The effects of post-training hot water immersion on concurrent training load and treadmill running performance in the heat

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Abstract

Background: Team-sport athletes of both elite and sub-elite status are often required to travel to hot and/or humid environments for competition; however, preparing for these environmental challenges can be difficult within a team-sport setting. Heat acclimation (HA) strategies for team-sports can typically involve the use of expensive equipment, or travel in advance of competition to naturally acclimatise to the competition environment; these may also affect the quality of concurrent training. These logistical challenges often faced by team-sports when preparing for competition in hot environments often dictate what is (un)available to them. Post-training hot water immersion (HWI) has emerged as a passive approach that is logistically friendly for sporting teams to use during a preparatory period for competition in the heat.

Aim: To investigate if 6-days of post-training HWI is an effective HA strategy for sub-elite, male, team-sport athletes, has any detrimental effects on concurrent training load and if it can improve aerobic capacity in the heat.

Methodology: In a randomised control study, fifteen, non-acclimatised, moderately-trained males performed an intermittent running protocol in temperate outdoor conditions (18°C, 67% RH) for six consecutive days followed by a post-training cool-down (CON; n=8) or an additional 40 min of HWI in 38°C (n=7). Three days before and two days following the intervention, participants completed a RAMP treadmill run in the heat (33°C, 30% RH).

Results: The HWI group displayed a reduced mean heart rate ($p=0.02$) during immersion from day-1 to day-6 (by 14±10 beats$\cdot$min^{-1}) and improved feelings (by 0.9±0.5 AU; $p=0.003$). Daily HWI had no detrimental effects on concurrent training as no significant differences (all $p<0.05$) were found between groups for total distance run, session RPE and the composite measure of training load (duration x RPE). Treadmill VO_2peak improved from pre-post for the HWI group (by 2.1 ml$\cdot$kg$^{-1}\cdot$min^{-1} or 4.2%; $p=0.003$) but not the CON group (0.2 ml$\cdot$kg$^{-1}\cdot$min^{-1} or 0%; $p=0.88$).

Conclusions: Six consecutive days of post-training HWI induces partial HA in moderately trained team-sports athletes with no detrimental effects on concurrent training load. This provides a practical acclimation strategy for sporting teams to implement when preparing for competition in the heat that acknowledges the logistical challenges often faced.

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List of Abbreviations

A

AFL	Australian football league

B

BLa	Blood lactate
$b \cdot min^{-1}$	Beats per minute

C

D

E

ES	Effect size

F

H

Hct	Haematocrit
HR	Heart rate

I

K

kg	Kilograms
$km \cdot h^{-1}$	Kilometres per hour

L

LIST	Loughborough intermittent shuttle test
L	Litres

M

m	Metres

$m \cdot s^{-1}$	Metres per second
min	Minute
mmol·L	Millimoles per litre

O

O_2	Oxygen

P

PV	Plasma volume

R

RPE	Rating of perceived exertion

S

SD	Standard deviation
s-RPE	Session-rating of perceived exertion
SR	Sweat rate

T

T_c	Core temperature
ThC	Thermal comfort
ThS	Thermal sensation
TL	Training Load
T_{sk}	Skin temperature

U

USG	Urine specific gravity

V

VO_2	Oxygen consumption

VO_{2peak}	Peak oxygen consumption
VO_{2max}	Maximum oxygen consumption

W

WBGT	Wet bulb globe temperature

Y

Yo-Yo IR	Yo-Yo intermittent recovery test

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Chapter One: Introduction

Exercising for prolonged periods in the heat can become a physiological challenge, our body's thermoregulatory, cardiovascular, neuromuscular and osmoregulatory all become strained due to increasing body temperature and internal heat storage. This physiological challenge can impair exercise performance, specifically aerobically-based activities such as team-sports; therefore, appropriately preparing for these stressful environmental conditions is necessary for optimal performance. Modern pinnacle sporting events such as the Summer Olympics and FIFA World Cup have a trend of being hosted in hot and/or humid environments e.g. 2008 Beijing, 2016 Rio de Janeiro, 2020 Tokyo Olympics and 2010 South Africa, 2014 Brazil, 2022 Qatar FIFA World Cup. These locations along with other similar environments need to be considered by all athletes during their respective preparatory periods to offset environmentally-induced impairments in performance. Smaller competitions involving primarily amateur or youth team athletes are also often required to travel to hot and/or humid environments, e.g. NZ sporting teams often travel to places which frequently display high temperatures like the Pacific Islands or Australia for competition. Sub-elite teams also need to prepare appropriately for these environmental conditions due to lower fitness levels compared to elite athletes, as their performance can be highly influenced by the environmental conditions in which they are playing. Sub-elite teams often face the same environmental conditions as elite teams during competition but will have a different set of resources that are (un)available during their respective preparatory period which can dictate how they prepare for the heat.

