant on the blood (temperature) entering the cutaneous vasculature being equal to the temperature of the core and skin, respectively.[60] Thus, reductions in core and skin temperature and associated improvement in sweat response work synergistically to reduce thermoregulatory strain during exercise in hot conditions.

Perceptual

Acute exercise in hot conditions increases thermal discomfort, possibly negatively affecting exercise capacity.[61] However, similar to physiological strain, the progressive nature of heat acclimation has the potential to reduce the perception of effort during subsequent exercise in the heat.[35] During fixed-intensity exercise in hot conditions when the body's ability to dissipate heat exceeds the rate of metabolic heat production, and consequently the attainment of high core temperature becomes intolerable, a voluntary (behavioural) decision to cease exercise is made.[62] Whereas during self-paced exercise in hot conditions, athletes will generally manipulate their work rates to avoid an intolerable core temperature, premature cessation of exercise and fatigue.[62] During match play in hot conditions, professional Australian football players appear to self-regulate low-intensity activity, and overall running volume through anticipatory pacing strategies enabling them to maintain high-intensity activity.[34] In addition to physiological and thermoregulatory adaptations, reduced perception of effort, and an improved sense of thermal comfort should enable athletes to better maintain exercise during fixed-intensity activities.[35] Self-regulation of activity is likely to maintain higher workloads for longer periods during self-paced activity in the heat.[35] On the contrary, a study involving team sport players, reported a significant reduction in the rating of perceived exertion (RPE) and thermal comfort following 5 x 27 min high-intensity interval sessions despite inducing partial heat acclimation.[13] Nonetheless, it remains unclear as to the extent to which perceptual responses influence performance improvements associated with heat training.[2]

Nature of traditional heat acclimation strategies in sport

When subject to unaccustomed heat stress, an athlete's exercise capacity and/or ability to sustain exercise can be reduced. Typically characterised by enhanced cardiovascular stability, thermoregulatory mechanisms (reduced core and skin temperature, enhanced sweat response), altered skeletal muscle metabolism, reduced perception of effort and thermal comfort,[7,35] enhanced thermal tolerance and impaired aerobic exercise capacity can be augmented via repeated heat exposure.[47] The traditional approach towards heat acclimation focuses on inducing sufficient physiological and perceptual changes to adequately prepare athletes for competition in hot environments. However, current trends have shifted towards exploring heat-based training as an avenue for supplementing athlete fitness and conditioning. As well as potentially aiding exercise performance in cooler conditions due to the acceleration of physiological adaptations that are comparable or additional to those gained by regular exercise training in temperate ambient conditions.

The magnitude to which physiological and thermoregulatory adaptations occur during heat training are dependent on the stimulus for adaptation. Generally, exposure to naturally hot environments where athletes can maintain sports-specific training is preferred[7], however, this is not always an option particularly in the winter months. Therefore, ambient temperature and humidity are also key factors to be considered when programming heat training in a laboratory setting. The interplay between these factors will influence the dose-response relationship required to elicit increases in core temperature and evoke profuse sweating to facilitate adaptation. Manipulating core temperature and sweat responses to exercise in the heat are mostly commonly achieved through one of five induction pathways: controlled heart rate, controlled hyperthermia, self-paced exercise, passive heat exposure, and/or constant work rate.[5] After 5–7 days of daily exposure, 75–80% of these adaptations are generally achieved.[8] In contrast, some thermoregulatory responses[7] and other aerobic exercise performance adaptations may take between 10–14 days to fully develop.

Protocol duration and frequency of exposure

There is no single heat protocol that delivers optimal physiological adaptation or superior performance gains for all athletes. A common categorisation system divides heat training into three durations: short-term (≤7 days), medium-term (8–14 days) and long-term (≥15 days) exposure,[55] with 10–14 consecutive days of heat exposure being considered the threshold or standard for inducing complete physiological adaptations.[63] However, there are many combinations of heat training and exposures in the literature and employed in a variety of sports. A similar degree of adaptation to 10 consecutive heat exposure sessions was induced following 1 exposure every 3 days, although in a third of the time.[64] This notion was supported some years later when 10 sessions completed over a 3 week period (3 sessions·wk^{-1}) was deemed less effective in facilitating thermal adaptation than 10 sessions performed consecutively.[15] Heat adaptation begins on the first day of exposure and progresses rapidly thereafter. Given that ~80% of adaptations are near complete within 5–7 days,[7,8] short-term interventions have gained considerable focus.[55] Similarly, given their training history, physiological adaptations often develop much quicker in highly-trained athletes than their lesser trained counterparts.[8] From a practical perspective, short-term heat training has surpassed traditional medium-long term protocols in popularity in the elite sporting world. Short-term heat training offers a time efficient approach allowing sports-specific training quality to be maintained in the weeks leading up to competition in the heat.[55]

The process of heat acclimation develops rapidly on the basis that heat exposure occurs daily and so physiological and thermoregulatory adaptations are likely compromised during intermittent exposure.[15,39,64] The benefits of daily (consecutive) exposure cannot be disputed when the primary aim is to acclimatise athletes to hot conditions to subsequently minimise performance impairments during competition. However, the nature of daily exposure can be debated when it comes to team sports. While there is an increasing interest in the football industry to determine the minimal dose of heat exposure required to return the desired benefit, complex questions remain on how to integrate heat-training into the team's overall training plan.[30] A current consensus statement recommends that heat training should be undertaken daily for certainly ~1 week, but ideally ~2 weeks (if possible) to maximise physiological and performance benefits.[6] In the context of team sports this is rarely practical in addition to sports-specific training and other off-field commitments. Hence, intermittent heat training sessions performed every other day to sports-specific training provide a more practically relevant alternative for team sports.

Session duration and intensity

A heat investigation dating back to the 1960s identified that daily exercise for 100 min was the optimal exposure time required to induce acclimation.[45] With the understanding that maintaining an elevated core temperature is the main stimulus behind subsequent adaptations, classical recommendations were formulated that intense interval or continuous exercise be performed at intensities equal to, or above 50% of the athlete's VO_{2max}.[65] However, more recent work indicates that elevating and maintaining core temperature $\geq$38.5°C for ~60 min is the minimal impulse for facilitating an adaptive response.[66] With five key methods for manipulating core temperature and sweat responses,[5] combining one or more induction methods (i.e active and passive exposure) could potentially offer greater flexibility for busy athletes. This is especially the case when maintaining sports-specific training and inducing thermal adaptations are of equal importance. Although short-duration, high-intensity programs offer some potential for adaptations to develop more rapidly, earlier guidelines maintain that exercise should be undertaken daily for a minimum of 60–90 min during heat sessions.[6,17] Depending on the phase of the season heat training is being considered for, this time frame may not be feasible for teams already training several times a day.

Traditional heat training methods in trained subjects typically involve relatively low exercise intensities between 40–50% VO_{2max}.[46] An early investigation using trained runners reported that 7 days of 30–35 min of exercise at 75% VO_{2max} in ~40°C resulted in a similar acclimation status to exercising for 60 min at 50% VO_{2max}.[46] Heart rate and core temperature were both substantially reduced during the post-intervention heat tolerance test, yet no differences between continuous exercise performed at 50% versus 75% VO_{2max} were observed.[46] Although team sports consist of intermittent periods of low-moderate intensity activity, undertaking prolonged exercise at these low intensities is arguably not sport-specific enough. When constrained by time, shorter duration, higher intensity programs have the potential to induce heat acclimation but perhaps not to the full extent.[35] Despite traditional exercise intensities being commonly prescribed at an absolute workload, both relative and absolute workloads should be progressively increased over the duration of the program to maintain the stimulus for adaptation.[17]

Environmental conditions

It is typically recommended that athletes acclimatise to the conditions, or to those slightly more demanding than they will compete in.[6,17] For athletes residing in similar conditions to which they will compete in or have the option to travel to more challenging environments, this presents the ideal scenario as sports-specific training can be maintained and adaptations developed simultaneously. For winter-based team sports and those living in the Southern Hemisphere who primarily compete in the Northern Hemisphere summer months (and vice-a-versa), this is not always a viable option for logistical and financial reasons. The most practical option for these athletes is to train indoors in a laboratory setting such as a climate controlled chamber and/or to passively expose themselves to hot conditions via sauna exposure[50,51] or hot water immersion.[52,67] Generally, a wet bulb globe temperature (WBGT; combined measure of temperature and humidity) of ≥30°C provides a sufficient heat stimulus to facilitate heat adaptations.[17]

Short-term heat training in sport

Considering the rapid (4–6 days) physiological and thermoregulatory responses associated with heat acclimation, short-term heat training (≤7 days) has become increasingly popular for athletes preparing to compete in hot conditions. For time poor high-level athletes, short-term heat training has been branded as a time efficient and practical alternative to traditional medium-to-long term strategies.[55] Although some investigations have shown little effect,[48,68] heat training can improve aerobic performance in cooler conditions by up to 5% in trained individuals.[4] Consequently, curiosity regarding the implementation of short-term heat training in a team sport setting has increased among coaches and sports scientists in recent years.[44] Likewise, the appeal and apparent ease of implementation, short-term heat training has driven investigators to determine the minimal does of heat exposure required to facilitate physiological and performance benefits[30] in both hot and cool conditions.

The most notable difference between traditional and more modern short-term heat training methods is the number of sessions undertaken. As few as four[14,38] or five[9,41,48,69] heat exposures have been reported to be similarly effective at inducing physiological, thermoregulatory and perceptual adaptations as longer programs. Additionally, individual session duration has also been reduced to 27–50 min in some short-term heat training programs involving team sports players.[12-14,38,39,70] In support of these shorter interventions, a total of 240 min of accumulated heat exposure (number of sessions x session duration) could be considered the absolute minimum required to facilitate performance gains in temperate conditions.[70] As the total number of sessions and duration per sessions decrease, the timeframe for which heat exposures are undertaken has increased in recent years. In contrast to consecutive day heat exposure, more recent investigations in team sports are now exploring the nature of intermittent (non-consecutive) heat exposure.[5,13,14,39] Lastly, to compensate for these shorter heat interventions, exercise intensity has increased to ensure the stimulus for increasing core temperature and sweating is maintained.[13,39,41,70] In an attempt to further fast-track adaptive responses, the potential of multiple heat exposures per day compared to single daily exposure has been explored.[71] However, there are a few differences in physiological, perceptual and performance outcomes between single versus multiple heat sessions per day.[71]

Alternative methods of heat exposure: Passive heat exposure

Active heat training sets the standard for inducing heat acclimation and acclimatisation and overcoming performance decrements in hot conditions. However, there are often barriers that prevent athletes, especially those in team sports and/or residing in cooler climates from doing so. Limiting factors that may influence protocol design include: access to environmental chambers, preferred training modes not attainable within the small confines of environmental chambers, occupancy limits, costs associated with travel to conduct heat camps, and the interference of consecutive exposures on higher priority training objectives.[30] To negate these challenges, passive heat exposure has emerged as a popular and practical alternative to active heat training.[72] Unlike during exercise, the responses to heat during passive exposure are largely driven by the body's need to maintain thermoregulatory requirements as opposed to metabolic needs during active (exercise) exposure.[73] The need to maintain thermoregulatory stability is therefore underpinned by a number of cardiac (stroke volume and heart rate), temperature, respiratory, vascular and blood flow adjustments.[72,73] The most common forms of passive heat exposure include hot water immersion and sauna bathing. Where climate/environmental chambers are accessible to the athlete or team, they also provide an avenue for facilitating passive exposure.[74] Additionally, passive exposure provides an opportunity to extend the duration of accumulated heat stress without subjecting players to prolonged activity and, consequently increasing total training load.

Hot water immersion

With most athletes having access to hydrotherapy facilities for recovery purposes, hot water immersion has emerged as a popular, accessible and affordable means of passive heat exposure. Conducted intermittently over 2 weeks, 7 x 45 min hot water immersion (44°C) sessions effectively reduces core temperature and heart rate by ~0.30°C and ~12 b$\cdot$min^{-1}, respectively.[75] Employing similar methods of passive exposure, 40 min submaximal exercise in 18–20°C was followed by 40 min of hot water immersion in 40°C.[52,67] Both investigations reported marked reductions in core temperature, and the onset of sweating as well as reductions in end-of-exercise heart rate, RPE and thermal sensation.[52,67] One of the two studies reported a 4.9% improvement in a 5 km time trial performance,[67] whereas the other study did not include a performance test. Six days of hot water immersion was beneficial in reducing thermal strain in submaximal exercise performed early in the morning and mid-afternoon.[52] Hot water immersion provides an opportunity to facilitate positive adaptations in home locations, and an accessible means of maintaining heat exposure during travel when the options for active sessions may be limited.

Sauna exposure

Sauna bathing in temperatures ≥50°C post-exercise[76] is an effective and accessible means for inducing physiological adaptations similar to those attained by active heat exposure. In trained runners, 30 min of sauna bathing (~90°C) immediately following exercise for 3 weeks (12 sessions in total) results in a ~7% increase in plasma volume, and ~2% improvement in 5 km time trial performance.[51] Similarly, plasma volume expansion peaked at ~17% on the fourth of six days of sauna exposure (30 min at 87°C) immediately following exercise in well-trained cyclists.[76] This adaptation equates to a rapid ~4% increase per day within the first four days of exposure and subsequent ~7% mean increase in plasma volume following the 12 exposures over 3 weeks.[76] In comparison, plasma volume increased by ~1% per day in semi-professional soccer players following 6 days of heat acclimatisation where sports-specific training was maintained,[20] and ~1% in elite males rowers following 5 consecutive days of laboratory-based heat acclimation.[9] In contrast, only one study has investigated the potential of sauna exposure prior to exercise. Five days of 20 min passive rest in 50°C, 30% RH for subjects wearing a vinyl sauna suit prior to 90 min of exercise in hot conditions effectively reduced resting and exercising core temperature and heart rate by 0.28–0.42°C and 10–12 $b{\cdot}min^{-1}$, respectively.[50] The onset of sweating, RPE and thermal sensation were reduced and plasma volume increased by ~9% in the heat condition compared to participants in the temperate condition.[50]

Passive heat exposure via hot water immersion or sauna bathing either independently, or combined with exercise in hot or ambient conditions, has the potential to initiate physiological and thermoregulatory adaptations similar to those achieved by active heaty training alone.[72] As with any new training stimulus, especially one known to unfavourably impact the body's natural homeostasis, it is recommended that physiological and thermoregulatory markers be monitored throughout passive heat sessions to ensure athlete wellbeing and assess the adaptive process.[30] In a real-world sporting context, these passive methods of heat exposure present practical and efficient alternatives to traditional heat training methods when time for exposure is limited, sports-specific training cannot be undertaken in hot environments, and there are large player numbers to manage (team sports). These methods also offer a means of extending total heat exposure duration without the need to unnecessarily increase musculoskeletal load in athletes.

Heat acclimation summary

Repeated exposure to natural or artificially hot conditions results in a range of physiological, thermoregulatory, metabolic and perceptual adaptations that alleviate heat stress and enhance performance in hot and potentially also cool conditions. Compared to traditional heat training, contemporary methods are more compressed with fewer sessions, are shorter in duration, and involve high-intensity exercise. However, there appears to be a central compromise and that is the degree to which physiological and thermal adaptations are achieved. A number of studies have shown that full heat acclimation is unlikely to be obtained following short duration, intermittent heat-training programs.[15,38,39] Compared to lengthy traditional heat interventions, it is clear that short-term programs are preferred for team sports. Likewise, alternative exposure methods such as hot water immersion or sauna bathing also present practical substitutes for active heat exposure for team sport athletes.

Prescribing heat training should not be viewed as a "one-size fits all" approach, given the multiplicity of factors that have the potential to influence both physiological and performance outcomes. Possibly the most important factor is the unique inter-individual response, in that no two athletes (or teams) will likely respond to the same heat program in the same way.[30,77] There have been several preliminary recommendations on how to best implement heat training for individual and team sport athletes,[5,6,30] under "real-world" circumstances. However, it will ultimately come down to how performance staff can manipulate the training variables (number of sessions, frequency of exposure, sessions duration, intensity, temperature) within the constraints of their environment. Understanding how each athlete within the team responds to heat stress will assist practitioners in tailoring suitable programs for each athlete,[30] whether that be active heat, passive or a combination of active and passive heat exposure.

Developing pragmatic heat training strategies for team sports

Heat training is not a one-sided model as there is no single protocol that would facilitate optimal physiological or performance benefits across a variety of sports.[5] While heat training has the potential to be integrated in a team sport context, the challenge is doing so without compromising sports-specific priorities. Currently, evidence-based guidelines surrounding heat training are directed at athletes seeking to achieve heat acclimation in preparation for competition in hot environments. However, despite the interest from team sport staff and athletes there is little information on how to practically implement heat training in a real-world setting. To enhance the practical relevance of heat training for team sports, manipulating the length of the protocol, frequency and duration of exposures, exercise intensity and environmental conditions will highlight how these variables can be customised to better suit teams. As passive heat exposure has emerged as a practical alternative to active exposure, it too should be considered as an attractive option for team sports.

Protocol duration and frequency of exposure

During the pre-season phase of the training plan when the focus is on regaining fitness[29] and time is available, heat-based training camps are a viable option. Alternatively, if based in naturally hot locations during this phase, outdoor training sessions could be strategically programmed to occur during the warmer parts of the day. These medium-long-term programs/camps[18,19] offer a two-fold benefit: fast-track fitness adaptations replicating those induced by heat acclimation, and maintenance of sports-specific training to develop skills and tactics. For teams that reside in cooler climates or those not wishing to commit to these camps for logistical and/or financial reasons, local laboratory-based options are desired.