Heat acclimation (HA) is an effective method for improving aerobic exercise performance in hot and/or humid conditions. Exposing an athlete to natural or artificially produced heat for a certain period will induce physiological adaptations that widen the dynamic regulatory range of body temperature (Horowitz, 2002). HA can result in numerous physiological adaptations that improve thermoregulation, cardiovascular stability, thermotolerance, fluid-electrolyte balance, and reduce perceived physiological strain leading to enhanced submaximal and maximal aerobic exercise performance in the heat (Chalmers, Esterman, Eston, Bowering, & Norton, 2014; Periard, Racinais, & Sawka, 2015). Preparing team-sport athletes is critically important as the physiological strain experienced during intermittent based team-sports is typically higher compared to continuous exercise. Team-sport athletes are also typically larger and more heavily clothed unfavourably affecting heat production and dissipation (Taylor & Cotter, 2006). HA regimes are frequently used for team-sports to prepare them for competition in hot environments but given that most sporting teams come together at short-notice, they are often time-scarce before competition departure. A short-term HA (STHA; <7-days) protocol is often the more practical protocol vs. longer, more time-consuming protocols (>7days). STHA protocols ranging from 4-6 days have shown beneficial results that can induce physiological adaptations to improve exercise performance in the heat (Sunderland, Morris & Nevill, 2008; Garrett, Goosens, Rehrer, Patterson & Cotter, 2009; Petersen, Portus, Pyne, Dawson, Cramer, & Kellet, 2010; Garrett, Creasy, Rehrer, Patterson, Cotter, 2012; Chen, Tsai, Lin, Lee, & Liang, 2013; Kelly, Gasitn, Dwyer, Sostaric & Snow, 2016; Neal, Corbett, Massey, & Tipton, 2016). These studies have shown that for teams and athletes who have minimal time together before competition in hot and/or humid environments, HA can still occur in as little as 4-days of exposure. Recently, more passive approaches to HA involving post-training hot water immersion (HWI) and post-training sauna bathing have shown encouraging results. Findings have shown that post-training HWI can induce physiological adaptations comparable to traditional exercise based-heat acclimation (Shin, Lee, Min & Yang, 2013; Brazaitis & Skurvydas, 2014) and improve exercise performance in the heat (Zurawlew, Walsh, Fortes & Potter, 2016; Zuralew, Mee, & Walsh 2018). Similar protocols employing sauna bathing following exercise have also shown to improve endurance exercise performance (Scoon, Hopkins, Mayhew & Cotter, 2007) and induce partial HA (Stanley, Halliday, D'Auria, Buchheit & Leicht, 2015). Although exercise-induced HA will likely produce greater physiological adaptation, following the concept of specificity, it will have greater transfer to performance improvements in the heat due to similar movement patterns to the sport of focus. The advantage of implementing passive approaches to HA such as post-training HWI and sauna bathing is that it could minimise any detrimental effects these HA strategies could have on concurrent training load (TL)/quality in comparison to an exercise-based HA regime. These studies show HA can be attained for team-sport athletes to cope with the physiological challenges of exercising in the heat, but often do not acknowledge the logistical challenges that teams often come up against during preparation for competition.

Research on performance in the heat has given sport scientists a great understanding of the physiological challenges it can impose and how HA can effectively combat these challenges. In a practical sense, challenges beyond the physiological, such as logistical, can often dictate what is (un)available for a team to prepare for competition in hot and/or humid environmental conditions. Different sporting teams will face different sets of logistical challenges at both the elite and sub-elite level, these need to be considered given the importance they can have during preparation for competition. Potential logistical challenges a team might face could be a lack of financial means to travel in advance of competition to naturally acclimatise to competition conditions, lack of access or finances to use an environmental chamber during preparation, minimal time before departure leading to prioritising of field-based training and maintaining and controlling TL. TL during a competition preparatory period should always be monitored as additional loading from a HA intervention could have a detrimental effect on the quality of concurrent team-based training. From the coach's point of view, he/she will be unwilling to employ any HA strategy that may interfere with the quality of their training. Especially for teams with minimal time together before departure, as the coach will want to make the most of that time for high-quality training to implement their own philosophies, plays, and tactics to transfer to match-play during competition. Therefore, monitoring TL is something that is extremely important when implementing any intervention to address the competition environment. The logistical challenges are often under acknowledged in the literature, despite numerous HA protocols being investigated, few studies give practical application with consideration for these challenges faced by team-sports. Therefore, the purpose of this study is to investigate the effects of post-training HWI as a practical HA strategy for sub-elite team-sport athletes, with consideration for the logistical challenges commonly faced during the competition preparatory period.

Chapter Two. Literature Review

2.1 Introduction

The following chapter provides an extensive review of the published literature regarding the impact the environment can have on team-sport performance, the practical application of heat acclimation (HA) with consideration for the vast range of resources (e.g. money, time) that may be (un)available for a given team. It touches on an often-under acknowledged aspect of HA literature, the effects of HA on concurrent training load and quality. This review then leads into a discussion of practical HA strategies that consider the logistical challenges often faced by teams during the competition preparatory period.

2.2 Demands of Team-Sports

Team-sports such as football, hockey, rugby at the elite level are played and viewed in countries all over the world. For example, the International Federation of Football Associations (FIFA) have reported that football playing numbers are close to 270 million participants worldwide including men, women and children (Barengo, Meneses-Echávez, Ramírez-Vélez, Cohen, Tovar, & Bautista, 2014). The final of the 2015 Rugby World Cup was viewed by 120 million people worldwide, along with 2.47 million tickets sold across the tournament ("RWC 2015 declared", 2015). Global events and worldwide popularity of team-sports can create pressure and expectations of elite players to perform at the highest quality week-in week-out, despite increasing game intensities (Wisbey, Rattray, & Pyne, 2008; Barnes, Archer, Hogg, Bush & Bradley, 2014) and differing environmental conditions. The increasing physical and physiological demands that team-sport athletes face is largely dictated by position, style of play, opposition, environmental conditions and level of competition.

2.2.1 Physical Demands

Most team-sports are of intermittent nature where they are dominated by relatively low-moderate intensity activity but interspersed with high-intensity actions. A football match (approximately 93-minutes in duration) can be characterized by approximately 1,200 acyclical and unpredictable changes in activity (every 3-5 seconds), activities typically involving various speeds of running, 30-50 sprints, more than 700 turns, and 30-40 tackles and jumps (Iaia, Rampinini, & Bangsbo, 2009). Other activities include accelerations, decelerations, kicking, dribbling and numerous technical skills (Iaia et al, 2009). Football players perform low to moderate-intensity work for approximately 70-80% of match duration, with the remaining 20-30% made up of high-intensity work. Time-motion analysis has shown that top-class football players on average will cover between 10-13km per match (Bangsbo, Mohr, & Krustrup, 2006; Dellal, Chamari, Wong, Ahmaid, Keller, Barros, Bisciotti, & Carling, 2011) and perform approximately 2-3km of high-intensity running (>15 km/h) and 0.6km of sprinting (>20 km/h) during a football match (Iaia et al, 2009). Elite hockey players have been shown to cover an average distance per position of 8,160±428m. This is significantly less than the average distance an elite football player would cover, this may be due to the smaller pitch size used in hockey. This total distance is predominantly low and moderate-intensity running interspersed with bouts of high-intensity actions, elite hockey players have displayed an average of 37 high intensity efforts at speeds >19 km/h (Lythe & Kilding, 2011). Contact sports such as Rugby Union and Rugby League are very position dependent in terms of the physical demands they face during match-play. Backs tend to cover a larger total distance compared to forwards, with distances ranging from 5,489 to 7,994m for backs and 5,139 to 7,006m for forwards during elite rugby union match-play (Cunniffe, Proctor, Baker, & Davies, 2009; Austin, Gabbet, & Jenkins, 2011; Coughlan, Green, Pook, Toolan, & O'Connor, 2011; Cahill, Lamb, Worsford, Headey, & Murray, 2012; Lacome, Piscione, Hager, & Bourdin, 2014). Backs will also commonly spend longer time at higher running speeds vs. forward players (Cunniffe et al, 2009; Austin et al, 2011; Coughlan et al, 2011; Lacome et al, 2013).