It is well accepted that longer protocols of 8–14 consecutive heat exposures yield larger thermoregulatory and physiological adaptations.[5,6] These longer programs are likely more feasible and appropriate when conducted during the pre-season phase. However, it is clear that this style of heat-based training is not often practical for team sports. Irrespective of whether 8 x 33–47 min high-intensity exercise sessions were undertaken consecutively or every other day for 16 days, improvements in work and power output during repeat sprint cycling only slightly greater following consecutive (8 days) exposure.[39] In-season heat interventions in particular are often reduced to 4–5 sessions distributed over several days,[13,14,41] allowing the continuation of sports-specific and weights training sessions.

Although a more practical approach, it is important to note that heat exposure every 2–3 days may take up to a full month to fully induce physiological adaptations consistent with more frequent exposure.[15,39,64] On the contrary, 2 x 45 min low-intensity cycling sessions per day, did not offer any faster gains than 1 x 45 min session per day for four consecutive days.[71] As a conditioning method programmed to be undertaken in combination with sport-specific training, intermittent heat exposure presents a more viable option for teams than a consecutive day program.

Session duration and exercise intensity

In recent years there has been a trend for the total number of heat sessions within a program to decline from 8–14 to <7 sessions. Individual heat exposure duration has also become as short as 27 min per session. An initial investigation comparing 7 x 35 min of exercise at 75% VO_{2max} in ~40°C induced a similar physiological and thermoregulatory adaptations to 60 min of exercise at 50% VO_{2max}.[46] To compensate for fewer and shorter duration sessions, the exercise intensity is typically increased. Five short 27 min sessions (3 x 5 min bouts with 30 s alternating intervals of 90% and 30% VO_{2peak}) across 9 days in ~39°C, 35% RH was implemented during the Australian Football League competitive season to assess the efficacy of a time efficient and pragmatic protocol for facilitating heat adaptation.[13] Inducing a partial adaptive response, this brief program was considered to be efficient and non-disruptive in terms of its application and implementation in a "real-world" setting.[13] In other laboratory studies involving team sports, sessions range from 30–50 min in duration[12,14,38,39,41] for a total of 150–340 min of accumulated heat exposure (number of sessions x session duration). In heat training studies pertaining to team sports, exercise is typically characterised by multiple sets (8–10) of repeat high-intensity efforts interspersed with brief periods of low-intensity activity (cycling or running).[12-14,38,39,41] A reduction in total session duration may warrant an increase in exercise intensity to provide a greater relative intensity for players. However, the absolute workload should be increased over the intervention duration to ensure the stimulus for elevating core temperature and sweat response remains constant[17] when integrated with other forms of training.

While shorter sessions involving high-intensity exercise or repeat sprint efforts have the potential to facilitate fast-tracked adaptations, it is important to consider the implications of this type of training when undertaken in addition to sports-specific training. A comparison of short, high-intensity (5 x 30 min sessions of 3 min intervals at 70% peak power output) and longer, low-intensity (5 x 90 min sessions at 40% peak power output) cycling indicated that laboratory-based heat training could be sport-specific.[42] For example, 90 min of low intensity cycling had a greater impact on endurance time trial performance, whereas a 30 min protocol was more favourable towards enhancing anaerobic variables. Depending on the phase of the season, these findings could inform the type of exercise team sport players should undertake during heat training when the aim is to enhance aerobic capacity or anaerobic characteristics.

It has been suggested that different forms of high intensity and repeated sprint interval training can also have different impacts on aerobic and anaerobic outcome measures when implemented in addition to sports-specific training. Specifically, intense intermittent running coupled with a high aerobic load comprising 2–3 sets of 5 x 30 s jogging, 20 moderate speed and 10 s maximal effort (10-20-30 concept[78]) can increase Yo-Yo Intermittent Recovery Test Level 1 by ~18% (330 m) in sub-elite football players.[79] Whereas, short-duration sprint interval training involving 2–3 sets of 6 x change-of-direction running sprints (maximal effort) for 6 s, interspersed with 54 s recovery is more favourable towards improving 30 m sprint time and change of direction agility test (*T* test) than Yo-Yo Intermittent Recovery Test Level 1.[79] Although high-intensity exercise presents a time efficient means for facilitating meaningful performance improvements, it is not without some concern. Significant impairments in exercise capacity (cycling time to volitional exhaustion task) following 5 (days) x 30 min high-intensity interval sessions in the heat were attributed to cumulative fatigue, maladaptation and minimal recovery time between sessions in well-trained cyclists/triathletes.[80] In comparison, neuromuscular discrepancies have been reported following 5 days x 90 min steady-state heat training sessions, possibly indicating signs of peripheral fatigue.[42] Appropriate consideration should be given to the possible impacts of high-intensity interval training programs in the heat on other forms of training, and vice versa to avoid overtraining and excessive fatigue.

Environmental conditions

When heat training is undertaken to facilitate thermal adaptation for specific environments, environmental conditions should mimic or slightly exceed the anticipated competition conditions.[6] Alternatively, if adopting heat training as a conditioning method, laboratory and/or climatic chamber conditions typically range between 30–40°C, 20–60% RH.[30] In conditions where ambient temperatures are high and relatively humidity low, evaporative sweat loss is the body's primary heat loss mechanism for maintaining thermal equilibrium.[7] Whereas, in conditions with low ambient temperature and high relative humidity, evaporative sweat loss is impaired due to the inability of the sweat to dissipate from the skins surface and cool the body. Thus, training in hot/dry conditions has the potential to confer benefits in hot/wet conditions.[81,82] Due to the physiological and biophysical differences between hot/dry and hot/humid conditions, it is likely that different physiological and thermal adaptations may develop.[7,69] Generally, a WBGT of ≥30°C is deemed sufficient for facilitating thermal and physiological adaptation.[17] Depending on the circumstances, when short-term heat training programs are intermittent in nature and each session is <60 min, hotter environmental conditions would be encouraged to promote adequate thermal stress required to facilitate physiological adaptations.

Passive heat exposure

Active heat training is considered best practice for inducing physiological and performance benefits. However, there are several challenges that often prevent team sport players from using this strategy. Alternatively, hot water immersion and sauna bathing have gained attention for their capacity to elicit desirable physiological adaptations[51,52,72,76] and in some cases performance improvements.[51,67] Hot yoga has also been proposed as an appealing alternative to active heat exposure. Six x 60 min yoga sessions in ~30°C, ~48% RH resulted in a 3.5% increase in plasma volume, small meaningful improvements in running performance at ventilatory threshold 1 and 2, and positive adaptations in the respiratory exchange ratio during high-intensity exercise in elite female hockey players.[83] Hot water immersion and sauna bathing techniques have been used in isolation independent of exercise[74,75] or in conjunction, before[50] or after[51,52,67,76] exercise. These methods are particularly appealing for teams residing in cooler climates as they are easily accessible, impose minimal musculoskeletal load. and depending on the size of the facility, can comfortably accommodate an entire team simultaneously.

Pragmatic applications in team sports summary

Team sports training is complex and presents several challenges when developing the annual training plan and prescribing individual sessions. Heat training offers potential for fast-tracking fitness, physiological adaptations and enhancing performance in team sport players. Although short-term interventions are seemingly more suited to teams, pragmatic strategies for implementing these types of interventions in a real-world context remain under-explored. When contemplating heat training there are several factors that must be considered, and there is no single protocol that facilitates substantial benefits for all athletes across a variety of sports.[5] It is not surprising that sports-specific training priorities, logistics, time and residential location often outweigh the ability to implement best practice heat training programs[30] within a team sport setting. It is ultimately the customisation and interaction of the protocol length, frequency and duration of exposure, exercise intensity and environmental conditions that will influence design and implementation approaches for coaches and conditioning staff. Nevertheless, whether heat training is undertaken for conditioning or specific acclimation purposes, the protocol should complement normal training as much as possible. For teams, the heat training program should be designed so it can easily be repeated at different times throughout the various phases of the seasons,[30] and the benefits transfer to sports-specific training and games. Finally, given that team sports participate in several different forms of training simultaneously, performance staff should carefully consider the impact heat exposure (passive or active) may have on regular training (and recovery) during discrete phases of the season.

Conclusion

Heat training has become increasingly popular among team sports, in particular the different football codes (i.e. Australian football, soccer, and rugby). When scheduled into the annual training plan and budget constraints permitting, traveling to naturally hot locations for pre-and-in-season training camps allow teams to maintain sports-specific (field-based) training.[18-20] However, the high expense associated with moving a team (staff and athletes) around the country, or internationally to facilitate these camps has increased the desire to seek solutions for teams to undertake heat training locally. When teams are unable to travel for training camps they face several challenges for undertaking traditional heat acclimation programs in a laboratory/climate chamber setting. A key challenge is the number of players within the team, which depending on the sport can range from 12–30+ players and their general requirement to training as a group. In terms of facilitating complete physiological and thermoregulatory adaptations, traditional medium–long term protocols involving daily low-moderate intensity exercise cannot be disputed. However, their applicability and feasibility within the context of team sports can be problematic.

Repeated exposure to hot conditions facilitates an adaptive process most commonly referred to as either *heat acclimation (artificial)* or *heat acclimatisation (natural)*. These relatively rapid processes induce a number of physiological and thermoregulatory adaptations in as few as four or five sessions in team sport athletes. When heat exposure is insufficiently maintained, these adaptations can be lost as rapidly as they are gained. In past decades, heat-based training has expanded its primary purpose of acclimatising athletes to train and compete in hot conditions to enhance performance in temperate conditions. Despite some inconsistencies around whether or not heat-training improves performance in temperate conditions, there is little evidence to suggest that it impairs performance in cooler conditions and thus, can be integrated into an annual training plan.[5]

When heat acclimation is desired, the consensus is that ~60 min per day for 1–2 weeks is required to facilitate adequate adaptation and performance benefits.[6] However, several investigations have diverted from this recommendation to manipulate the key training variables (exposure duration, frequency, exercise intensity, exercise duration and environmental conditions) to modernise heat training for team sports. The modern style of heat training consists of fewer sessions (4–8) involving high-intensity running and cycling[12-14,38,39,41] for shorter durations (30–50 min) performed either consecutively or intermittently. Further, alternative strategies such as hot water immersion[52,67] or sauna bathing[50,51,76] offer a practical alternative to heat exposure when player loads peak or reduced running volume is desired.

Heat training is largely diverse offering a number of pathways to facilitate physiological adaptations and performance benefits. While no two pathways would return the same benefit, heat training has the potential to be customised to best suit the purpose and timing of implementation within the team. Whether it is required during the pre-season, in-season or for specific heat acclimation, rapid fitness gains, promoting athlete rehabilitation, or improving performance in cooler environments, heat-training should be tailored accordingly to meet the needs of the athlete and/or team. A compromise between well-established traditional heat training practices and real-world feasibility is likely required. Insight into how the key variables can be manipulated in a laboratory setting during the pre-and-in season phases of an annual training plan would be advantageous for team sports. Thus, the purpose of this thesis is to manipulate and combine elements of traditional and modern heat training practices to explore more pragmatic short-term heat training options for team sports that can be easily applied in a real-world context. Specifically, a short-term mixed-mode heat training intervention during the pre-season will be explored in Chapter 3 to evaluate its influence on endurance running and thermal tolerance in state-level Australian football players. Subsequently, the utility of short effort, repeat sprint training in the heat combined with passive heat exposure to enhance player conditioning, running capacity and thermal adaptations will be evaluated in Chapter 4.

Chapter 3: Mixed-mode heat training: A practical alternative for enhancing aerobic capacity in team sports

Abstract

Heat training can be implemented to obtain performance improvements in hot and temperate environments. The effectiveness of such interventions for team sports during discrete periods of the season remains uncertain. We investigated the effects of a short pre-season heat training intervention on fitness and thermal tolerance. In a counterbalanced crossover design, eleven state-level male football players undertook 6 x 60 min sessions in HEAT (35°C, 50% RH) and TEMP (18°C, 50% RH) conditions over 12 days. Running performance pre- and post-intervention was assessed via the Yo-Yo (IRT1), and thermal adaptation using a submaximal (4 x 4 min @ 9–13 $km{\cdot}h^{-1}$) treadmill heat stress test in 35°C, 50% RH. Running distance increased by 9, ±9% in HEAT (standardised mean, ±90% confidence limits) and 13, ±6% in TEMP, the difference in the mean change between conditions was unclear (0.24, ±0.64 standardised mean, ±90% confidence limits). Irrespective of training interventions, there was an order effect indicated by a substantial 476 ± 168 m increase in running distance between the first and final Yo-Yo tests. There were trivial to small reductions in heart rate, blood lactate, RPE and thermal sensation after both interventions. Differences in mean core and skin temperature were unclear. A large training effect and few clear differences between HEAT and TEMP indicate conditioning in the heat appeared to offer no additional benefit to that of training in temperate conditions. Six heat training sessions were insufficient to induce clear thermal adaptations further to those attained in temperate conditions.

Keywords: hot, football, fitness, pre-season, running

Introduction

Physiological, thermoregulatory and performance benefits associated with repeated heat exposures are well documented.[7,16] However, uncertainty remains on how, and when to implement short-term heat training interventions within team sports. Despite the appeal and apparent ease of implementation, the recommended >7 x 90 min sessions[6,7] performed daily are often not practically achievable within a team sport setting. Given the multifactorial nature of team sports, weekly competition schedules, number of athletes, travel demands, and off-field commitments, coaches and high-performance staff seek pragmatic guidance on how best to tailor traditional heat training regimes to better suit their athletes.

Characteristic thermal adaptations including improved cardiovascular stability, skin blood flow, sweating efficiency, thermal tolerance and reductions in core and skin temperatures[7,16] often develop rapidly. One key difference between traditional medium (8–14 days) to long (>15 days) term and short-term (<7 days) protocols is the total amount of accumulated heat exposure. Total exposure time among short-term regimes involving team sport players (both consecutive and non-consecutive) ranges from 135 to 324 min.[12-14,38,39,84] These short-term regimes are noticeably shorter than traditional medium- to long-term protocols varying between 450 to 900 min.[4,44,57]

Despite being more practical for teams, non-consecutive heat exposure is likely to limit the opportunity to facilitate thermal adaptation, thus compromising the magnitude of physiological change. Compared to 10 x 30 min bouts of consecutive day heat exposure, 30 min every second day for a total of 10 sessions is less effective in acquiring thermal adaptations than consecutive exposures.[15] Similarly, there were few consistent changes in thermal adaptation markers following 8 x 33–47 min high-intensity cycling sessions conducted consecutively and intermittently over 16 days.[39] Furthermore, eight sessions across 16 days seem equally as effective (as sessions performed consecutively) in improving total work and mean power output in team sport players during a repeat-sprint cycling heat tolerance test compared to baseline.[39] It seems non-consecutive, short-term heat training programs have the potential to be integrated into a team sport setting without compromising sports-specific objectives that might otherwise occur with a consecutive day intervention. However, this may occur at the expense of facilitating complete thermal adaptation.

Heat exposure triggers physiological adaptations that are comparable and often additional to those induced by regular exercise training that, in turn could facilitate performance gains in cooler environmental conditions.[3,4] If heat acclimatisation is not the intended (primary) outcome, intermittent heat exposures could offer additional conditioning benefits for team sports. Undertaking conditioning activities in hot environments could offer an additional stress to regular sessions which players would be unaccustomed to. This training intervention could promote physiological and/ or performance benefits before and during the regular competitive season. With up to 72 h between exposures being the suggested threshold for offering the potential preservation of adaptive responses,[44] non-consecuitive heat exposures may also be effective in reducing residual fatigue while simultaneously providing a stimulus for enhanced performance.[84] Cumulative fatigue and insufficient recovery following five consecutive days involving 30 min of high-intensity cycling undertaken in conjunction with regular cycling training may have contributed to impaired exercise capacity during subsequent performance in hot condtions.[80]

The physiological and performance benefits associated with traditional heat training practices are well researched. However, there are questions regarding the scheduling and periodisation of heat training regimes among athletes,[30] particularly for team sports. Cycling-based interventions appear to be the preferred mode of supplementary training for a range of team sports players,[38] as practitioners seek to maintain fitness and performance without unnecessarily increasing total running volume and risk of injury.[12,38] Therefore, a combination of stationary cycling with small bouts of treadmill running, to maintain an element of sports specificity could be an appealing method for gaining supplementary fitness benefits in team sport players.

The purpose of this investigation is to evaluate a pragmatic heat training intervention during the pre-season that would be simple to implement and realistic within a team sport setting. Professional teams often travel to warmer locations for pre-season camps or Australian senior national teams for pre-departure camps prior to international tour and competition in the warmer Northern Hemisphere. Given the logistical and financial implications of these camps, coaches and performance support staff seek practical alternatives that can be engaged in home locations. If player fitness and conditioning can be regained in a shorter timeframe following the off-season period by these kinds of short-term heat training interventions, coaches should have more time for skill development and sport-specific training sessions. This information would clarify for coaches whether supplementary conditioning sessions performed in the heat offers fast-tracked fitness and/or performance benefits and thermal adaptation in state-level Australian Rules Football players during pre-season training.

Methods

Participants

Twelve male state-level Australian Rules Football players (age 24.8 ± 5.4 y, body mass 85.1 ± 10.5 kg, height 1.81 ± 0.68 m; mean ± SD) from the same team volunteered for this study. One participant withdrew due to interstate relocation resulting in 11 players completing the study. All players had a sub-elite training history of at least 3 years, with a minimum 4 hours on-field training per week during previous pre-seasons. Participants were concurrently engaged in the team's annual 10-week pre-season block. They were required to maintain normal football training sessions (3 x 90 min sessions$\cdot$wk^{-1}) and advised to avoid any additional training outside the study. The study was conducted in the late Southern Hemisphere summer and early autumn (~28 ± 1°C; mean daily maximum temperature across study duration). All participants provided written informed consent. The study was approved by the University of Canberra's Human Research Ethics Committee (Project number 15-44).

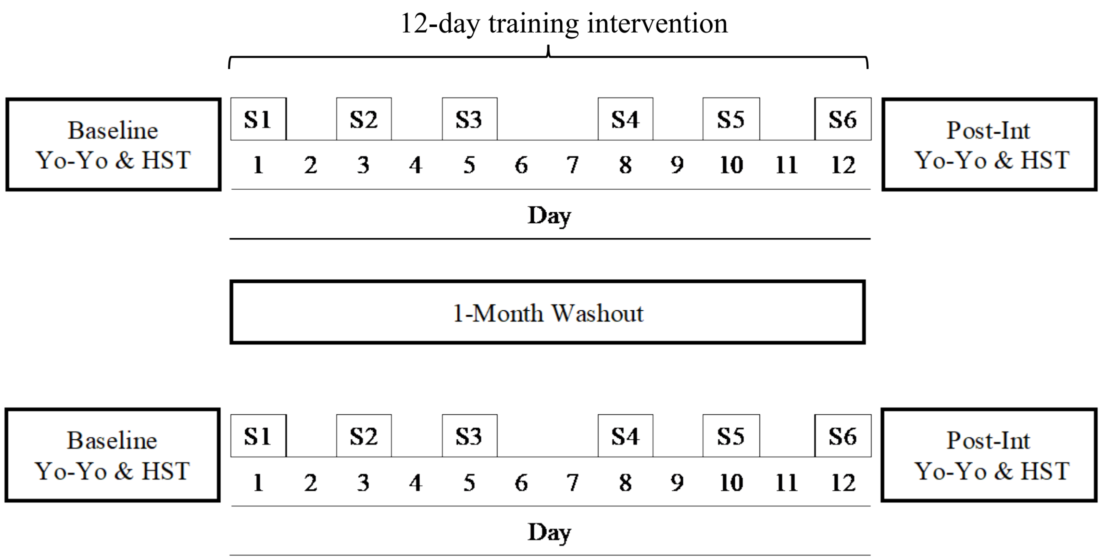
Study Design

Participants undertook a counter-balanced crossover design requiring them to complete two separate training interventions (T1 & T2) either side of a 4-week washout period (no intervention). All participants completed 6 x 60 min training sessions (3 sessions$\cdot$wk^{-1}) over 12 days (Figure 3.1). Participants were randomly assigned to complete T1 in HEAT (n=6; target temperature 35°C, 50% relative humidity; RH) or TEMP (n=5; target temperature 18°C, 50% RH) conditions. Before and after each 12-day intervention, participants completed the Yo-Yo Intermittent Recovery Test Level 1 (IRT1) to assess running performance and a submaximal heat stress test to assess thermal adaptation. All participants maintained regular field-based football specific training two days per week (~90 min per session) during the washout period. Participant training loads were not directly measured during the washout period. After the one-month wash out period, participants completed the second training intervention (T2) in the opposite condition to the first trial. All training sessions took place in a climate-controlled environmental chamber (Altitude Training Systems, Lidcombe, NSW, Australia).

Performance and Physiological Testing

The Yo-Yo (IRT1) was performed on an indoor running track at the same time of day in warm ambient conditions (25 ± 3°C, 54 ± 9% RH) to assess endurance running performance.[85] The test was performed as a group and participants were asked to continue running until they could no longer maintain the target running speed. Encouragement was standardised for each Yo-Yo test.

Figure 3.1. Schematic overview of the crossover study design. Yo-Yo Intermittent Recovery Test Level 1 (IRT1); HST – Heat stress test; S1-S6 refers to the six training sessions.



A heat stress test (HST) was conducted to assess physiological adaptations to the heat training sessions. Participants completed a submaximal HST on a treadmill (TrackMaster TX55, Trackmaster Inc, Newton, KS, United States) in hot conditions (35 ± 2°C, 48 ± 12% RH). This test was adapted from a traditional VO_{2max} protocol.[86] After a 5 min warm up (3 min @ 6 $km{\cdot}h^{-1}$ and 2 min @ 10 $km{\cdot}h^{-1}$), participants completed four or five submaximal running stages of 4 min in duration. Each stage was separated by 1 min rest in which the participants were instructed to remain stationary on the treadmill (straddling). Each stage was fixed at 9, 10, 11, 12 and 13 $km{\cdot}h^{-1}$ (1% gradient) respectively. When blood lactate was <4 mmol/L and Rating of Perceived Exertion (RPE, 6–20 scale) was <16 after the fourth stage participants completed a fifth stage. Eight of the eleven participants completed the 5th running stage at 13 $km{\cdot}h^{-1}$. The number of stages completed during the initial HST was kept consistent for each individual for the subsequent three HST tests.

During each 1 min rest period between stages, heart rate (HR), core temperature (T_c), skin temperature (T_{sk}), blood lactate, RPE and thermal sensation (TS) were recorded. The completion of 4 stages equated to 30 min within the heated environment and 35 min for those who completed 5 stages. Temperature and humidity were monitored using a pocket weather meter (Kestral 4000 Nielsen-Kellerman, PA, USA) fixed to a portable tripod. Participants were permitted a maximum 600 mL of water (actual consumption: HEAT 260 ± 170 mL; TEMP 320 ± 210 mL) to consume ad libitum throughout the test.

Training Interventions

The training interventions involved 6 sessions each, undertaken every second day (Mon/Wed/Fri) over 12 days in either HEAT (34.4 ± 2.2°C, 56.6 ± 3.1% RH) or TEMP (17.8 ± 0.7°C, 64.7 ± 2.5% RH) conditions. All sessions took place within a climate controlled environmental chamber. After a 5 min warm up, participants completed 5 x 8 min efforts interspersed with 3 min of passive rest. Participants elected to warm up on the Wattbike (Wattbike Ltd, Nottingham, England; air resistance level 1 @ 90 rpm) or treadmill (same ergometer as HST; 3 min @ 6 $km \cdot h^{-1}$ and 2 min @ 10 $km \cdot h^{-1}$). Thereafter, participants alternated between the Wattbike (2.0 $W \cdot kg^{-1}$; individualised per participant) and treadmill (2 $km \cdot h^{-1}$ below final HST speed achieved) for 5 x 8 min efforts (i.e. 3 Wattbike & 2 treadmill efforts). The total session duration was 60 min and was completed at the same time of day. Participants were permitted a maximum 600 mL of room temperature water (actual consumption: HEAT 415 ± 205 mL; TEMP 365 ± 160 mL) to consume throughout the session.

Physiological Measures

Body mass was recorded before and after the HST and each training session using pre-calibrated scales (FG-150KAL Platform Scales, A&D Weighing Australasia Pty Ltd). Participants were weighed wearing sports shorts only and instructed to towel off as much sweat as possible before the post-exercise measurement. Heart rate was monitored continuously throughout all sessions using Firstbeat Sports analysis software (Firstbeat Technologies Ltd, Jyväskylä, Finland). Four hours before the HST participants ingested a telemetric temperature sensor (CorTemp, HQ Inc., Palmetto, FL, United States) for assessment of T_c. Skin temperature was assessed on the right, anterior side of the body at the chest, thigh, bicep, and posterior calf (iButton, Maxim Integrated, San Jose, CA, United States). Mean T_{sk} was calculated using the Ramanathan equation.[87] A 5 μL capillary blood sample was taken from the finger tip for analysis of blood lactate using a portable Lactate Pro analyser (Arkray Inc., Kyoto, Japan). HR, T_c, T_{sk} and blood lactate were assessed at rest and during each 1 min rest period of the HSTs. Heart rate was recorded after each 8 min effort during the environmental training sessions.

Perceptual Measures

Participant's self-rated their RPE using Borg's 6–20 scale[88] and TS on Young's 8 point (0 unbearably cold – 8 unbearably hot) Likert scale.[89] RPE and TS were recorded 5 min after completion of the Yo-Yo IRT1, at rest and during the 1 min rest periods of the HST, and after each 8-min effort during training sessions.

Statistical Analysis

Descriptive data are presented as mean ± SD. All raw and derived data were collated, checked for outliers and corrected for any errors. Data modeling involved point estimation of Yo-Yo test response and thermal adaptation markers (heart rate, core and skin temperature, RPE and TS) to heat training, and confidence interval estimates of the uncertainty about the value of these parameters.[90] Data was log-transformed, then back-transformed to obtain changes in means and variation as a percent. Sample size estimation indicated 12 subjects in each condition (HEAT and TEMP) was sufficient to employ a crossover group design to confidently detect a 200 m change in Yo-Yo total distance covered (reference change) assuming a typical error of 160 m, and Type I and II errors of 5 and 20% respectively. Within- and between-participant variability in Yo-Yo and thermal markers are reported as the % coefficient of variation (%CV). The magnitude of change between the standardised means (ES) was interpreted against the following criteria: <0.19 trivial, 0.2-0.59 small, 0.6-1.19 moderate, 1.2-1.99 large and >2.0 large.[91] Precision of estimation was determined using 90% confidence limits (CL). When the magnitude of the standardised effect crossed the threshold of ±0.2 the change or difference was deemed unclear.

Results

Performance Outcomes

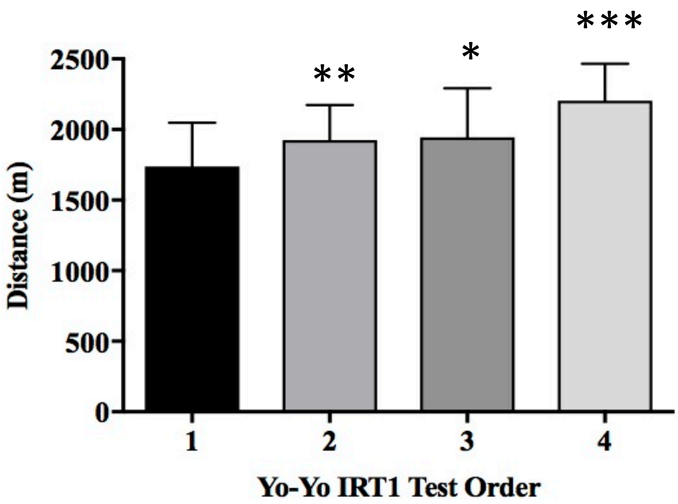
Both HEAT and TEMP conditions yielded small to moderate improvements in Yo-Yo IRT1 level and total distance covered after six training sessions (Table 3.1). Running distance and (consequently) final Yo-Yo level improved substantially in both groups: 149 ± 274 m (9, ±9%) in HEAT and 225 ± 156 m (13, ±6%) in TEMP. The differences in mean change between the conditions were unclear for both level and distance covered. Irrespective of the training interventions, there were small to large improvements in Yo-Yo running performance indicative of a substantial training effect from the first to the final test across the study (i.e. T1 pre-test to T2 post-test). Relative to the first Yo-Yo test conducted, mean running distance increased by 196 ± 305 m during the second test (0.61, ±0.53 standardised change, ±90%confidence limits), 207 ± 421 m (0.59, ±0.70) during the third test and 476 ± 168 m (1.31, ±0.30) in the fourth test (Figure 3.2).

Table 3.1 Yo-Yo Intermittent Recovery Test Level 1 (IRT1) performance, physiological and perceptual variables between baseline and post-intervention for HEAT and TEMP conditions. Mean ± SD or mean, ±90% confidence limits as specified.

	HEAT				TEMP				Difference in change in means
	Baseline	**Post-Intervention**	**ES, ±90% CL**	**Magnitude**	**Baseline**	**Post-Intervention**	**ES, ±90% CL**	**Magnitude**	**ES, ±90% CL**
Yo-Yo IRT1 (Level 1)	18.5 ± 1.0	19.1 ± 0.7	0.49, ±0.42	Small	18.0 ± 1.1	18.9 ± 1.3	0.65, ±0.26	Moderate	0.25, ±0.50; Unclear
Distance (m)	1924 ± 318	2073 ± 208	0.43, ±0.43	Small	1769 ± 350	2035 ± 386	0.59, ±0.28	Small	0.24, ±0.64; Unclear
Heart Rate$_{max}$ (b·min^{-1})	192 ± 9	190 ± 8	-0.25, ±0.23	Small	192 ± 9	191 ± 7	-0.30, ±0.12	Small	-0.08, ±0.35; Unclear
RPE	17 ± 1	18 ± 2	0.48, ±0.51	Small	17 ± 1	18 ± 1	0.83, ±0.56	Moderate	0.37, ±0.79; Unclear
Thermal Sensation	7 ± 1	6 ± 1	-0.91, ±0.79	Moderate	6 ± 1	6 ± 1	0.02, ±0.58	Unclear	1.03, ±1.58; Unclear

IRT - Intermittent Recovery Test; RPE – rating of perceived exertion; ES – effect size; CL – confidence limits.

Figure 3.2. Order effect of changes in Yo-Yo Intermittent Recovery Test Level 1 (IRT1) running performance relative to the first test. *Small, **Moderate, ***Large effect (Effect Size, ±90% Confidence Limit) relative to test 1.



Physiological Outcomes

Mean HR, T_c, T_{sk} and blood lactate responses to the treadmill HST for HEAT and TEMP conditions are presented in Table 3.2. There were trivial reductions in mean submaximal heart rate during the HST in both HEAT and TEMP conditions after the six training sessions. At baseline, during the heat stress test HR increased by 35 ± 9 b.min^{-1} (143 ± 15 to 178 ± 8 b·min^{-1}) in HEAT and 37 ± 11 b·min^{-1} (145 ± 13 to 182 ± 8 b·min^{-1}) in TEMP. The mean increase in HR was similar between conditions during the post-intervention HST with a progressive increase of 36 ± 9 b·min^{-1} in HEAT and 37 ± 8 b·min^{-1} within TEMP.

Measures of thermal adaptation, T_c and T_{sk} were inconsistent between HEAT and TEMP conditions (Table 3.2). The six heat training sessions appeared to have little influence on reducing mean T_c and T_{sk} within HEAT. Both T_c and T_{sk} were ~0.2°C higher during the post-intervention HST than at baseline within HEAT. Conversely, mean exercise T_c and T_{sk} were ~0.4°C lower within TEMP after the six training sessions than the baseline trial (Table 3.2). Given the opposing differences in T_c and T_{sk}, the difference in T_c between conditions was unclear and the uncertainty of T_{sk} within HEAT and large decrease in TEMP resulted in large difference in T_{sk} between the two conditions. There was a greater reduction in blood lactate concentration in HEAT after the training intervention than TEMP (Table 3.2).

Table 3.2. Changes in physiological and perceptual variables during stages 1 to 5 of the baseline and post-intervention heat stress tests for HEAT and TEMP. Mean and SD, or mean, ±90% confidence limits as specified.