2.2.2. Physiological Demands

Team-sports will often tax the aerobic energy system significantly, as football players can often display an average maximal oxygen uptake of around 70-80% during match-play (Alghannam, 2012) along with mean and peak heart rate (HR) of around 85% and 98% of maximal values been reported, respectively (Bangsbo et al, 2006). Although the primary source of energy is supplied by aerobic metabolism, the high-intensity efforts are an essential part of the game, increasingly so between levels of competition as high-intensity anaerobic activity has been reported to distinguish between different standards of players e.g. sub-elite vs elite (Stølen, Chamari, Castagna, & Wisløff, 2005). To perform short sprints and high-intensity actions such as jumping, tackling, turning and duel play requires anaerobic energy production, these actions can be crucial to the outcome of the match. This can create a high metabolic demand on players as the large amount of high-intensity actions (approximately 150-250) indicate that the rates of creatine phosphate (CP) utilization and glycolysis are frequently high throughout football and other team-sports (Bangsbo et al, 2006). Low muscle glycogen is correlated to fatigue and a decrease in performance (Balsom, Wood, Olsson, & Ekblom, 1999; Williams & Rollo, 2015) this is important given that the rate of muscle glycogen depletion is accelerated when exercise is performed in hot conditions (Febbraio, Snow, Stathis, Hargreaves, & Carey, 1994). Analysis of rugby union match play has shown players display a mean HR of 172 and 170 $b \cdot min^{-1}$ for backs and forwards, respectively. Accompanied by an estimated percentage of VO_{2max} during an entire match of 82% and 85% for backs and forward, respectively (Cunniffe et al, 2009), values slightly higher, but very similar to those during a football match. A later study using Super 12 rugby teams showed similar HR responses as measured at %HR peak, (84%; outside back, 82%; adjustables, and 84%; forwards; Waldron, Twist, Highton, Worsfold, & Daniels, 2011). These similar physical and physiological demands between team-sports are on a very generalised level, the more in-depth demands can still vary greatly between sports. The physical and physiological demands of team-sports have increased over time (Wisbey et al, 2008; Barnes et al, 2014) which can subsequently increase the physical strain experienced. Any additional stress from the environment, such as high heat and humidity, may augment the physical/physiological strain on athletes and impair performance. This highlights the importance of preparing appropriately for these conditions given the high physical/physiological demands of team-sport alone. The demands outlined in this section were recorded during temperate conditions, at the same given output, performance in the heat will result in a higher cardiovascular output along with higher body temperatures compared to a cooler environment leading to higher physical/physiological strain (Maughan, Shirreffs, Ozgünen, Kurdak, Ersöz, Binnet, Dvorak, 2010).

2.3 The Impact of Heat on Team-Sport Performance

It is beyond any doubt that the capacity for humans to perform exercise in hot and/or humid environments for a prolonged period is impaired due to increased heat storage (Flouris & Schlader, 2015). Team sports, both professional and amateur all over the world experience playing in hot conditions with many players competing almost year-round, including the hot summer periods. This can pose a big problem for sporting teams as the heat and humidity has been shown to impair athletic performance by 6-16% (Casadio, Kilding, Cotter & Laursen, 2016), but not all players will prepare appropriately for the hot conditions to minimise the detrimental effects it can impose, for these athletes, an impairment in performance will be inevitable. A study by Mohr, Nybo, Grantham, & Racinais, (2012) compared the physiological responses and physical performances in two football matches, one match in temperate conditions (21°C) and the other in hot conditions (43°C). Players decreased total running distance (-7%) along with high-intensity running (-26%) when the match was played in the heat compared to the temperate conditions. A later study (Aldous, Chrismas, Akubat, Dascombe, Abt, & Taylor, 2016) showed similar impairments in a simulated football match in the heat (30°C, 50% RH) vs. temperate conditions (18°C, 50% RH). In the hot condition, players decreased total distance (-4%), high speed distance (-7%), and variable distance (-13%) compared to the cooler condition. Professional football players competing in the heat (35°C) typically display significantly higher levels of dehydration (3.38±1.11%) accompanied by a high core temperature (Tc; >39°C), these physiological changes can negatively influence performance and should be addressed (Aragon-Varagas, Moncada-Jimenez, Hernandez-Elizondo, Barrenechea, & Monge-Alvarado, 2009). These studies highlight the detrimental impact the heat can have on football performance (i.e. reduced high-intensity running) compared to temperate conditions during match-play. Players will often adjust their behaviour and running patterns, producing a pacing strategy to cope with the stressful environment in which they are competing. Data from the recent FIFA World Cup in Brazil 2014 analysed the environmental conditions in over 64 matches and classed them into three categories (low, moderate, and high) based on the amount of environmental stress (WBGT; wet bulb globe temperature) the players would experience. Physical and technical indices were then recorded for each respective match as an average of both teams playing. As WBGT increased with match-play, players tended to increase low-intensity running with a subsequent decrease in high-intensity running, showing players would slow the pace of the game to match environmental conditions to avoid attaining high body temperatures. The rate of successful passes per minute also increased with higher environmental temperatures, suggesting players would play safer passes to avoid any unnecessary running that would waste energy, such as chasing long passes (Nassis, Brito, Dvorak, Chalabi, & Racinais, 2015). This study shows that elite football players will alter their activity pattern during match-play depending on the environmental conditions to preserve global match characteristics (e.g. similar playing time, goals scored). Suggesting that a team who prepares appropriately for environmental conditions will not need to implement a pacing strategy and would be able to sustain higher intensity running/movements for longer periods of the match, resulting in a superior performance.

Australian Football (AFL) players have shown similar alterations during competition in the heat, Duffield, Coutts, & Quinn, (2009) analysed T_c responses and running performance of AFL players during match-play in warm conditions (>29°C). The novel finding was that when T_c rose to a certain level during the match, it plateaued with minimal changes observed in the final quarter of the match. This was regulated by a reduction in moderate-intensity activities (speeds of 7.0-14.4 km/h), showing that pacing strategies were employed by the athletes to cope with the internal heat load and preserve ability for high-intensity running. Similar results found in a later study (Aughey, Goodman, McKenna, 2014) showed that AFL players reduced low-intensity running activity in the latter stages of each half of matches played in hot conditions (27±2°C, 58±15% RH) to preserve energy for high-intensity running compared to matches played in cooler conditions (17±4°C, 51±11% RH). These studies reported that elite AFL athletes will commonly reach a T_c approaching 40.0°C which is commonly known to put an athlete at risk of developing heat illness but will employ a pacing strategy to avoid further increases in T_c. Although none of the athletes showed any signs or symptoms of heat-related illness, this may have been due to their superior physiological make-up and mental strength to manage internal strain. Data from one of the recent World Rugby Sevens series investigated T_c rises during match play in both warm (Singapore) and temperate (London) environments. Interestingly, no differences were found in T_c values between the two environments, with some players reaching T_c values of above 39°C in both warm and temperate environments. Showing despite environmental conditions, T_c approached values associated with both heat illness and reduced repeated sprint performance, highlighting the high physical demand of rugby sevens and the physiological strain they can induce on players (Drust et al, 2005; Taylor, Thornton, Lumley & Stevens, 2018).

The maintenance of physiological function is extremely important during team-sport competition, it is well-known that as fatigue develops over the course of a game which can lead to a decrease in skill performance, even more so when performed in hot conditions. Sunderland, Morris, & Nevill, (2008) investigated intermittent running and skill performance with female hockey players in the heat. Nine hockey players performed the Loughborough Intermittent Shuttle Test (LIST) concurrently with three specific field hockey skill tests in both hot (30°C) and temperate (19°C) conditions. Hockey skills test performance decreased following the intermittent running protocol, but the decrement in performance was greater when it was performed in hot conditions, likely due to the significantly higher body T_c, HR, rating of perceived exertion (RPE) and blood glucose values observed. Impairment of skill performance could also be due to reduced cognition, which has been shown to be negatively affected in the heat (Simmons, Saxby, McGlone, & Jones, 2008). This can impact decision-making, understanding plays/tactics, and reading the opposition, ultimately affecting performance. A review by Lieberman, (2007) explained that when 2% or more reduction in body weight is induced by heat and exercise exposure, detriments in visual-motor tracking, short-term memory and attention are reported. This reduction in bodyweight during match-play in the heat has consistently been observed in football players (Shirreffs, Aragon-Vargas, Chamorro, Maughan, Serratosa, Zachwieja, 2005; Aragon-Vargas et al, 2009; Mohr et al, 2012), showing cognitive impairments can frequently occur during team-sport match play. Understanding that exercising in the heat can affect more than just the physiological, it's negative impact on cognition can also contribute to performance impairments. These studies highlight the impact heat can have on team-sport performance and how athletes will often alter their activity patterns for the given environmental conditions with the aim of maintaining performance. If athletes prepare appropriately for competition in the heat, athletic performance (physical, physiological and cognition) can be maintained or improved when coming from temperate environments. This can lead to an advantage over opponents who are not acclimatised to the environmental conditions, as they are forced to alter competition behaviour/movement patterns, potentially limiting optimal performance.

2.4 The Reality of Performing in the Heat

Modern global competitions such as the Summer Olympics and FIFA World Cup are frequently hosted in hot and/or humid countries, (e.g. Beijing 2008, Tokyo 2020 Olympics, and Brazil 2014, Qatar 2022 FIFA World Cup) meaning elite athletes from a range of sports all face the reality of travelling to countries to perform optimally in unfamiliar environmental conditions. Countries such as Qatar and Japan often display high environment temperatures, typically accompanied by high humidity levels. Humidity should be treated differently to hot and dry conditions as it can further reduce the ability of the body to dissipate heat due to the skin-environment temperature and water vapour pressure gradients necessary for the transfer of heat and evaporation of sweat is inhibited (Nielsen, 1996). A high relative humidity can prevent evaporative heat loss whereas evaporative heat loss is promoted when relative humidity is low. Larger domestic countries can show a high range of temperature and humidity, e.g. the NCAA Sun Belt Conference in the USA can see drastic changes in temperature at different playing locations, changes that can differ by as much as 20°C, with humidity varying as much as 36% (Coker, Wells, & Gepner, 2018). In the more elite setting, the environmental conditions can play a major part in performance and subsequent match outcome as shown in the final football match of the Beijing 2008 Olympic where on-field air temperatures reached 42°C (Maughan et al, 2010). These examples show the drastic environmental conditions both elite and sub-elite teams can face during competition. In New Zealand we would not find these drastic changes in environmental conditions, but due to its secluded location in the world this often means that NZ athletes are likely to travel to neighbouring countries for competition such as the Pacific Islands and Australia which frequently display high environmental temperatures. Not only at the elite level, but especially at the sub-elite level, such as amateur and age-group teams. These athletes are often travelling to these hot and/or humid environments for competition, typically during the colder months of the NZ winter. Hyperthermia and dehydration, which often occur can have severe negative effects on performance (Maughan & Shirreffs, 2004) and lack of acclimation is a major risk factor for exertional heat injury. Strategies to mitigate the effects of the environment on performance have been extensively researched, these strategies include acclimation/acclimatisation, hydration, pre-cooling and clothing selection. These methods should be appropriately implemented to avoid heat-induced impairments in exercise performance.