	HEAT				TEMP				Difference in change in means
	Baseline	**Post-Intervention**	**ES, ±90% CL**	**Magnitude**	**Baseline**	**Post-Intervention**	**ES, ±90% CL**	**Magnitude**	**ES, ±90% CL**
Heart Rate ($b{\cdot}min^{-1}$)	163 ± 14	159 ± 14	-0.19, ±0.03	Trivial	166 ± 15	164 ± 15	-0.13, ±0.09	Trivial	0.07, ±0.10;
Heart $Rate_{max}$ ($b{\cdot}min^{-1}$)	177 ± 14	176 ± 14			182 ± 14	181 ± 15			Trivial
T_c (°C)	37.5 ± 0.3	37.7 ± 0.3	0.40, ±0.18	Small	37.8 ± 0.2	37.4 ± 0.4	-1.84, ±2.06	Unclear	-1.39, ±0.98;
$T_{c\ max}$ **(°C)**	37.9 ± 0.3	38.1 ± 0.3			38.0 ± 0.2	37.9 ± 0.4			Unclear
T_{sk} (°C)	35.4 ± 0.2	35.6 ± 0.4	0.97, ±1.21	Unclear	35.8 ± 0.3	35.4 ± 0.4	-1.31, ±0.50	Large	-1.51, ±0.48;
$T_{sk\ max}$ **(°C)**	35.5 ± 0.2	36.0 ± 0.4			36.1 ± 0.3	35.7 ± 0.4			Large
Blood lactate	3.1 ± 1.4	2.8 ± 1.3	-0.24, ±0.06	Small	3.6 ± 1.8	3.6 ± 1.5	-0.02, ±0.15	Trivial	0.30, ±0.26;
Blood $Lactate_{max}$	5.3 ± 1.4	4.8 ± 1.3			6.2 ± 1.8	5.6 ± 1.5			Small
RPE	13.3 ± 2.0	12.7 ± 2.2	-0.27, ±0.26	Small	13.7 ± 2.2	13.4 ± 1.7	-0.08, ±0.16	Trivial	0.23, ±0.39;
RPE_{max}	15.6 ± 2.1	15.2 ± 2.2			6.1 ± 2.2	15.5 ± 1.7			Small
Thermal Sensation	5.9 ± 0.7	5.6 ± 0.6	-0.31, ±0.04	Small	6.0 ± 0.7	5.9 ± 0.6	-0.10, ±0.19	Trivial	0.25, ±0.27;
Thermal $Sensation_{max}$	6.6 ± 0.7	6.4 ± 0.6			6.9 ± 0.7	6.6 ± 0.6			Small

T_C – core temperature; T_{sk} – skin temperature; RPE – rating of perceived exertion; °C – degrees Celsius; ES – effect size; CL – confidence limits

Perceptual Measures

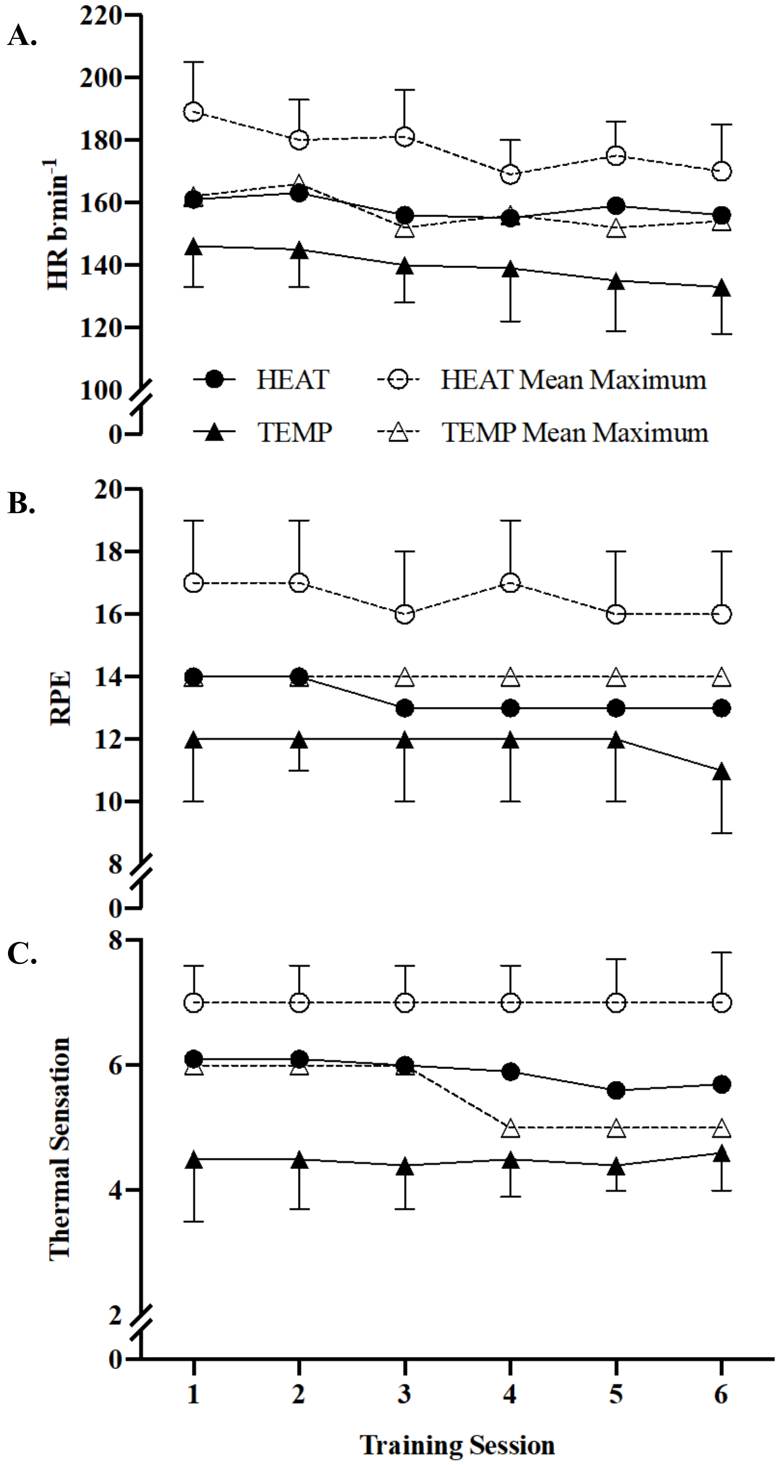
No substantial differences or changes in post-exercise RPE were observed between conditions after the baseline or post-intervention Yo-Yo IRT1 tests. While self-reported mean RPE was identical in HEAT and TEMP conditions following post-intervention trials, participants in both conditions ran further following the post-intervention Yo-Yo test compared to baseline but at a similar perceived RPE to baseline (i.e. players completed more work at a similar perceived load to baseline; Table 3.1). There were no substantial changes in TS between conditions after the six-training sessions. Participants in the HEAT condition reported feeling moderately cooler after the post-intervention Yo-Yo IRT1 test (ES -0.91, ±0.79; Table 3.1).

Self-reported RPE and TS for HEAT and TEMP conditions during the HST are presented in Table 3.2. Mean exercise RPE was lower after the post-intervention HST in both conditions but declined further in the HEAT condition. Both HEAT and TEMP conditions displayed similar increases in RPE from stage 1 (10–11, "light") through to 4 or 5 (15–16, "hard") of the HST during baseline and post-intervention trials. Perceived TS was lower after HEAT than TEMP training during the post-intervention HST. The six heat training sessions were more effective in reducing self-reported RPE and TS during submaximal exercise than TEMP training (Table 3.2).

Training Interventions

Reductions in exercising HR were unclear. Exercising HR progressively declined during both HEAT and TEMP training interventions from session one to six by ~5, ±14 and ~11, ±17 $b \cdot min^{-1}$ respectively (mean difference ES -0.45, ±0.99; Figure 3.3). Reductions in mean exercise HR were observed by the third training session compared to the first in both HEAT and TEMP conditions; however, differences between conditions were unclear (ES -0.13, ±0.49). While there was little change in RPE between the conditions (HEAT -0.8, ±1.2; TEMP -0.7, ±1.0; ES 0.00, ±0.45), perceived TS during exercise was lower in HEAT. No clear changes in TS were observed within the TEMP condition (Figure 3.3).

Figure 3.3. Changes in mean and maximum A) heart rate, B) RPE and C) thermal sensation after the six training sessions for HEAT and TEMP conditions (mean ± SD).



Discussion

When superimposed with sports-specific field training during the pre-season, supplementary conditioning sessions performed in HEAT and TEMP conditions resulted in small improvements in endurance running performance. The sessions performed in the heat did not offer any additional performance benefits above those attained by training in temperate conditions. Irrespective of the intervention conditions (HEAT and TEMP) and relative to the first Yo-Yo test, there was a 28% improvement in running performance after the final test indicating a substantial training effect. In this case, moderately fit team sport players benefited more from the additional fitness training than training specifically in the heated conditions. The six heat training sessions induced small reductions in blood lactate, RPE and TS during the post-intervention submaximal running test compared to TEMP. There were minimal signs of thermal adaptation in the HEAT condition after the intervention.

While other studies have undertaken non-consecutive heat exposure,[13,39,41,84] to our knowledge, this is the first study to employ a mixed-mode (running and cycling) intervention. In contrast to traditional heat training studies where participants have run/walked and cycled for prolonged periods of time; team sport players are unlikely to sustain similar continuous efforts. We maintained an element of sports specificity through the inclusion of treadmill running due to the large majority of team sports being running-based. Stationary cycling was incorporated to maintain cardiorespiratory load, reduce musculoskeletal load and avoid risk of injury that may be associated with prolonged treadmill running.[38] When matching exercise intensities across the two exercise modes (treadmill running and stationary cycling) for the training sessions, it is likely the prescribed training intensity was not high enough to evoke sufficient thermal stress required for adaptation. At the time of the study and with a moderate level fitness, it is unlikely that participants would have been able to sustain higher intensity exercise without potentially increasing injury risk and symptoms of overtraining. The combination of treadmill running, and stationary cycling was well tolerated by the players. This mixed-mode approach offers variety in comparison to the monotony of prolonged treadmill running or stationary cycling, something which team sport players are not often accustomed to.

In terms of offering a year-round opportunity for teams to engage in heat training, laboratory (artificial) heat exposure provides a useful and relatively accessible means to do so. Although some recommendations are clearer than others, uncertainty remains around the precise combination of training variables (frequency, intensity, duration and number of exposures) for prescribing heat training.[17,35] For team sport players, there appears to be merit in mixed-mode training and performance testing. A small number of studies, including this one had participants complete a cycling intervention (or in our case, cycling and running) and subsequently a running-based performance test.[12,38] Five x 50 min supplementary cycling-based training sessions at 70% heart rate reserve in hot or cool environments yielded small improvements in high-intensity intermittent running abilities in state league Australian football players.[12] A study involving senior club-level cricket players undertook 4 x 30–45 min cycling training sessions coupled with subsequent running-based tests to ensure sports-specificity was maintained.[38] The likelihood of team sports undertaking a running-only heat training intervention is not high. Therefore, a combination of mixed-mode testing and training could be an effective means of ensuring performance benefits transfer back to the field or court.

The 12-day heat training intervention in this study provided 360 min of total heat exposure. This offered an additional 110 min beyond previous short-term regimes involving team sport players accumulating around 250 min of total exposure time.[12,41] This is 36 min extra compared to a recent study utilising Australian football and soccer players that similarly reported mild thermal adaptation.[39] Despite the additional heat exposure, differences within but not between conditions align with other reports where changes in intermittent running performance were trivial or unclear following short-term heat training.[12,38] Likewise, the non-consecutive nature of heat exposure may have contributed towards the variable trivial-small thermal adaptations observed. Although this project set out to develop a pragmatic means of utilising heat-based training as a conditioning tool for team sports, the protocol implemented was shorter than the traditionally recommended >7 (consecutive) x 90 min sessions. Given the relatively low fitness level among participants, the potential for thermal adaptation to develop was likely obscured by training load-related improvements in fitness. It appears the additional training favoured improvements in running performance, as identified through the Yo-Yo IRT1 rather than classical benefits of heat acclimation.

There was a moderate disconnection between T_c, T_{sk} and self-reported TS after the heat training sessions. Participants in the HEAT condition reported feeling cooler after the 12-day intervention despite T_c and T_{sk} increasing by ~0.2°C after the post-intervention HST. The participants in the TEMP condition reported a similar TS to baseline, however, T_c and T_{sk} were -0.4°C lower than after the post-intervention HST. Given the opposing small (clear) ~0.2°C increase in T_c within HEAT and large but unclear -0.4°C decrease within TEMP, the resulting difference in the mean change was large but unclear following the six heat training sessions. These findings are similar to those reported by Petersen et al., 2010[38] who were also unable to identify clear differences in T_c and T_{sk} between the intervention and control groups despite moderate reductions in HR and improved self-reported TS and RPE. It is possible the submaximal HST in this study was not demanding enough at baseline to sufficiently elevate T_c and T_{sk} to observe clear changes in the post-intervention trial. The trivial to small reductions in HR, blood lactate, RPE and TS in both conditions are likely accounted for by general training-induced adaptations associated with the 28% increase in endurance running performance, rather than the environmental stimulus per se.

At the time of the study, participants were simultaneously taking part in field-based pre-season training in the late summer months. To some degree the participants may have been partially acclimatised to the warmer conditions as a result (~28.1 ± 0.6°C; average daily maximum temperature across study duration). In conjunction with the participants modest fitness level and short (laboratory) heat exposure, the effects of training were favoured over thermal adaptation. While the additional six heat training sessions were successfully implemented into the pre-season training phase of the state-level participants, it is apparent that the nature of the training/heat exposure was inadequate to facilitate heat acclimation.

Conclusion

When integrated with sports-specific training, supplementary conditioning sessions in heat and temperate conditions performed every other day in state-level team-sport players were effective in enhancing player fitness. However, sessions performed in the heat offered no further performance benefit or thermal adaptations above those gained by training in temperate conditions. As indicated by the 28% increase in endurance running, in a moderately trained population, extra conditioning session may suffice during the pre-season preparation as opposed to specific heat-based training. A mixed-mode (running and cycling) protocol like the one implemented in this study is practically relevant for team sports and was successfully incorporated with routine sports-specific football training without causing disruption. Future investigations involving team sport players and non-consecutive heat training interventions should consider hotter environmental conditions (i.e. 40°C), greater exercise intensities to stimulate sufficient metabolic heat production (i.e. controlled hyperthermia or heart rate methods) and additional sessions (i.e. 8–10 sessions across three weeks).

Chapter 4: Cycling-based repeat sprint training in the heat enhances running performance in team sport players

Abstract

This study investigated the effects of integrating short-term, repeat sprint heat training with passive heat exposure and sport-specific training on running performance and general conditioning in team sport players. Thirty male club-level Australian football players were assigned randomly to: Passive + Active Heat (PAH; n=10), Active Heat (AH; n=10) or Temperate (TEMP; n=10) conditions to complete 6 x 40 min repeated sprint cycling training sessions over 12 days in 35°C (PAH and AH) or 18°C (TEMP) and 50% relative humidity. Players in PAH were exposed to passive heat (seated) for 20 min prior to commencing exercise. Physiological adaptation and running capacity were assessed at baseline and post-intervention via a treadmill submaximal heat stress test followed by a time-to-exhaustion (run capacity) in 35°C, 50% RH. Running capacity increased by 26 ± 8% PAH (0.88, ±0.23; standardised mean, ± 90% confidence limits), 29 ± 12% AH (1.23, ±0.45) and 10 ± 11% TEMP (0.45, ±0.48) compared with baseline. Both PAH (0.52, ±0.42; standardised mean, ± 90% confidence limits) and AH (0.35, ±0.57) conditions yielded a greater substantial improvement in running capacity than TEMP. Physiological measures assessed during the HSTs were trivial and small, but mostly uncertain following the two heat training interventions between baseline and post-intervention testing. In contrast, there were small to moderate reductions in RPE and thermal sensation within AH and also in both AH and PAH compared to TEMP, respectively. Where thermal adaptation is not a direct priority, a short-term, repeat sprint efforts cycling in hot conditions integrated with sports-specific training can enhance running performance in team sport players. Repeated sprint cycling training coupled with brief passive heat exposure returned greater improvements in running capacity than active heat or temperate training alone.

Keywords: football, conditioning, performance, passive heat

Introduction

Team sports involve a large number of players, are complex, and depend on the interplay of tactical, technical, physical and psychological elements.[1] Therefore, athletes and coaches are continuously seeking new efficient ways to improve general conditioning so that players can better perform during training and competition. Medium to long term (>8 days) heat training interventions known to facilitate comprehensive cardiovascular and thermoregulatory adaptations[7] typically consist of daily heat exposure involving extended periods (60–100 min) of low-intensity (50–60% VO_{2max}) exercise.[6,17] Long duration daily heat exposure in an environment where multiple elements compete consistently for training time, is time consuming and arguably not sport-specific for many team sports.[39,44] However, the logistical challenges associated with team sports often limit the capacity to systematically prescribe and schedule[92] heat-based training using traditional recommendations.

Heat training interventions have become increasingly appealing for team sports given the relatively rapid physiological responses[7] and ergogenic potential to improve performance in temperate conditions[3] following short (<7 days)[12-14] and medium term (8 days)[39] interventions. When constrained by time, short duration, high intensity interval training (HIIT) in hot conditions has been suggested as a practical alternative to lower intensity exercise for stimulating physiological adaptations.[35] Studies involving team sport players have employed a combination of consecutive (4–5 sessions)[12,38] and intermittent (4–8 sessions over 9–16 days)[13,14,41] heat exposure involving high intensity repeat sprint cycling. One study consisted of four high intensity running sessions (shuttle test) over 10 days.[14] Session duration generally ranges from 27–50 min and exercise intensities prescribed as 80–90% VO_{2max},[13,41] maximal effort[38,39] or 70% heart rate reserve.[12] Training that enhances a player's capacity to perform these high intensity efforts, and/or recover quickly would be highly advantageous come game day.[93,94] Similarly, short term repeat sprint training or HIIT in the heat could be particularly useful as a mid-season fitness and performance top-up or a preparation tool for teams residing in cooler conditions needing to travel to warmer locations during the competitive season. This type of mid-to-late season programs could also be beneficial for national teams preparing for international tour and/or competitions hosted in warmer locations. In a direct comparison between eight consecutive high intensity interval cycling sessions in the heat versus intermittently across 16 days, the latter resulted in similar improvements in work and power output during repeat sprint testing to eight sessions performed daily.[39] Moreover, heat exposure involving high intensity exercise undertaken consecutively induced cumulative fatigue and impaired subsequent performance in well-trained cyclists by ~2%[10] and ~22%.[80] One study also reported that 30 min of high intensity exercise induced greater improvements in anerobic exercise performance (vertical and countermovement jump height, sprint power output) highlighting that training specificity can influence subsequent performance outcomes following heat training.[42] Heat exposures and/or training every other day may be more beneficial for team sport athletes to allow adequate recovery between sessions.

The magnitude for heat adaptation to develop via HIIT may be lower than traditional longer term protocols.[12,13] However, passive heat exposure may offer a practical means of extending exposure duration needed to facilitate heat adaptations.. Six days of hot water immersion performed immediately following submaximal exercise in 18°C reduced resting and end of exercise rectal temperature in 18°C (-0.28°C) and 33°C (-0.36°C), thermal sensation and RPE.[67] Time trial performance was subsequently improved by 5.9% in heat but unaffected in temperate conditions.[67] Similarly, 3 weeks of post-exercise sauna bathing for 30 min increased plasma volume by 7.1% and 5 km time trial performance by 1.9% in endurance runners.[51] Passive heat is likely more accessible, better able to accommodate large player numbers, and promote physiological adaptations without the need to increase active training and subsequently musculoskeletal load. A combination of passive and active heat exposure could offer attractive mid-season fitness top-ups and performance benefits.

Heat training can be appealing to team sports in many ways. However, as there is no single strategy that would facilitate optimal benefits for different sports,[5] a compromise is likely required when designing protocols for team sports. The ability to complete more work in less time makes repeated sprint training and HIIT appealing to players and coaches. However, with player load monitoring at the forefront of high-performance sport, alternative methods of conditioning while reducing musculoskeletal load are of interest (i.e. reducing training time and adding an external stimulus such as passive heat to maintain physiological stress). This is where a combination of active and passive heat exposure for time poor team sports could become an attractive conditioning method. Passive heat exposure provides the option to rapidly elevate, maintain and/or extend imposed heat stress/load without necessarily needing to subject players to prolonged exercise in the hot conditions. The aim of this study was to evaluate the effects of a repeated sprint (cycling) heat training program with and without passive heat exposure in addition to sports-specific training on player conditioning and running capacity in team sports players. This type of mid-season program could enhance player fitness and/or prepare teams in cooler conditions to travel to warmer locations for competition late in the season.

Methods

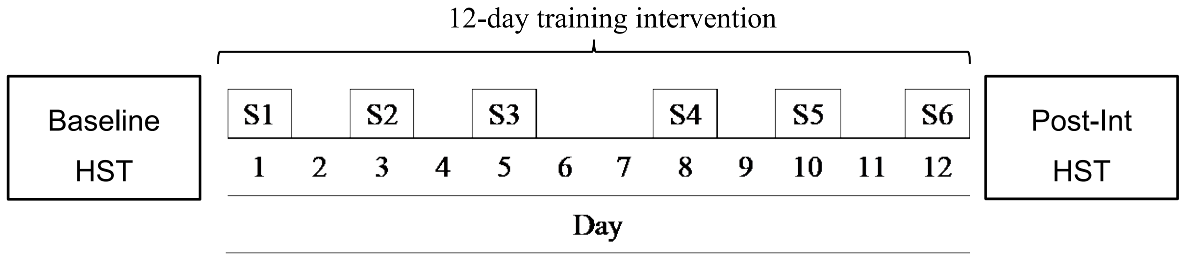
Participants

Thirty male, club-level Australian football players (age 23.9 ± 4.6 y, body mass 84.8 ± 9.7 kg, height 1.83 ± 0.07 m) volunteered for this study. All players had a sub-elite training history of ≥3 years. The study ran in parallel with rounds 16–22 of a 22-round competition. Players were advised to maintain normal field-based football training sessions (2 x 90 min skills/tactics session·wk^{-1}) and avoid any additional training outside of the study. Players played one game per week, except for rounds 18 and 21 which were bye rounds. Players were free of injury and illness and provided written informed consent. The study took place between July and September (mean monthly temperature 14.0 ± 0.9°C). This study was approved by the University of Canberra Human Research Ethics Committee (Project number: 15-262).

Study Design

In a randomised pre-post parallel, three-factor experimental design, players were assigned to either Passive + Active Heat (PAH; n=10), Active Heat (AH; n=10) or Temperate (TEMP; n=10) conditions. Players completed a running-based heat stress test (HST) within one week before and no more than 72 hours after the sixth heat training session to assess physiological adaptations and running performance (time-to-exhaustion). All players completed 6 x 40 min repeated sprint cycling sessions over 12 days (3 sessions·wk^{-1}; Figure 4.1); PAH and AH training were conducted in 35°C, 50% RH and TEMP training in 18°C, 50% RH. Players in PAH were exposed to the heated environment for 20 min prior to commencing exercise. All sessions took place in an environmental chamber (Altitude Training Systems, Lidcombe, Australia) at the same time of day.

Figure 4.1. Schematic overview of the12-day training intervention. HST – Heat stress test; S1-S6 refers to the six training sessions.



Experimental Trials

A two-stage running (TrackMaster TX55, Trackmaster Inc, Newton, United States) HST involving submaximal and maximal stages was undertaken in hot conditions (34 ± 3°C, 57 ± 12% RH) before and after heat training to assess physiological adaptation and running capacity. Adapted from a traditional VO_{2max} protocol,[86] players completed a 5 min warm up (3 min @ 6 $km{\cdot}h^{-1}$; 2 min @ 10 $km{\cdot}h^{-1}$) followed by 3 min passive recovery before 4 x 4 min running stages fixed at 9, 10, 11 and 12 $km{\cdot}h^{-1}$ at 1% gradient. Each stage was separated by 1 min rest where players were instructed to remain on (straddling) the treadmill. Heart rate (HR), core temperature (T_c), skin temperature (T_{sk}), blood lactate, RPE and thermal sensation (TS) were recorded at each rest period.

After 5 min passive recovery (inside the chamber), players commenced the time to volitional exhaustion to assess running capacity. Treadmill speed commenced at 9 $km{\cdot}h^{-1}$ (0% gradient) and increased 0.5 $km{\cdot}h^{-1}$ every 30 s until 12 $km{\cdot}h^{-1}$. Once at 12 $km{\cdot}h^{-1}$ the treadmill gradient was increased 0.5% every 30 s until the player reached volitional exhaustion or running was no longer deemed safe. HR was monitored continuously, and all other physiological and perceptual measures recorded upon cessation of running to avoid disruption. Players totaled ~35–45 min inside the heated environment. Environmental conditions were monitored via a pocket weather meter (Kestral 4000 Nielsen-Kellerman, PA, USA). Players were permitted a maximum of 300 mL room temperature water (actual consumption PAH: 240 ± 50 mL, AH: 230 ± 60 mL, TEMP: 230 ± 50 mL) to consume throughout baseline and post-intervention trials.

Training Interventions

Following a 5 min self-selected warm up and 3 min passive rest, each of the six heat training sessions comprised 6 sets of 5 x 10 s maximal effort sprints (Wattbike air resistance level 8-10 at >90 rpm) on a stationary cycle ergometer (Wattbike Pro Ltd, Nottingham, England). Each 10 s sprint was interspersed with 30 s active recovery (Wattbike air resistance level 2-4 at 50 rpm) and each set separated by 2 min passive recovery. Prior to exercise, players in PAH were seated passively in the hot environment for 20 min. Training for both PAH and AH conditions was undertaken in 34 ± 5°C, 56 ± 15% RH, and 17 ± 1°C, 62 ± 10% RH for TEMP. Players completed three heat or control sessions$\cdot$wk^{-1} on alternating days to field (football) training and no training was undertaken on weekends given the player's football commitments. Mean and peak power output (PO; Watts) were recorded during each sprint, HR was monitored continuously and tympanic temperature (T_{tymp}; ThermoScan 4000, Braun, Kronberg, Germany), RPE and TS were recorded at rest and after each of the 6 sets. Players were permitted a maximum of 600 mL (actual mean consumption for the six training sessions PAH: 420 ± 140 mL, AH: 330 ± 130 mL, TEMP: 390 ± 120 mL) room temperature water to consume during each training session.

Physiological Measures

Players ingested a telemetric temperature sensor (CorTemp, HQ Inc., Palmetto, United States) four hours prior to the pre-and-post intervention HST to assess T_c. All players were euhydrated upon arrival to the laboratory for each testing and training session. Players provided a small mid-stream urine sample to ensure euhydration (Urine Specific Gravity; Pen Refractometer, ATAGO, Tokyo, Japan) prior to commencing exercise. In the case a player was deemed severely dehydrated (USG >1.020), their training session was rescheduled. Body mass was recorded (sports shorts only) before and after all experimental and training sessions on a standing scale (FG-150KAL Platform Scale, A&D Weighing Australasia Pty Ltd). Heart rate (HR) was monitored continuously during all sessions via a chest strap receiver transmitting real time data via Bluetooth to Firstbeat Sports analysis software (Firstbeat Technologies Ltd, Jyväskylä, Finland). Mean skin temperature (T_{sk}) was assessed on the right anterior side of the body at the chest, forearm, thigh and posterior calf (iButton, Maxim Integrated, San Jose, CA, United States) using the Ramanathan equation.[87] A 5 µL capillary blood sample was taken from a fingertip at rest, and following each stage of the HST, for analysis of blood lactate concentration using a portable Lactate Pro analyser (Arkray Inc., Kyoto, Japan).

Perceptual Measures

Players self-rated their RPE using Borg's 6–20 scale[88] and thermal sensation (TS) on Young's 8-point (0 unbearably cold – 8 unbearably hot) Likert scale.[89] RPE and TS were recorded at rest prior to exercise and as specified during HST and training sessions.

Statistical Analysis

Descriptive data are presented as mean ± SD. All data was log-transformed, then back-transformed to obtain changes in means and variation as a percent. Data modeling involved point estimation of time-to-exhaustion running capacity and thermal adaptation markers (HR, T_c, T_{sk}, , RPE and TS) to heat training, and confidence interval estimates of the uncertainty about the value of these parameters.[90] Time-to-exhaustion data was converted from raw decimal format into minutes via division of the numeric decimal by 1440 (minutes per day) and formatted into time using Microsoft Excel (Version 15.41). Preliminary analysis indicated substantial differences in the time-to-exhaustion running capacity between groups at baseline. Time-to-exhaustion values were adjusted to mean baseline values for all groups to ascertain between conditions effects. Within condition analysis remained unadjusted. The magnitude of change between the standardised means (ES) was interpreted against the following criteria: <0.19 trivial, 0.2-0.59 small, 0.6-1.19 moderate, 1.2-1.99 large and >2.0 large. Precision of estimation was determined using 90% confidence limits (CL). When the magnitude of the standardised effect crossed the threshold of a small positive and small negative (-0.2 and +0.2) the change or difference was deemed unclear.

Results

Performance Outcomes

Table 4.1 presents running time-to-exhaustion, physiological and perceptual responses to the baseline and post-intervention HST for PAH, AH and TEMP. Within condition running capacity increased by 26 ± 8% (1:54 ± 1:02 min) in PAH, 29 ± 12% (1:48 ± 1:11 min) in AH and 10 ± 12% (0:48 ± 1:16 min) in TEMP compared to baseline. After being adjusted to baseline values, the difference in the change in the mean in running time-to-exhaustion was 7 ± 11% (0.27, ±0.45; standardised difference, ±90% confidence limits) greater in PAH than AH.

Similarly, time-to-exhaustion was 13 ± 10% (0.52, ±0.42) greater in PAH compared to TEMP. The difference between AH and TEMP was small 8 ± 13% (0.35, ±0.57) but unclear.

Physiological Outcomes

Figure 4.1 presents mean exercise HR, T_c, T_{sk} and blood lactate responses to the submaximal HST for PAH, AH and TEMP. Exercising HR progressively increased from stage 1 to 4 in all conditions from 135 ± 7 to 174 ± 12 $b \cdot min^{-1}$ at baseline and 135 ± 11 to 171 ± 14 $b \cdot min^{-1}$ post-intervention. Trivial to small changes in HR between and within PAH, AH and TEMP were inconsistent and uncertain (Figure 4.1a). There were no changes in HR_{max} between or within the conditions following the post-intervention time to exhaustion task (Table 4.1).

There were no clear changes in T_c or T_{sk} during submaximal exercise between or within PAH, AH and TEMP (Figure 4.1b & c). While T_c and T_{sk} appeared to be lower in PAH compared to AH and TEMP, large variability precluded any firm conclusions. Small changes in mean T_{sk} between baseline and post-intervention were clear in PAH compared to AH (0.41, ±0.45; ES, ±90% confidence limits) and TEMP conditions. There were no substantial changes in T_c or T_{sk} following the time-to-exhaustion task between or within any condition (Table 4.1).

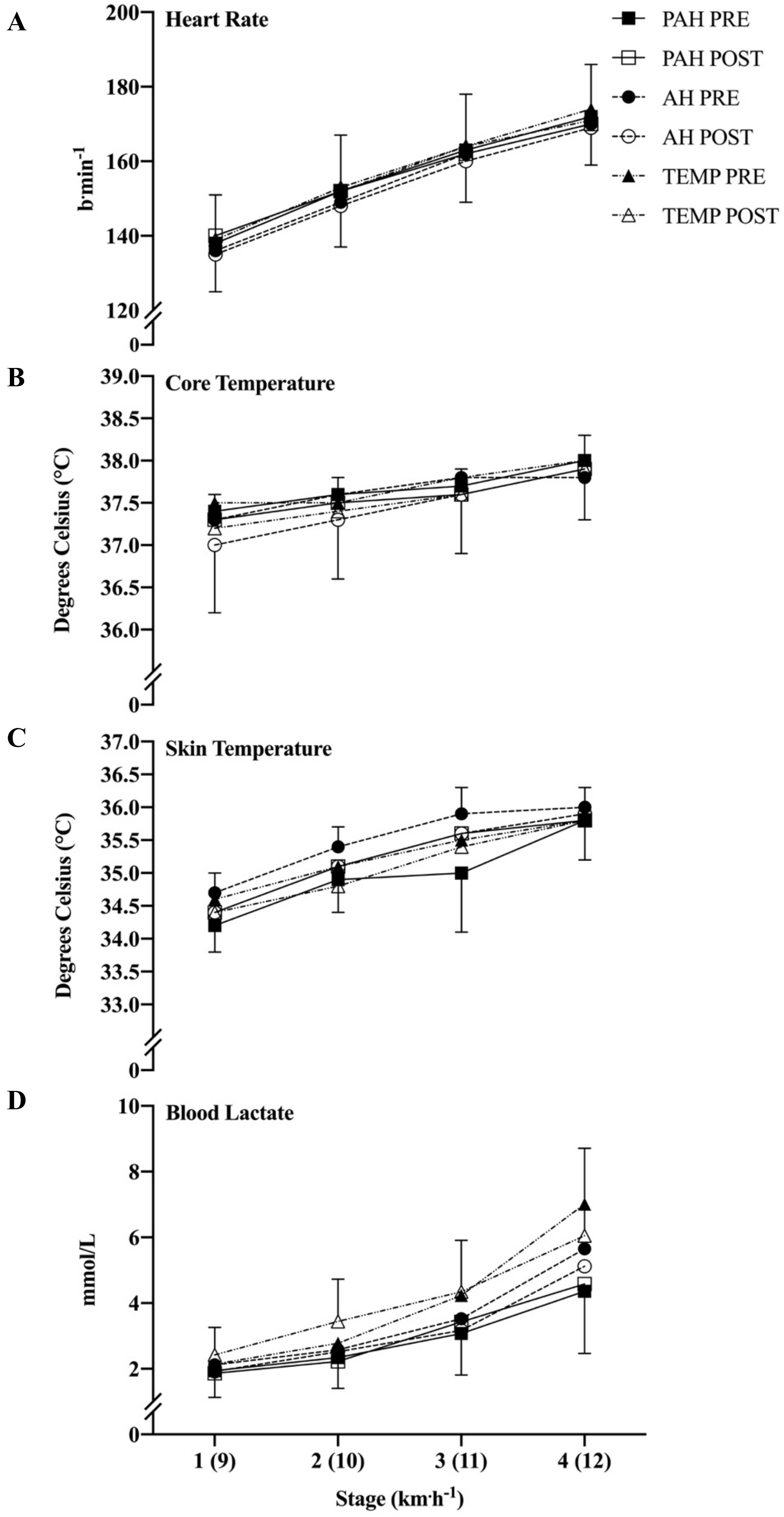
Changes in blood lactate were mostly unclear between and within conditions (Figure 4.1d). Mean blood lactate increased 0.3 ± 1.3 mmol/L in PAH after the post-intervention trial compared to baseline. Mean blood lactate was -0.3 ± 2.5 mmol/L lower in AH and -1.2 ± 3.3 mmol/L lower in TEMP after heat training compared to baseline. Blood lactate was moderately lower in AH than TEMP at stages 1 (0.60, ±0.69; ES, ±90% confidence limits) and 2 (0.77, ±0.70) of the post-intervention HST compared to baseline (Figure 4.1d). Post-exercise blood lactate was moderately higher after the time-to-exhaustion task in PAH and AH compared with baseline (Table 4.1).

Table 4.1. Mean performance, physiological and perceptual variables for the time-to-exhaustion component of the heat stress test for PAH, AH and TEMP at baseline and post-intervention trials. Data are presented as mean ± SD. Within condition effects (standardised mean, ±90% confidence limits) remain unadjusted to baseline values.