2.5 Heat Acclimation & Acclimatisation

Heat adaptation is a series of physiological changes that occur in response to heat stress over a certain period. The extent of adaption can be significantly determined by the length, duration, intensity of the protocol and the pre-existing fitness levels of the athletes. It is the most effective method to subside environmentally induced impairments in exercise performance, it can be completed in the natural environment (heat acclimatisation) or artificially invoked in an environmental chamber (heat acclimation). Heat acclimation (HA) produces a large range of physiological adaptations that can improve exercise performance in the heat, Sawka, Wenger & Pandolf, (2011) suggested that the "four classical markers of HA" were a lower HR, a lower body T_c, a higher sweat rate and improved exercise performance in hot conditions, Table 2.1 outlines further notable adaptations. The physiological adapyations and mechanisms that induce HA are beyond the scope of this review, see Périard, Racinias, & Sawka, 2015.

Table 2.1: Physiological adaptations produced from HA, adapted from Sawka & Young, (2000)

Thermal comfort – improved	Exercise performance - improved
Core temperature – reduced	Metabolic rate – reduced
Sweating – improved	Cardiovascular stability - improved
Earlier onset	Heart rate - lowered
Higher rate	Stroke volume - increased
Redistribution	Blood pressure- better defended
Skin blood flow – increased	Fluid balance – improved
Earlier onset	Thirst – improved
Higher flow	Electrolyte loss – improved
	Total body water – increased
	Plasma volume - increased

2.5.1 Team-Sport Heat Acclimation

It is typically reported that 10-14 days of heat exposure is needed to induce full adaptation (Sawka et al, 2011), but for team-sports this is typically not an appropriate protocol length to use during preparation for competition in the heat. A short-term HA protocol (STHA; <7-days) will often be the preferable choice, given its minimal time-commitment when considering the numerous other factors involved in team-sport settings e.g. strength and conditioning, on-field training, etc. Despite this, STHA can produce significant physiological adaptations and performance benefits for athletes. A recent meta-analysis (Tyler, Reeve, Hodges & Cheung, 2016) found no differences between short-term and medium-term (MTHA; 7-14 days) protocols on T_c adaptations and changes in HR. STHA had only a small effect on sweat rate, compared to larger effects observed by MTHA and long-term protocols (LTHA; >14-days). T_c, HR, thermal comfort (ThC), PV expansion and improvements in exercise capacity all seem to show significant improvements during STHA protocols as shown on Figure 2.1. Skin temperature (T_{sk}), resting measures and SR may require further exposures to the heat to produce meaningful changes. Showing that although full adaptation will not occur, it can still produce partial HA in a time-efficient manner and given other considerations for sporting teams during their build-up/preparatory period for competition, a STHA is a more practical and appropriate protocol for team-sports.

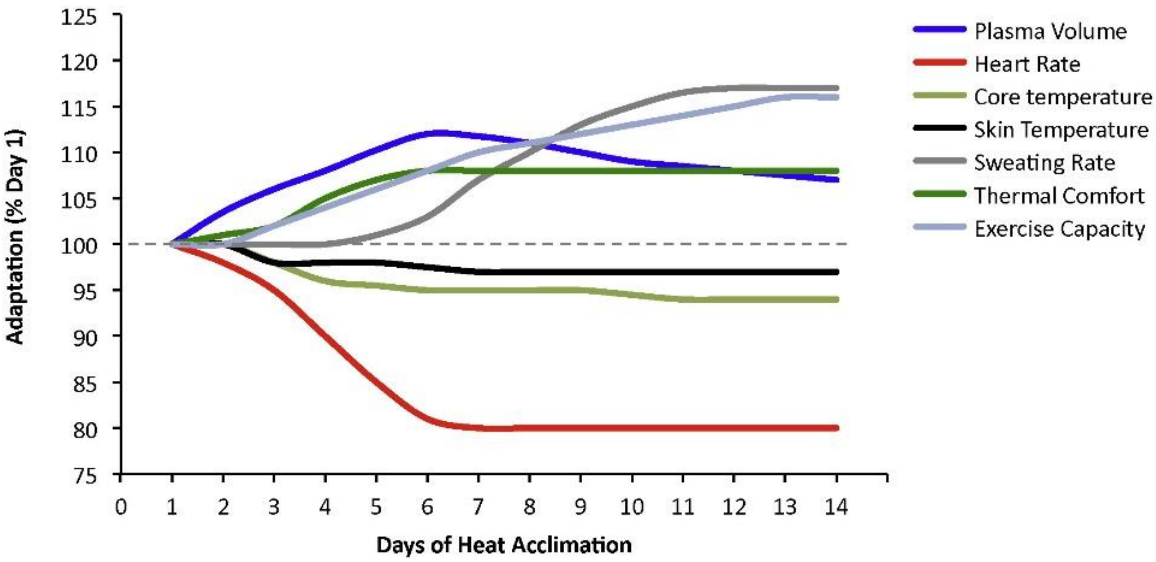


Figure 2.1: *The time-course of the physiological adaptions that occur with heat acclimation*

2.5.1.1 Football

The global popularity of football can create high expectations and pressure for players to perform week-in week-out, despite the differing environmental conditions they may face. Surprisingly, only a handful of studies have investigated HA for football teams to explore how footballers respond to HA strategies. Buchheit et al, (2011) analysed the effects of a week-long football camp in Qatar. A team consisting of 15-well trained football players completed a typical pre-season camp in hot conditions (7-days at 34.6±1.9°C), a pre- and post-camp Yo-Yo Intermittent Recovery 1 (Yo-YoIR1) test was performed in temperate conditions (22°C) to indicate improvements in intermittent running. Following the camp subjects produced a 7±9% increase in running time in the Yo-Yo IR1 post-test, PV expansion and a lower HR at the end of the Yo-Yo IR1. Although this study produced notable physiological adaptations associated with performance improvements in the heat, the post-intervention Yo-Yo IR1 test was performed in temperate conditions. If the post-test was performed in hot and/or humid conditions, we would be able to analyse how the observed physiological changes affected sport-specific running in the heat. A similar study by Racinais et al, (2012) also used semi-professional football players and completed an in-season acclimatisation camp in Qatar. The players completed a 90-minute football game in temperate conditions (22°C) followed by a 5-day training period in hot conditions (38-43°C), following this, subjects played another 90-minute match, but in hot conditions (43°C). HA increased the subjects sweat rate by 34%, accompanied by an 18% reduction in sweat sodium concentration during a standard heat-exposure test (30-minutes of walking followed by 30-minutes of rest), PV expansion occurred, but there were large individual variations (-10 to +20%). During the post-acclimatisation football match, further individual variations were observed in changes in high-intensity running (-16.4 to +21.5%), highlighting that the acclimatisation protocol improved physical performance for some players, but had no effect for other players.