	Passive-Active Heat			**Active Heat**			**Temperate**		
	Baseline	**Post-Int.**	**Δx ES, ±90% CL**	**Baseline**	**Post-Int.**	**Δx ES, ±90% CL**	**Baseline**	**Post-Int.**	**Δx ES, ±90% CL**
Time to Exhaustion (min)	7:39 ± 1:50	9:33 ± 1:43	0.88, ±0.23 Moderate[a,c]	6:21 ± 1:17	8:09 ± 1:14	1.23, ±0.45 Large	7:27 ± 1:26	8:15 ± 1:38	0.45, ±0.48 Small
HR_{max} ($b \cdot min^{-1}$)	193 ± 8	193 ± 9	0.01, ±0.36 Unclear	188 ± 7	189 ± 10	0.12, ±0.48 Unclear	193 ± 9	194 ± 8	0.19, ±0.33 Trivial
Peak T_c (°C)	38.5 ± 0.2	38.5 ± 0.5	0.01, ±1.32 Unclear	38.2 ± 0.6	38.2 ± 0.6	-0.02, ±0.58 Unclear	38.3 ± 0.6	38.4 ± 0.2	0.12, ±0.49 Unclear
T_{sk} (°C)	35.8 ± 0.6	35.8 ± 0.3	0.02, ±0.44 Unclear	35.5 ± 1.6	35.8 ± 0.5	0.24, ±0.64 Unclear	35.7 ± 0.4	35.9 ± 0.4	0.47, ±0.68 Unclear
Blood Lactate (mmol/L)	8.0 ± 3.5	10.5 ± 2.8	0.66, ±0.44 Moderate[d]	7.9 ± 2.9	11.5 ± 5.7	0.73, ±0.54 Moderate[e]	8.6 ± 2.9	9.2 ± 2.4	0.13, ±0.43 Unclear
RPE	19 ± 1	19 ± 1	0.16, ±0.62 Unclear	18 ± 1	18 ± 1	-0.25, ±0.24 Small[e]	19 ± 1	19 ± 1	0.32, ±0.42 Small
TS	7.3 ± 0.4	7.3 ± 0.4	-0.01, ±0.70 Unclear[c]	7.3 ± 0.4	6.9 ± 0.4	-0.86, ±0.73 Moderate[e]	7.4 ± 0.5	7.7 ± 0.3	0.60, ±0.30 Unclear

HR_{max} – heart rate maximum; T_c – core temperature; T_{sk} – skin temperature; °C – degrees Celsius; RPE – rating of perceived exertion; TS – thermal sensation; ES – effect size; standardised mean change or difference; CL – confidence limits. **PAH v AH:** [a]Small Effect, [b]Moderate Effect; **PAH v TEMP:** [c]Small Effect, [d]Moderate Effect; **AH v TEMP:** [e]Small Effect, [f]Moderate Effect

Figure 4.2. Physiological responses to the submaximal heat stress test before and after 6 sessions of repeated sprint training a) heart rate, b) core temperature, c) skin temperature and d) blood lactate for PAH, AH and TEMP between baseline and post-intervention.



Perceptual Measures

Figure 4.2 presents perceptual responses for PAH, AH and TEMP at baseline and post-intervention HSTs. Changes in RPE from stages 1 to 4 of the HST between baseline and post-intervention were relatively similar and unclear between conditions (Figure 4.2a). RPE was lower after AH compared to PAH (at stages 1 and 3) and TEMP (at stages 2–4) following heat training. A small reduction in RPE was present after PAH compared to TEMP at stages 1 (0.20, ±0.30; ES, ±90% confidence limits) and 2 (0.37, ±0.45) of the post-intervention HST compared to baseline. Players in AH reported lower end exercise RPE after the post-intervention time-to-exhaustion task than both PAH and TEMP (Table 4.1).

TS was consistently lower from stages 1 to 4 of the post-intervention HST within each of the three conditions compared to baseline. The reduction in TS following the six heat intervention sessions was greater in AH than PAH or TEMP (Figure 4.2b). Small to large reductions in TS were evident within the AH condition between stages 1 to 4 of the post-intervention HST compared to baseline (Figure 4.2b). Changes in TS for PAH and TEMP were variable and unclear. TS was moderately lower in AH compared to PAH after the post-intervention time-to-exhaustion task (Table 4.1).

Training Interventions

Mean PO, physiological and perceptual responses to the 6 training sessions in heat (PAH and AH) and temperate (TEMP) conditions are presented in Table 4.2. Mean PO increased 16 ± 23% in PAH, 5 ± 13% in AH and 6 ± 8% in TEMP. Average PO for T1–T6 was 536 ± 36 W in PAH, 521 ± 21 W in AH and 564 ± 18 W in TEMP and there were no clear differences between conditions. Peak PO increased 16 ± 24% (107 ± 149 W; 0.61, ±0.54; ES, ±90% confidence limits) in PAH, 7 ± 15% (45 ± 85 W; 0.23, ±0.32) in AH and 3 ± 10% (25 ± 66 W; 0.19, ±0.33) in TEMP from T1–T6. There were no clear differences in HR from T1–T6 except for a small and clear -6 ± 10 $b{\cdot}min^{-1}$ mean reduction after AH training. Small to moderate reductions in T_{tymp} responses to training were consistent across the 6 sessions, except for mean T_{tymp} in AH which was unclear. Mean RPE and TS did not differ between T1–T6, except for a small reduction in mean RPE within PAH. There was a small increase in peak TS (0.53, ±0.47; ES, ±90% confidence limits) after PAH and TS in TEMP (0.33, ±0.33). All other changes in peak RPE in TS were unclear.

Figure 4.3. Perceptual responses to the submaximal heat stress test a) RPE and b) thermal sensation PAH, AH and TEMP between baseline (Pre) and post-intervention (Post) trials. Data presented as mean ± SD; *Small, ∆moderate and ◊large decreases in AH compared to baseline. PAH v AH: aSmall Effect; PAH v TEMP: cSmall Effect; AH v TEMP: eSmall Effect, fModerate Effect.

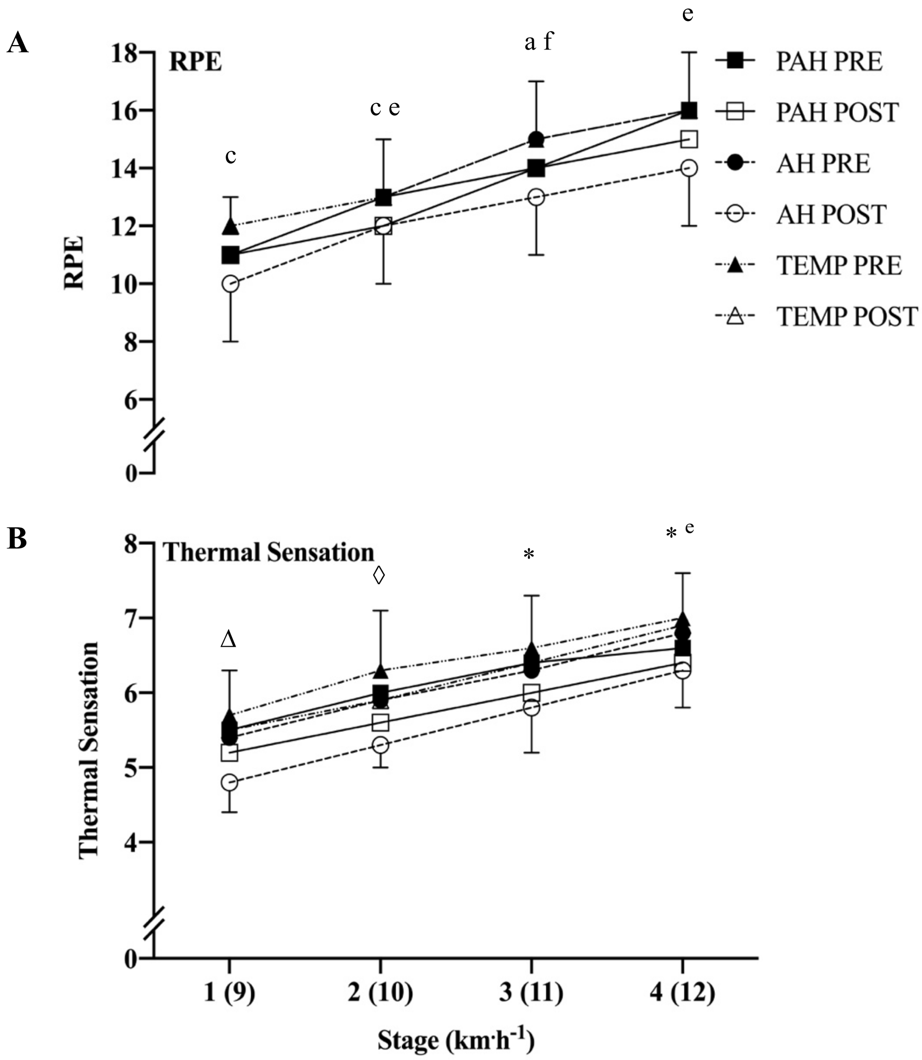


Table 4.2. Mean ± SD performance, physiological and perceptual responses to the six repeat sprint training (T1 – 6) sessions in hot (PAH and AH) and temperate conditions (TEMP). Within condition effects (standardised mean, ±90% confidence limits).

		T1	T2	T3	T4	T5	T6	T1 v T6 Δ	T1 v T6 Δx ES, ±90% CL
Mean Power (W)	*PAH*	497 ± 101[d]	514 ± 74	548 ± 101	510 ± 101	552 ± 115	594 ± 127	80 ± 109	0.64, ±0.55***
	AH	517 ± 112	518 ± 88	484 ± 127[g]	530 ± 104	544 ± 109	532 ± 125[e]	30 ± 63	0.18, ±0.26**
	TEMP	556 ± 75	539 ± 60	564 ± 79	555 ± 102	584 ± 81	586 ± 75	31 ± 40	0.35, ±0.28**
HR ($b \cdot min^{-1}$)	*PAH*	164 ± 9	162 ± 15	164 ± 7	158 ± 10	160 ± 10[c]	164 ± 7[b]	0 ± 7	-0.04, ±0.47
	AH	163 ± 10	161 ± 10	158 ± 14	157 ± 12	161 ± 9	156 ± 11[f]	-6 ± 10	-0.43, ±0.38**
	TEMP	164 ± 8	161 ± 11	164 ± 10	163 ± 9	166 ± 8	164 ± 6	0 ± 8	0.04, ±0.48
T_{tymp} (°C)	*PAH*	37.5 ± 0.3	37.4 ± 0.3	37.3 ± 0.2	37.4 ± 0.2	37.3 ± 0.3	37.4 ± 0.1	-0.1 ± 0.3	-0.55, ±0.67**
	AH	37.6 ± 0.3	36.8 ± 1.6	37.4 ± 0.4	37.5 ± 0.3	37.2 ± 0.4	37.3 ± 0.5[f]	-0.4 ± 0.4	-0.93, ±0.55
	TEMP	36.9 ± 0.6	36.9 ± 0.6	36.6 ± 0.7	36.5 ± 0.5	36.6 ± 0.5	36.8 ± 0.7	-0.2 ± 0.3	-0.22, ±0.23**
RPE	*PAH*	14.5 ± 1.4	15.0 ± 0.9	15.1 ± 0.7	14.8 ± 0.8	14.8 ± 1.2	14.9 ± 0.9	0.4 ± 1.2	0.37, ±0.60
	AH	14.5 ± 1.3	14.2 ± 1.4	14.2 ± 1.1	13.7 ± 0.7	13.9 ± 1.1	13.8 ± 1.1	-0.7 ± 1.0	-0.51, ±0.44**
	TEMP	15.3 ± 1.6	14.9 ± 0.9	15.1 ± 0.6	15.1 ± 0.7	15.1 ± 0.5	15.0 ± 0.3	-0.3 ± 1.8	-0.15, ±0.79
TS	*PAH*	6.1 ± 0.7[d]	6.3 ± 0.5[b]	6.3 ± 0.4	6.2 ± 0.5	6.2 ± 0.7[b]	6.1 ± 0.1	0.0 ± 0.5	0.02, ±0.51
	AH	6.2 ± 0.5	5.9 ± 0.6[e]	5.8 ± 0.6[f]	5.6 ± 0.3[f]	5.8 ± 0.3	5.6 ± 0.5	-0.6 ± 0.6	-0.97, ±0.62
	TEMP	5.6 ± 0.3	5.5 ± 0.3	5.4 ± 0.3	5.2 ± 0.6	5.3 ± 0.4	5.6 ± 0.4	-0.1 ± 0.5	-0.23, ±0.91

W – watts; $b \cdot min^{-1}$; HR – heart rate; T_{tymp} – tympanic temperature; °C – degrees Celsius; RPE – rating of perceived exertion; TS – thermal sensation; ES – effect size; standardised difference; CL – confidence limits. **T1 v T6:** *Trivial Effect, **Small Effect, *** Moderate Effect, ****Large Effect

PAH v AH: [a]Small Effect, [b]Moderate Effect; **PAH v TEMP:** [c]Small Effect, [d]Moderate Effect; **AH v TEMP:** [e]Small Effect, [f]Moderate Effect

Discussion

When integrated with real-world sports-specific training and towards the end of a football season, six short repeat sprint cycling sessions with (PAH condition) and without (AH condition) brief passive heat exposure (35°C) resulted in a 13% (PAH) and 8% (AH) greater improvement in running capacity than training in temperate (18 °C) conditions. While the purpose of the study was not solely to elicit specific heat adaptation per se but to improve general conditioning, i.e. running capacity in a pragmatic team sport setting, the lack of physiological responses indicates the stimulus for achieving heat adaptation was limited. Notably, running capacity in the heat was also improved after training in 18°C. It appears the threshold of training required for thermal adaptation (if desired) is higher than the threshold needed for improvements in aerobic fitness in moderately fit team sport players.

The present study is one of few that have undertaken heat training in parallel with sport-specific training and games in team sport players.[12,13] To the authors' knowledge it is the first study to investigate combined active and passive heat exposure with high intensity repeat sprint training in team sport players. While the ability to complete more work in less time makes repeat sprint training and HIIT appealing, consensus recommendations advocate a minimum of 60 min heat exposure be undertaken in a single about.[6] Given the unlikeliness of team sport athletes to sustain extended periods of continuous running during training and games and the probability of coaches exposing their players to this type of running during the season, we adopted a cycling-based protocol, similar to others.[38,39] To extend the otherwise short-duration exposure to meet the recommended 60 min, a brief period of passive heat exposure was incorporated. Despite prolonging heat exposure, the current approach was insufficient to induce the classic indicators of traditional heat adaptation.

In the absence of thermal adaptation, the observed improvements in running capacity are likely training load related. Recent consecutive day investigations highlighted that HIIT in the heat promoted cumulative fatigue and impaired subsequent exercise performance in endurance athletes.[10,80] In contrast, the marked improvements in running capacity and cycling PO observed in this study indicate the intermittent nature of our design appeared to facilitate adequate recovery between sessions. Positively, this approach appears to have limited fatigue and overreaching previously reported following consecutive day heat-training interventions.

In addition to the increased training load, it is possible that the improvements in running capacity in PAH and AH were perceptually mediated. Despite mean and peak RPE and TS being either reduced or maintained throughout the six training sessions, cycling PO measures were progressively improved. Consequently, players in PAH and AH reported lower RPE and TS during the post-intervention submaximal HST and were able to run for almost 2 min longer in the time-to-exhaustion task at a similar perceived thermal load to baseline. Other studies involving team sports have also shown improvements in perceptual and/or performance measures with varied physiological outcomes.[13,14,39] It is possible that exposure to a novel training stimulus (heat) and the positive reports surrounding heat training among elite teams may have imparted a positive belief effect on the players. In part, a possible belief effect and increased training load are likely the underlying explanations for the observed improvements in running capacity. In this case, the heat interventions may have had more of a placebo effect[95] than a physiological effect on this cohort of players. However, perceived thermal tolerance could be equally as important as physiological changes for limiting performance decrements in hot conditions.[96]

When adjusted to account for the difference in the mean change of baseline scores (Table 4.1), the additional 20 min passive heat exposure offered a small 7% greater increase in running capacity than AH and 13% compared to TEMP. While our study was not mechanistic by design, a recent study highlighted the effectiveness of 20 min passive sauna exposure while wearing a vinyl sauna suit in 50°C, 30% RH prior to a 90 min heat acclimation protocol on facilitating heat acclimation by reducing resting and exercising rectal temperate and heart rate, thermal sensation, RPE and increasing plasma volume and the onset threshold of sweating.[50] Likewise, six days of 40 min of hot water immersion performed after submaximal treadmill running in 18°C improved 5 km time trial performance by 4.9% in hot conditions.[67] Given that team sport players often train in groups, passive heat exposure before sport-specific training provides an accessible and efficient means of exposing multiple players to heated conditions in a shorter time frame.

The strength of the present study is its integration with sports-specific training during the season of a league style competition. However, the study is not without limitations. Including a familiarisation session for the repeated sprinted protocol would have been beneficial, however, the real-world context in which the study was conducted (the middle of the club's competitive season), the opportunity for additional sessions was not favorable. Given the intermittent, repetitive nature of Australian Rules Football it was believed that the players were appropriately accustomed to this type of repeated effort activity. The supplementary training and novel exposure to hot conditions late in the southern-hemisphere winter was well tolerated by players. However, in addition to instilling a possible belief effect, the increased training load may have also contributed to improvements in running capacity. The need to adjust baseline running capacity highlights the challenges of implementing rigorous group allocations in the sporting domain. Despite the applied nature, the study did not include a running performance test in cool conditions. This inclusion would have been beneficial for assessing the transfer of performance gains between hot and cooler conditions. While this is the first study to explore a combination of active and passive heat exposure in team sports, the 20 min passive exposure did not provide substantial physiological benefit on top of the 40 min AH condition. Due to inconsistencies within the data, it was difficult to ascertain whether core temperature was in fact elevated following the 20 min passive heat exposure prior to exercise. Passive heat exposure may have been better undertaken post-exercise and for a longer duration.

Conclusion

When the direct priority is not to specifically elicit heat acclimation, heat-training programs can be incorporated successfully into the daily training environment of a team. Six x 40 min repeat sprint interval training sessions in the heat with and without brief passive heat exposure were effective in enhancing running capacity in the heat. Training sessions coupled with 20 min passive heat exposure provided a greater advantage for enhancing running capacity in the heat compared to active heat training alone. However, passive heat exposure offered little benefit above that of 40 min active heat training in facilitating thermal adaptation. A combination of increased training load and positive belief effects in state-level team sport players likely facilitated improved running capacity.

Practical Applications

- 6 x 40 min repeated sprint heat training sessions can be successfully integrated with sport-specific football training during a competitive season.
- In state-level team sport players, the perceived benefits of engaging heat training may complement increases in training load and any underlying thermal/physiological adaptations.

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Chapter 5: General Discussion

The purpose of this thesis was to enhance the applicability of short-term heat training for team sport athletes by manipulating the principles of traditional heat acclimation and applying them in a real-world environment. Heat training has become a popular training intervention for endurance and team sport athletes as a preparatory method to facilitate acclimation for competition in hot conditions, or possibly promoting performance in cooler conditions. Heat acclimation training is well established for preparing athletes physically and psychologically to compete in hot conditions.[6,7] However, few studies to date have investigated its use as a standalone conditioning intervention in team sports, and only two have explored its implementation in addition to sport-specific training.[12,13] As several elements compete for players' time (i.e. skills training, strength and conditioning, recovery, physiotherapy), implementing additional sessions or interventions requires careful consideration. When strategically integrated with sports-specific training, heat training has the potential to promote rapid fitness and performance gains in team sport athletes.

The broader aims of this thesis were addressed in two laboratory-based experimental chapters. Chapter 3 explored the implementation of a novel mixed mode (cycling and running), intermittent day intervention during the pre-season in Australian football players. When superimposed with sports-specific training, the mixed mode training intervention was well tolerated by the players and facilitated a 28% improvement in endurance running performance (irrespective of the interventions conditions). Endurance running was similarly improved within HEAT and TEMP conditions, respectively. However, the HEAT intervention appeared to offer no additional benefit regarding thermal adaptations than training in TEMP ambient conditions. Chapter 4 investigated the effects of repeated sprint cycling training, with and without passive heat exposure, on running capacity late in a state-level Australian football season. When acquiring heat acclimation is not a direct priority, this type of heat-based training offers a practical and time efficient method for enhancing aerobic conditioning in state-level team sport players. Running capacity in the heat improved by 13% in PAH and 8% in AH compared to training in temperate ambient conditions (TEMP). Although, like in Chapter 3, the presence of clear thermal adaptation in line with more classical markers was limited following the two heat-based innervation conditions. Both studies ran in parallel with the team's regular field-based training prescribed by the coach and sanctioned pre-season and competition games.

Non-Consecutive Heat Exposure in Team Sports

Given the logistical complexities of team sports, a consecutive day approach to heat training is rarely practical for the modern-day team. Thus, we opted for an intermittent day design (6 sessions across 12 days) in both experimental studies in Chapters 3 and 4. This pragmatic approach was employed so that players could maintain regular sports-specific (football) training and game commitments throughout the experimental study periods. We aimed to minimise disruption to regular football training by undertaking heat training every other day to prevent cumulative fatigue and compromising subsequent sports-specific training and game performance. However, dispersing heat exposures over a number of days has the potential to limit thermal and physiological adaptation.[15] A recent study highlighted similar improvements in total work and mean power output during repeat sprint cycling following 8 exposures over 16 days compared to 8 consecutive sessions.[39] When undertaken during the season, and in conjunction with training and games, an intermittent day heat program should allow sufficient recovery between sessions. In support of this assertion are two studies using five consecutive days of high intensity heat training in endurance-trained athletes impairing subsequent performance in the heat as a consequence of cumulative fatigue and possibly over-reaching.[10,80] While measures of fatigue were not directly assessed in Chapters 3 and 4, reducing the impact of fatigue during the season is of interest so that game performance is not compromised. An intermittent heat exposure program should avoid heat training sessions within 24–48 hr prior to a game to ensure players are fresh and well-prepared.

Mixed Mode Heat Training During the Pre-Season

In Chapter 3, a unique training intervention comprising a combination of stationary cycling and treadmill running was implemented and evaluated during the pre-season. This type of mixed mode intervention has not been previously undertaken in any other heat study. The protocol involved 5 x 8 min efforts interspersed with 3 min passive recovery, alternating between cycling and running to make up a 60 min session. Training was completed every other day for a total of 6 sessions. Given the intermittent nature of team sports and the frequency to which they undertake cross-training activities, treadmill running was included to maintain some element of sports specificity and stationary cycling to reduce the number of lower limb impacts during the session. Similarly, with extended periods of low-moderate intensity running being atypical of team sports, stationary cycling was incorporated to maintain cardiorespiratory load while reducing musculoskeletal load during the heat training sessions. Heat training offered no additional benefit on top of training in 18°C but irrespective of the intervention conditions, running performance increased by 28% following the fourth (final) Yo-Yo Intermittent Recovery Test Level 1 compared to the first. Given that this study ran in combination with sports-specific football training during the team's pre-season, it appears the moderately-fit players benefited more from the additional training than specific heat training at that point in the season. Overall this approach was well tolerated by players and offered variety as opposed to traditional single mode forms of heat training.

During the pre-season, it has become popular for teams to travel to naturally warmer locations to undertake training camps where field-based skills, tactical and conditioning sessions can be completed.[18,19,97] However, these camps are typically costly and logistically demanding. Given these constraints there is a clear need to provide teams, particularly those with limited financial resources, with local options that don't require travel. The study design in Chapter 3 employed a pre-post crossover design, in which the two training blocks coincided with the first and last 3 weeks of a 12 weeks pre-season. The two training interventions took place in the Southern Hemisphere during the late summer months and into the first month of autumn. The extended study period was to ensure an adequate washout period (4 weeks) between the two training interventions, and also in response to the coach's interest and objectives in maximising conditioning and performance adaptations during this pre-season period.

Physiological and performance responses between HEAT and TEMP conditions were unable to clearly differentiate the mixed mode intervention employed in Chapter 3. This outcome aligns with the only other study known to add supplementary heat training in addition regular sports-specific pre-season training.[12] The difference between studies centred on our heat exposures being programmed intermittently over 12 days, while the other study used a consecutive day intervention. Five x 50 min cycling sessions resulted in 2.6% (heat) and 2.2% (control) improvements in high intensity running during the final weeks of an 18-week pre-season (22°C average maximum daily temperature), with heat offering no additional benefits compared to control.[12] Despite similar improvements between conditions, the heat condition improved running performance to a similar magnitude of the control group despite performing 30% less mechanical load during the cycling sessions.[12] It appears that state-level Australian football players benefit more from brief periods of intensified aerobic conditioning during the pre-season as opposed to artificial laboratory-based heat training.

Repeated Sprint Heat Training During the Competitive Season

Chapter 4 explored the utility of heat training employing short repeated sprint (6 sets x 5 x 10 s efforts) cycling intervals as a means of enhancing player conditioning during the season. The study ran late in the season (winter months) in parallel with rounds 16–22 of a 22-round state-level Australian football competition. In consultation with the team coach, players were instructed to maintain 2 x 90 min field-based skills sessions per week. Superimposed with regular team training and games, this is the first scientific research study to investigate a combination of passive and active heat exposure in team sport players during the season in a real-world context. When transitioning from the pre to the competitive season the training focus was shifted to ensure players were adequately prepared for weekly competition, and recovery was emphasised. Strategies aiming to maintain adaptations developed during the pre-season[29] and reduce the impact of any underlying detraining throughout the season were encouraged.[98] The nature of the heat exposure undertaken in Chapter 3 was insufficient to clearly differentiate the responses between HEAT and TEMP conditions during the pre-season. Therefore, other avenues of imposing adequate heat stress in Chapter 4 were required. To construct a time efficient conditioning program that could be easily implemented during the season, low-moderate intensity mixed-mode training (Chapter 3) was substituted with a high-intensity, repeated sprint cycling program. Recent studies have reported performance impairments linked to cumulative fatigue following 5 consecutive days of HIIT in endurance athletes.[10,80] To ensure high relevance to a real-world setting, the intermittent exposure of 6 sessions across 12 day undertaken in Chapter 3 was also utilised in Chapter 4.

HIIT is well known for improving cardiovascular and metabolic function and in turn athletic performance.[99] Similar adaptations can be induced by HIIT with substantially lower training volumes[100] than traditional endurance training, and it offers a practical alternative to traditional heat training methods when constrained by time.[35] A short 40 min session involving 6 sets of 5 x 10 s maximal effort cycling sprints was undertaken in 35°C with and without 20 min of passive (seated) heat exposure prior to exercise. With respect to weekly training intensities reduced to accommodate for higher game intensity across a professional Australian football season,[27,101] subjecting players to $\geq$60 min of HIIT in hot conditions using a consecutive day format is largely impractical. To comply with classical heat exposure recommendations advocating a minimum of 60 min per session (exposure),[6] we added 20 min of passive exposure to reduce the total work time but at the same time extend the total heat exposure duration as much as practically possible. While running capacity was improved following the post-intervention time-to-exhaustion task in both PAH and AH, running was also improved following training in more temperate 18°C ambient conditions. The additional 20 min passive heat exposure offered a greater improvement in running capacity compared to TEMP (PAH v TEMP, 13%) than 40 min of AH (AH v TEMP, 8%), indicating a positive and worthwhile conditioning effect.

The progressive increase in peak and mean power output during the six cycling training sessions in both PAH and AH suggests the intermittent day exposure may have permitted sufficient recovery between sessions. Enhanced recovery may have in turn negated performance impairments otherwise reported following consecutive day interventions.[10,80] However, measures of fatigue were not explicitly assessed in this study and thus this observation is speculative rather than objective. The lack of thermal adaptation, however, implies that the threshold required for moderately fit team sport players to develop heat adaptation is greater than that required for facilitating improvements in aerobic fitness. Coaches, conditioning staff and sports science advisors need a clear understanding of the program's objectives when planning, conducting and evaluating pre- and in-season training interventions.

Passive Heat Exposure

With load monitoring at the forefront of high performance sport, balancing training stress and recovery throughout the season is essential for maintaining optimal performance.[25] In professional Australian football and Rugby League where games are played weekly, high training loads can impair sprint capacity and explosive actions that are characteristic of intermittent activity,[102] and also increase the risk of injury.[103] Conditioning activities that enable players to perform these continuous high intensity and repeated sprint efforts, explosive actions and, recover from them quickly would be highly advantageous.[93,94] This is where a combination of passive and active heat exposure becomes highly appealing to team sports. We added passive heat exposure to reduce the total amount work required per session, as it is unlikely that coaches would subject their players to $\geq$60 min of high intensity repeat sprint efforts or HIIT in the middle of the season.

The two-fold benefit of adopting passive heat exposure is to simultaneously reduce the training load, while still exposing players to the hot conditions. In contrast to the variable pattern of physiological responses in Chapter 4, other investigators have reported successful reductions in core temperature, heart rate, RPE and TS following passive exposure via hot water immersion.[52,67,75] Post-exercise hot water immersion and sauna bathing have shown to improve time trial performance by ~6% in well-trained males[67] and ~2% in endurance runners.[51] Passive heat exposure methods such as hot water immersion and sauna exposure are easily accessible, better able to accommodate large player numbers, and have the potential to offer physiological and performance benefits. Yet despite the potential for this form of intervention, passive heat exposure remains largely unexplored in team sports.

Physiological Responses to Heat Training

With respect to traditional heat training protocols, the heat stimulus applied in Chapters 3 and 4 was evidently insufficient to evoke the classical reductions in heart rate (HR), core (T_c) and skin (T_{sk}) temperature[16] and subsequently heat acclimation. Classical aerobic adaptations induced by long-term habitual exercise training often mimic those promoted by heat exposure.[104] Despite possibly having more to gain by undertaking heat training, it seems that the threshold for general fitness related improvements was greater than the threshold for thermal adaptation to develop in our cohort of moderately trained football players. It appeared that this cohort of players benefited from a combination of the extra conditioning activity and the stress triggered by undertaking exercise in the unaccustomed hot conditions. This was manifested by improvements in Yo-Yo (IRT1) running performance in the temperate condition being similar to the improvements observed following six training sessions in the heat (Chapter 3).There may also have been physiological responses that were not directly assessed in either study (i.e. plasma volume, sweat response, core temperature during the 6 training sessions) that may be linked to the observed performance improvements in both Chapters 3 and 4. Despite the lack of thermal adaptation achieved in Chapters 3 and 4, it can be argued that heat training has the potential to act as an additive stimuli for accelerating fitness and performance gains in team sports.

In Chapter 3 there was a variable pattern of change between T_c, T_{sk} and thermal sensation (TS) following the six heat training sessions. Despite players reporting that they felt cooler during the post-intervention heat stress test (HST), T_c and T_{sk} were actually increased by ~0.2°C. In contrast, the T_c and T_{sk} were ~0.4°C lower but the changes following training in 18°C were unclear. The explanation for this divergent physiological and perceptual response between training in the heat and temperate conditions is uncertain. It is possible that the HST was not physically demanding enough to sufficiently elevate T_c and T_{sk} at baseline to observe clear changes following the post-intervention trial. It is also plausible that the experience of the six heat training sessions prior to the post-intervention HST, existing knowledge and/or beliefs may have had an influence on the participants perceptual responses to the identical HST conducted at baseline. This links to the psychobiological model proposed by Marcora, 2008,[105] whereby prior experience and motivation can have a subconscious influence on an individual's perception of effort during an exercise task, or in this case, potentially perception of thermal tolerance. This shortcoming provided the rationale for adding the time-to-exhaustion task to the HST following the completion of the 4 x 4 submaximal stages in Chapter 4 to ensure players were challenged to their maximum physiological capacity.

Despite efforts to make the HST more demanding and changing the training protocol from low-moderate to higher intensity maximal effort intervals, the heat stimulus in Chapter 4 was also inadequate in yielding clear thermal adaptations. Changes in HR, T_c and T_{sk} were variable and unclear precluding any firm conclusions. However, players in both heat conditions (PAH and AH) were able to improve their running capacity in the heat by almost 2 min at a similar perceived thermal load to baseline. These findings are similar to other studies involving team sport players using consecutive[12,38] or intermittent[13,39] heat exposures who have also reported partial/limited thermal adaptations, and varied physiological responses to short term heat-training. Likewise, other studies have shown perceptual and/or performance improvements in lieu of clear physiological outcomes.[14,39] There is no single heat training method for facilitating optimal physiological and performance benefits in endurance or team sport athletes.[5] Although thermal adaptation was unable to be directly isolated as the mechanism for improved performance in either Chapters 3 or 4, it appears a positive training effect was imparted. Thus, short term heat training may offer a relatively rapid means of enhancing player conditioning and general fitness in moderately trained team sport players. When thermal adaptation/heat acclimation is desired, moderately fit team sport players would likely benefit from establishing an adequate baseline level of fitness prior to undertaking heat training.