The paucity of literature on HA specifically for football teams highlights the need for more research in this area, especially given its popularity and the various football competitions (e.g. FIFA World Cup, European Championships) often hosted in warm environments. The few studies that have been conducted were acclimatisation camps (Buccheit et al, 2011, Racinais et al, 2012), which is often not a practical option for a lot of smaller clubs and countries that lack the time and financial resources to travel in advance of competition to naturally acclimatise. It is important to note that the training camp used in Racinais et al, (2014) took place during pre-season, and the camp used by Buchheit et al, (2011) took place during the in-season for their respective teams. Adaptations induced by repeated heat exposure occur more quickly in trained athletes (Pandolf, Burse, & Goldman, 1977), therefore athletes who are in-season would be more trained vs. athletes who are completing pre-season and would adapt to training in the heat more quickly (Racinais et al, 2015). This is important to consider when bringing together a group of athletes for a competition preparatory period, some athletes may be playing in different leagues or clubs around the world which have differing schedules, potentially dictating their current fitness levels and subsequent heat adaption. A recent study (Pethick, Stellingwerff, Lacroix, Bergstrom, & Meylan, 2017) investigated the effects of a team-sport specific HA protocol primarily investigating PV changes in elite female football players. The athletes completed 5-days of training in the heat (34.8±0.2°C, 36.6% RH), training sessions were 90-minutes in duration and consisted of a 10-min warm-up, 20-min high-intensity intervals performed on a treadmill and bike, and 60-min circuit training that included all football specific exercises (e.g. squat variations, core stability exercise and plyometrics). The 30-15 Intermittent Fitness Test was used as the performance marker pre- and post-intervention. This short-term HA protocol was successful in increasing PV by 9.5% and running performance by 1.5% in thermo-neutral conditions (20°C), given that the HA protocol was isothermically controlled, T_c and perceptual measures (RPE, thermal sensation/comfort) were relatively stable throughout the acclimation period. Like Buchheit et al, (2011), the limitation of this study was that the performance test was not performed in hot conditions to show if HA would improve exercise performance in the heat.

2.5.1.2 AFL

Racinais et al, (2014) investigated the physiological and performance responses to a 14-day acclimatisation training camp in the heat (31–33°C, 34–50% RH) in elite AFL players. Following the 14-day camp, players produced significant improvements in Tsk, sweat sodium concentration (more dilute sweat), PV expansion and thermal sensation (ThS). Players improved running distance in the Yo-YoIR2 test (+311m) which was performed indoors in temperate conditions (23°C) and standardised training drills (+45.6m) in hot conditions (32°C) post-camp. The authors did reiterate the individual physiological and performance responses to the HA camp, further highlighting the need for individual monitoring during a HA regime.

Similar results in an earlier study (Buchheit, Racinais, Bilsborough, Bourdon, Voss, Hocking, Cordy, Mendz-Villanueva, & Coutts, 2013) where elite AFL athletes completed a pre-season training camp based in Qatar. Although this investigation was primarily focussed on monitoring the athlete's fitness, fatigue and running performance during the camp, they showed that after two-weeks of training in the outdoor heat (32±1°C) players improved Yo-YoIR2 running distance (+23.7m day^{-1}) in temperate conditions (23±1°C) and high-speed running during standardised drills (+4.1m day^{-1}) in the heat (32±1°C) similar to the results observed by Racinais et al, (2014). Kelly et al, (2016) used a shorter and more practical HA protocol with AFL players, they completed 5-days of high-intensity interval training (HIIT) on a cycle ergometer in an environmental chamber set at 38.7°C across a 9-day period (alternate days of HA). Players significantly improved RPE and thermal discomfort during the HIIT and sub-maximal cycling in the heat, blood lactate (BLa) and the rate of rise in T_{sk} also decreased. These studies show the benefits of HA for AFL players, like football they are predominantly acclimatisation camps or having the use of an environmental chamber, which is something not all AFL teams/players will be able to utilise given various logistical challenges (e.g. finances, time), therefore are not a practical option for some teams.

2.5.1.3 Other Team-Sports

Sunderland et al, (2008) used 17 female hockey players who completed 4-days of the LIST in the heat (30°C, 27% RH) across a 10-day period, a pre-and post-LIST was also completed in the heat as a performance measure. This STHA strategy improved total running distance by 33%, lower rectal temperature and an improved ThC following acclimation. This practical HA protocol showed that four sessions of intermittent and sport-specific running on alternate days can improve exercise capacity in the heat. A later HA study using cricket players (Petersen et al, 2010) found encouraging results whilst using a consecutive four-day HA regime. The subjects were split into an acclimation (ACC) or control (CON) group, both groups completed a 30-min treadmill run (10km$\cdot h^{-1}$) in the heat (30±1.0°C, 65±5% RH) pre- and post-intervention. The ACC group completed four consecutive days of high intensity cycling in the heat (30°C, 60% RH), whilst the CON group completed the same protocol in temperate conditions (20°C, 60% RH). Partial HA occurred in the ACC group, characterised by a moderate decrease in HR (-11 b$\cdot min^{-1}$), and moderate to large reductions in electrolyte concentrations Na^+ (-18%) and K^+ (-15%) compared to CON, they found trivial changes in T_c and T_{sk}. These aforementioned studies showed the effects of a consecutive and alternate day STHA protocol can have on team-sport athletes to improve exercise performance in the heat. The studies on AFL (Racinais et al, 2014; Kelly et al, 2016) and football (Buchheit et al, 2011; Racinais et al, 2012) athletes lacked a control group to analyse the training effect that may have occurred, potentially contributing to subsequent performance improvements and were primarily acclimatisation camps (10-14 days) which are often not a viable option for most team-sports. But other team-sport HA studies mentioned (Sunderland et al, 2008; Peterson et al, 2010) show encouraging results from as many as 4-days of heat training on exercise performance in the heat.

2.5.2 Decay, Maintenance and Re-Acclimation

In contrast to the induction of HA, the rate of decay is generally slower, allowing for maintenance or "top-ups" of the acquired physiological adaptations. It has been reported that for two days spent away from the heat, only one day of HA is lost (Givoni & Goldman, 1972). Higher levels of aerobic fitness seem to be associated with greater retention of HA as they have been shown to lose adaptations at a slower rate when inactive in a cool environment (Armstrong & Maresh, 1991; Pandolf, 1998; Weller, Linnane, Jonkman & Daanen, 2007),. A study by Weller et al, (2007) compared the decay and re-acclimation rates after 12- and 26-days following a 10-day HA regime. Both groups (12-day, 26-day) took only one re-acclimation day to re-attain the rectal temperature before and after exercise observed immediately after the HA period. Complete re-acclimation was attained after just two and four days of re-exposure to heat following 12 and 26 days of HA decay, respectively. Suggesting that once HA is attained, athletes could spend 2-3 weeks (depending on pre-existing fitness levels) in cooler conditions before returning to a hot environment, without the need for extensive re-adaptation to the heat. A later study by Pryor, (2015) showed that following 10-days of low-moderate intensity exercise (90-240-min) in a hot environment (40°C, 40% RH), intermittent heat exposures (every 5-days in a 25-day period) can maintain adaptations (HR, T_{sk}, T_c) that occurred during the acclimation period. Garrett et al, (2009) used 10-moderately trained participants who completed a 5-day STHA protocol involving 90-min exposure (40°C, 60% RH) using controlled hyperthermia (rectal temperature 38.5°C). A heat stress test (HST; 90-min of cycling at 40% PPO, followed by an incremental performance test) was performed on the 2nd and 8th day following the HA period, seven subjects then completed the HST a further 2- and

3-weeks following the HA period. Rectal temperature at the end of the 90-min was reduced (-0.3°C), HR at 90-min was also reduced (-13 $b \cdot min^{-1}$) following the HA period, these physiological changes remained at this level a week following the HA period, but not 2-weeks. Therefore, a STHA protocol (non-sport specific) can induce physiological adaptations that last up to a week following the last heat exposure, but not 2-weeks. A study by Casadio, Kilding, Siegel, Cotter, & Laursen, (2016) investigated the retention and re-acclimation responses during a HA protocol in elite sailors preparing for a World Championships in Oman (27-30°C, 40-60% RH). Two elite male sailors completed five consecutive days of HA which consisted of cycling for 45-60 min at a power output corresponding to 60-70% VO_{2max}. A heat response test (HRT) was used to assess the thermoregulatory responses in the two athletes, this was completed on day-1 and day-5 of HA as well as 1- and 2-weeks post HA. Contrary to Garett et al, (2009) most thermoregulatory adaptations that occurred during the HA period (improved HR, thermal discomfort and RPE) were maintained following two weeks of training in thermoneutral conditions, decreases in rectal temperature following HA were only maintained in one of the two athletes following the two-week decay period. In accordance with the findings by Weller et al, (2007) and Casadio et al, (2016), active HA could occur 2-3 weeks prior to leaving for competition, with 1-2 heat exposures in the final 1-2 weeks. that occurred during the HA period would be maintained and ensure the athletes will be re-acclimated for subsequent competition, whilst minimising any effect on quality of tactical based trainings in the final week where a taper is typically utilised. Although these studies did not use team-sport athletes, they still show the prolonging benefits of HA for both moderately (Garett et al, 2009) and highly trained (Casadio et al, 2016) athletes.

2.6 Logistical Challenges for Teams

Logistical challenges that arise during preparation for competition in hot environments can vary for different team-sports and competition levels. These challenges are always important to consider when looking to implement any sort of HA protocol, they can often dictate what can be used within the team setting and structure. Financial resources, accessibility, time and concurrent training load are typical considerations/challenges that team-sports often face before competition but are not always acknowledged in the research literature.

2.6.1 Financial Resources/Accessibility

Resources such as money, equipment and facility accessibility can be a challenge for many sporting teams when seeking to implement a HA protocol for competition. Many elite teams will have some access to an environmental chamber, which, as mentioned, can be effectively used for a HA protocol. For many sub-elite teams this is often not the case, they will not typically have access to a facility that houses an environmental chamber to use for HA. Lack of financial means can also hinder the chance of renting or hiring expensive equipment such as an environmental chamber, given other more important costs such as travel, accommodation, etc. Although this is a challenge, it should not prevent a team from wanting to acclimate prior to competition, other more logistically friendly alternatives exist that can be used to ensure that players are physiologically prepared for the environmental conditions.

2.6.2 Time

The time a team has before competition departure can dictate the method of HA that will be suitable. Due to larger number of players that typically make up a team, some athletes may be based overseas playing professionally with various clubs which have their own schedules and policies around releasing players. This may hamper these players time with team, adjusting to the team's culture, playing style and perhaps HA protocols that may be setup in preparation for competition. These players need to be considered when looking at employing a HA strategy i.e. ensuring they can complete the HA protocol set in place for the team to attain the same physiological and performance benefits that will be needed during competition. Teams will typically come together on short notice prior to competition, this leaves minimal time to train effectively and build team cohesion. Players will often have other commitments (e.g. strength and conditioning, recovery, video sessions, etc.) that need to be packed into a time-scarce schedule, further limiting time for HA. If access to an environmental chamber is available, it may still be difficult/time-consuming (depending on the size of the chamber) getting 15-20 players through each HA session. A taper period is usually incorporated during the final preparations for competition where training intensity is dropped in order to have players 'fresh'. If time is limited and a taper is to be integrated into preparations this can further strain the time available along with the additional loading on the player prior to departure. Time can often be the primary limiting factor with team-sports as the many factors that contribute to performance and preparation can leave little time for environmental considerations.