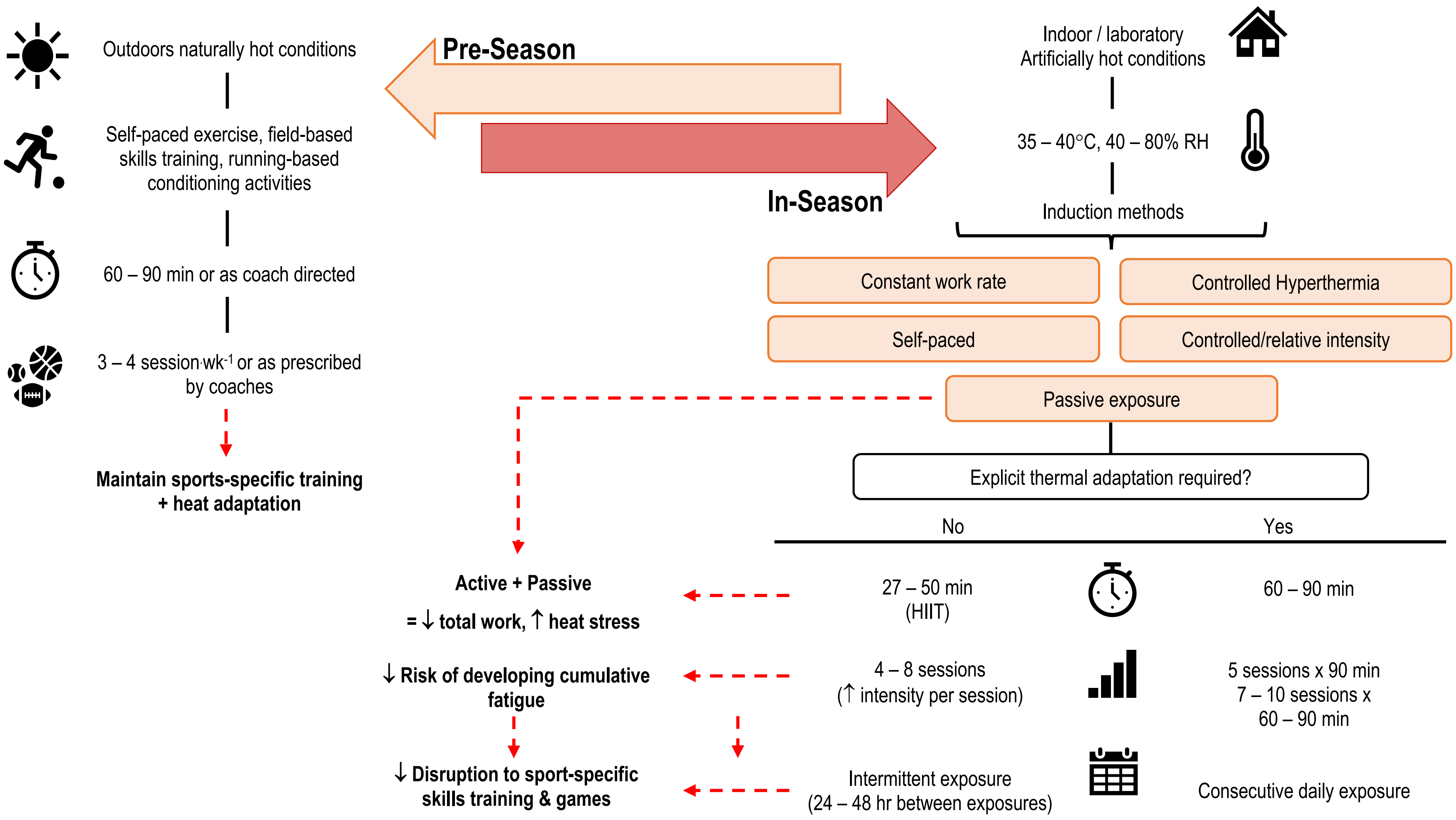
Perceptual Measures

A combination of the moderate fitness status of the state league-level players, and increased training load induced by the integration of heat training and sports-specific training, are the likely explanations for improved performance outcomes observed in both Chapters 3 and 4. In lieu of clear physiological adaptations the concept of performance outcomes being perceptually mediated emerged in Chapter 4. Peak and mean power output were progressively increased across the six training sessions with corresponding peak and mean RPE and TS declining or maintained in both heat conditions. Thereafter, players reported lower RPE and TS during the submaximal stages of the HST before running for ~2 min longer during the time-to-exhaustion task in 35°C compared to baseline. Athletes' internal states, external and social environments all contribute to explicit and implicit cost-benefit analysis influencing an athlete's beliefs, expectations and motivations leading to self-regulated adjustments to physical performance.[106] Coaches and conditioning staff should always consider the context and influence of baseline fitness, environmental conditions, and perceptual factors when evaluating the likely benefits of heat training.

The introduction to a novel training stimulus (heat), positive reports surrounding heat training among professional teams, and the group training sessions may have imparted a positive belief effect on the players in Chapter 4. In addition to the physiological threshold for general improvements in fitness being greater than the ability to acquire specific thermal adaptation, the opportunity to engage a style of training that often appears only accessible to high level athletes may have to some degree instilled a placebo effect[95] among this cohort of players. The multitude of environment and social stimuli evident in sport has the potential to influence and alter an athlete's performance,[107] and the idea that a placebo effect can be elicited without specifically administering a placebo is somewhat controversial.[106] In relation to heat training, perceived thermal tolerance has been suggested to be equally as important as a physiological response for negating performance decrements in hot environments.[96] The idea of heat training providing a placebo for improving performance is similar to the concept of utilising this type of training intervention as an ergogenic aid for performance in cooler environments. The collective performance and perceptual benefits are of particular interest to team sports seeking improvements in physical and perceptual capacity either in the pre-season, or late in the main competitive season, without necessarily requiring substantial heat adaptation.

Based on the pertinent study outcomes, a practical schematic for coaches and conditioning staff has been developed for when heat training is being considered (Figure 5.1). During the pre-season, Figure 5.1 illustrates that state-level teams would likely benefit from undertaking football-specific training during the warmer parts of the day. Once players have established an adequate baseline level of fitness, laboratory-based heat exposure may be beneficial in the later weeks of the pre-season. When specific thermal adaptation is not a direct priority, other strategies could be undertaken by team sports during the season to facilitate a conditioning top-up.

Figure 5.1. Practical strategies for coaches and conditioning staff when considering heat training programs for field-based team sport players. Laboratory-based heat training can be undertaken during the pre-season but is likely more beneficial once players have established an adequate baseline level of fitness. When thermal adaptation is not a direct priority short duration, high intensity interval training (HIIT) every other day can be effectively integrated with sports-specific training and games.



Chapter 6: Conclusions and Practical Applications

Limitations and Delimitations

The strength of the two experimental Chapters in this thesis was their practical application and integration with sports-specific training and games during the pre and competitive seasons. However, several experimental and environmental limitations were apparent. Chapter 3 was undertaken during the late Southern Hemisphere summer and early autumn months while the players were also engaged in field-based skills training. During this period the average daily maximum was ~28°C and average daily minimum was ~19°C, which likely means the players may have been partially acclimatised to the warmer conditions to some degree prior to undertaking the study.

The combined workload of treadmill running, and stationary cycling was likely insufficient to elevate core temperature to the required level for thermal adaptation. The 2.0 $W \cdot kg^{-1}$ cycling load was relative to body mass for each player, whereas the treadmill running speed was at a constant rate determined by the final stage completed during the baseline HST. For example, if players completed stage 4 of the HST which was at 12 $km \cdot h^{-1}$, their training speed was set at 10 $km \cdot h^{-1}$ and 11 $km \cdot h^{-1}$ for those that completed the fifth stage. A controlled intensity (i.e a percentage of VO_{2max} or VO_{2max} heart rate) or a controlled hyperthermic (altering work rates to maintain a core temperature of 38.5°C) approach may have been more applicable in terms of matching exercise intensities across the cycling and running modes.

Due to funding constraints, core body temperature was not measured during the six training sessions in Chapter 3. Thus, there was little empirical observation on the players core temperature during these sessions. The variable changes in perceived thermal sensation during the training sessions, and subsequent disassociation between core temperature and thermal sensation following the post-intervention HST, indicate the training sessions were not taxing enough to sufficiently elevate core body temperature. In light of the large training effect, irrespective of the intervention conditions, the players may have benefited from establishing a baseline level of fitness prior to undertaking heat training. The players benefited more from the additional training as opposed to specific heat training at this time.

In Chapter 4, there was a substantial difference in time-to-exhaustion running capacity between conditions at baseline. Consequently, this required post-intervention values to be adjusted to baseline to ascertain the differences in running capacity between conditions. It was acknowledged that alternative methods of analysis may have accounted for this difference at baseline. However, the more contemporary method of analysis (detailed in Chapter 4 methods) offers the same function as the more traditionally utilised methods would have to account for the difference in running capacity at baseline. This adjustment implies the randomisation of players to conditions failed to be completely effective, highlighting the challenges of implementing rigorous group allocations in a sporting context. Tympanic temperature was used to monitor core temperature during the six-training session in Chapter 4 as a practical, inexpensive and non-invasive alternative to ingestible core temperature sensors or rectal thermometers and can also be easily be used in the field. Given that tympanic temperature is often variable, it was difficult to ascertain the (true) core temperatures of the players and whether core temperature was sufficiently elevated to 38.5°C during the repeated sprint interval sessions.

With the lack of thermal adaptation observed, an increased training load and possible belief effect likely facilitated the improvements in running capacity. As time-to-exhaustion tasks are often variable, a laboratory or field-based task more specific to the nature and/or activity patterns of team sports may have been more appropriate for assessing thermal adaptation and exercise capacity. Despite the applied nature of this study, it did not include a performance test in cooler conditions. This inclusion would have been beneficial for assessing whether or not running capacity would have been similarly improved in cooler conditions. Finally, passive heat exposure may have been better undertaken post-exercise and for a duration longer than 20 min.

A further limitation to the applied nature of the two studies undertaken was that football-specific training, game loads and measures to fatigue were not specifically monitored outside of the study. Thus, it is difficult to identify the impact outside training (football) and games on specific physiological measures and performance tests pertaining to the respective studies. Given the real-world scenarios in which the studies were applied, having to manage player logistics was challenging and thus, the time available for extra sessions such as a familiarisation session was limited. In Chapter 4, the repeated sprint interval cycling training sessions were controlled by a pre-set interval timer with audio sounds signalling the beginning and end of each sprint. Players were asked to complete a maximal effort for each 10 s sprint. Following the first session (and possibly second) there may have been a learning effect as a result of not having an initial familiarisation session prior to commencing the study. The players may have adapted their sprint pace across the sessions to ensure they were able to complete the required 40 min repeated sprint interval session. It is possible that not all sprints were to the player's maximal capacity. Lastly, psychological measures to assess the players beliefs or attitudes towards heat training may have had an influence on the respective outcomes but were not included in either study.

Practical Applications and Considerations

The strength of this research highlights that heat training has the potential to offer more than the classical thermoregulatory benefits when applied in a real-world context (Figure 5.1). The outcomes of this research can be applied by coaches and support staff when considering the inclusion of heat training at different phases of the season.

- When considering heat training, coaches, conditioning staff and sports science advisors should have a clear understanding of the program's objectives and rationale behind the decisions to engage heat training (i.e. conditioning effect, specific acclimation, regaining fitness post-injury). The context and influence of factors such as baseline fitness, external environmental conditions (if undertaking indoor heat exposure), timing of the season, and player's perceptions and beliefs pertaining to heat training, should be considered when designing heat training programs for team sports.

- Moderately fit team sport players benefit more from additional aerobic conditioning over specific heat training during the pre-season. Conditioning coaches should assess the fitness levels of players in the planning of pre- and in-season training. Laboratory-based heat training may be better undertaken late in the pre-season just before the commencement of the competitive season.

- State-level team sport players likely need to establish a substantial baseline level of fitness prior to engaging laboratory-based heat training during the pre-season. A program involving short repeat sprint or high intensity intervals may be better suited to the team's pre-season goals as opposed to longer 8 min efforts.

- Mixed-mode heat training involving stationary cycling and treadmill running is practically relevant for team sports as cycling allows adequate training intensity to be maintained while reducing lower limb load and running an element of sports specificity.

- Intermittent, mixed-mode heat training can be applied during the pre-season (or during the season) allowing players to maintain field-based skills training. Treadmill running includes an element of sports specificity and stationary cycling reduces the amount of 'time-on-legs'.

- Short 40 min repeated sprint cycling intervals involving a series of maximal 10 s efforts were well tolerated by the players when undertaken on the off-days to field-based sport-specific training. This outcome indicates that intermittent heat training can be successfully integrated with sport-specific training and game commitments during the competitive season.

- Stationary repeat effort cycling training in the heat can improve subsequent running performance in hot conditions. This indicates that cycling training is an effective conditioning method for running-based team sport players.

- Passive heat exposure offers a practical alternative for prolonging heat exposure without necessarily needing to undertake extended periods of high intensity or prolonged exercise.

- Passive heat exposure is an efficient means of exposing multiple players in a short time frame with potential physiological and performance benefits.

- Intermittent day heat training is evidently more practical for team sports as it allows players to fulfil team training and game commitments simultaneously as required..

- In state-level team sport players, the perceived benefits of engaging heat training may complement increases in training load and any underlying thermal/physiological adaptations in facilitating a performance outcome.

- The short duration mixed-mode (5 x 8 min efforts) or repeat sprint interval (6 x 5 x 10 s) training interventions in hot conditions could be used interchangeably throughout the pre-and-in season as required.

Directions for Future Research

The competitiveness of field-based team sports is continuously increasing and so is the level of athleticism required by players to meet this demand. The interest from coaches, support staff and athletes to employ heat training to improve athletic performance is apparent. However, the application of heat-training within a real-world team sport setting remains under investigated. The research outcomes highlighted in this thesis provide incentive for future areas of research specific to team sports.

- Future studies involving team sport players should consider a mixed-mode training intervention However, to ensure that exercise intensities are appropriately matched across modes, a controlled/relative intensity (i.e. a percentage of VO_{2max} / VO_{2max} heart rate) or controlled hyperthermia (altering work rates to maintain a core temperature of 38.5°C) prescription[17] method should be considered.

- In terms of physiological adaptations, when pre-season training coincides with the warm summer months, teams should be encouraged to undertake field-based skills and conditioning sessions outdoors during the warmer parts of the day. A direct comparison between field and laboratory-based heat training on thermal/physiological and performance adaptations has not been explored and is of practical and research interest. Where possible, core body temperature should be assessed during field and laboratory heat exposures to determine whether the nature of exposure is sufficiently demanding enough to elevate core temperature required for adaptation.

- The use of passive heat exposure either independently or following sport-specific training in team sports is feasible given the ability to expose multiple players at one time. For practical purposes, the influence of passive heat exposure on performance would be of interest for coaches and athletes.

- Currently, there is no information on the effect heat training has on other forms of training (i.e. weights or skills sessions) when undertaken concurrently. These insights would enhance the ability to manipulate traditional practices to evaluate other applications of heat exposure among team sports, and also the periodisation of heat training into the team's annual plan.

- High intensity and/or repeat sprint interval training in the heat is preferred among team sport players. This form of training has the potential to increase player fatigue, however, the time course of fatigue, soreness and reduced exercise capacities have not been previously investigated in team sports. Assessing player fatigue both objectively and subjectively during consecutive day and intermittent day heat exposure would be informative for prescribing heat training in addition to regular sport-specific training.

- Appropriate perceptual measures and questionnaires on beliefs and attitudes towards heat training should be employed to determine whether improvements are perceptually mediated as much as they are physiologically driven.

- Future heat training studies involving team sports should include a performance trial in cool conditions to assess the transfer of heat-related benefits back into a sport-specific setting.

- The interventions explored in Chapter's 3 and 4 could be a useful option for injured or rehabilitating athletes as a way of increasing their fitness in preparation for their return to full training. The imposed physiological benefits from being exposed to the heat are an appealing means of increasing cardiovascular stress without necessarily increasing musculoskeletal load.

Conclusions

Short-term heat training should be a useful training intervention for team sports and can be incorporated into the daily training environment without disrupting sport-specific goals and priorities. With some modifications, either one of the two heat training interventions evaluated here (5 x 8 min cycling/running or 6 x 5 x 10 s cycle maximal efforts) can be effectively integrated into the team training schedule. Many of the mechanistic thermoregulatory and physiological responses associated with heat training often are similar to those induced by habitual exercise training in thermoneutral conditions.[56] Hence, the combined stress of physical exercise and the heat stimuli has the potential to prompt fast-tracked fitness and performance benefits a misted an already congested team sport training schedule without impacting sports-specific training.

Traditional practices involving consecutive day designs consisting of low-moderate, continuous exercise for >60 min is not practical for team sport athletes. Usually undertaken as a means of negating performance decrements and enhancing thermal tolerance for competition in hot environments, it is apparent that heat training has the potential to offer more than just thermoregulatory benefits. In state-level football, moderately fit players heat training appears to have the potential to complement and/or accelerate general training related fitness adaptations offered by regular exercise training alone. When eliciting heat acclimation is not the direct priority, short-term intermittent heat training interventions can be implemented into the daily training environment in addition to sport-specific training (i.e. field-based sessions) and weekly games. Similarly, heat training has the potential to complement and/or enhance team sports performance in temperate environmental conditions.[3,4] This is particularly appealing for predominately winter-based team sports seeking a competitive edge over their competitor.

During the pre-season, it appears that state-level football players benefit more from brief periods of intensified training, as heat training offered little additional benefit above those obtained from training in temperate conditions. Nonetheless, the novel mixed-mode training method is practically relevant for field-based teams sports as it offers variety, maintains an element of sports-specificity, and reduces 'time-on-legs' during the pre-season. Given the moderate fitness level of the players early in the pre-season, this protocol may have yield more substantial thermoregulatory benefits or adaptations if players had an established baseline level of fitness prior to commencing heat training.

A short-term program comprising six repeat sprint cycling sessions over 12 days with and without passive heat exposure was effectively implemented during the competitive season (Chapter 4). In contrast to Chapter 3 (5 x 8 min cycling/running intervals), there was a substantial greater improvement in running performance capacity after combined passive and active heat exposure than the temperate condition. Although there was a small difference in performance improvements between active heat and temperate, it was unclear. During the season, it appears that combined passive and active heat exposure is more beneficial for improving running capacity than training in temperate conditions alone.

Acknowledging that the players' threshold for general fitness related improvements to develop was greater than that of thermal adaptation, which would typically account for subsequent performance improvements in hot conditions, the observed increases in running capacity may have also been perceptually mediated. The idea that heat training may have imparted a belief effect, and could offer a potential placebo effect for improving performance without actually being administered as a placebo,[106] is of interest and a concept that is unexplored. If it is not thermal adaptation per se that teams seek, a combination of passive and active heat exposure is appealing for winter-based sports seeking a late-season conditioning and performance top-up.

Ultimately, there is no one-size-fits-all approach to programming heat training. No two teams are the same and designing a best-fit heat training program will need to consider evidence-based guidelines, and what is practically feasible for the individual team and its players, to facilitate the maximum heat exposure possible. While future work in applying heat training to team sports is required, it seems that a compromise between evidence and practice will inform planning, execution and review of team sport heat training programs.

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