2.6.3 Training Load

In team-sports, monitoring training load (TL) provides the coach with feedback regarding compliance between planned and performed training drills. During preparation for competition, the coaching staff will have their own philosophies, tactics, plays they want to implement, which need to be performed during training sessions at a certain intensity to optimise transfer to match-play. When additionally implementing a HA protocol to help the team adapt to the upcoming environmental conditions, monitoring TL becomes increasingly important to ensure players are still fresh for the field-based training sessions. Different measures of internal and external load are used in both elite and sub-elite team-sport settings. HR and GPS-based measures of TL require expensive equipment, often not available to those sub-elite sports teams due to a lack of financial means. Although they are valuable measures of internal and external TL, they are often not practical for many teams. The use of a more practical method such as session-RPE (s-RPE) measure of TL is a valid indicator of internal load for team-sport athletes and can be easily implemented into the team setting (Impellizzeri, Rampini, Coutts, Sassi, & Marcora, 2004; Casamichana, Castellano, Calleja-Gonzalez, San, Román, & Castagna, 2013). Impellizzeri et al, (2004) found s-RPE to be significantly correlated to various HR-based measures of TL from 479 football training sessions (moderately trained athletes) collected, similar findings in semi-professional rugby league players following data gathered from 306 training sessions across a 7-week period (Coutts, Murphy, Pine, Reaburn, & Impellizzeri, 2003). S-RPE was significantly ($p<0.01$) related to several indicators of external physical load during training in semi-professional football players as Casamichana, et al, 2013 showed a relationship between s-RPE and players total distance covered, player load and frequency of efforts. S-RPE is a valid measure of TL for team-sport athletes and should be considered during preparation for competition when concurrently completing regular field-based training and HA sessions. It is a cheap and easy tool to implement within a team setting, allowing the trainer/coach to monitor and control TL during a HA regime, see Halson, (2009) for more information regarding TL.

2.7 Alternative Methods for Heat Acclimation

It may be unrealistic for all sporting teams (elite and sub-elite) to have access to facilities to use for HA or to travel in advance of competition to naturally acclimatise due to different logistical challenges outlined. This does not mean they are unable to prepare for the environmental challenge they will face during competition as other alternatives exist. Although exercise-based HA is the more effective protocol to develop sport-specific adaptions to help athletes cope with the heat, other methods of HA that are more practical and easier to implement and can still produce notable physiological adaptions to improve exercise performance in the heat.

2.7.1 Hot Water Immersion

Hot water immersion (HWI) involves submersing the body in water of warm temperatures (40°C to 44°C) for short periods of time (30-40 minutes), it has shown to be a viable method of inducing HA (Bonner, Hall, Harrison & Edwards, 1976; Shin et al, 2013; Brazaitis & Skurvydas, 2014; Zurawlew et al, 2016; 2018) leading to exercise performance improvements in the heat. Zurawlew et al, (2016) used 17 active, un-acclimatised males who completed a 6-day intervention involving a 40-min treadmill run at 65% VO_{2max} immediately followed by HWI at either 40°C (HWI group) or 34°C (CON group) for 40-min. The HWI group showed a decrease in resting rectal T_c and final T_c during submaximal exercise in hot conditions. T_{sk} and RPE also showed improvements following the intervention compared to the CON group. The HWI group also produced a 4.9% improvement in the post-intervention 5km time-trial performance in hot conditions (33°C), highlighting the benefits HWI can have on exercise performance in the heat. HWI just of the lower body was investigated by Brazaitis & Skurvydas, (2010) where subjects completed 7-days of HWI on alternate days across a 2-week period. Water temperature was set at 44°C and subjects were immersed for 45-minutes. The subjects showed decreases in resting and final rectal T_c, HR and increased sweat rate following the 7-days of HWI. A later study by Shin et al, (2013) used a slightly longer, but similar, protocol where subjects completed 10-days of HWI (42±0.5°C) across a three-week period. Following the acclimation period subjects displayed lower mean T_c values and increased sweat volume, a limitation for these two studies is that there was no performance test pre- and post-intervention to analyse exercise capacity in the heat. Future studies may look to employ similar protocols but using full immersion as this may produce higher body temperatures during immersion and perhaps induce further adaption. However, these studies provide evidence that HWI can induce partial HA that is comparable to adaptations induced from traditional exercise-based acclimation methods that enhance thermoregulation and improve exercise performance in the heat (Zurawlew et al, 2016; 2018).

2.7.2 Sauna Bathing

Early research on sauna bathing provided evidence of the potential physiological benefits it can induce, such as PV expansion and an improved thermoregulatory capacity that could lead to performance benefits. An early study (Leppaluoto, Tuominen, Vaananen, Karpakka & Vour, 1986) measured various cardiovascular and metabolic effects of repeated sauna bathing for 60-min, twice a day at 80°C across seven consecutive days in 10 healthy males. Subjects displayed a decrease in HR during sauna bathing accompanied by a lower rectal T_c before and following each sauna session, indicating both cardiovascular and thermoregulatory adaptions occurred. Two current studies used post-exercise sauna bathing on athletes to induce HA and improve endurance performance (Scoon et al, 2007; Stanley et al, 2015). Scoon et al, (2007) used six endurance trained athletes who completed 12 post-exercise sauna sessions at 89.9°C for a period of 31±5 minutes spread across three weeks. Subjects produced a 2% improvement in a 15-minute run to exhaustion test following the post-exercise sauna intervention period. The authors speculate that the increases in PV and total blood volume contributed to the performance improvements. Concurrent training intensity, frequency and duration were recorded during the post-training sauna intervention, a decrease in training intensity and frequency was observed during the sauna period, showing it had some negative effects on concurrent training, although this was not substantial. Stanley et al, (2015) using well-trained cyclists observed similar findings. Participants completed 10-days of post-exercise sauna bathing (30-min/day at 87°C following their normal training) leading to PV expansion that peaked on the 4th day. A potentially more important finding is that this study also measured subsequent TL and found that post-exercise sauna bathing offered a time-efficient means in which to induce partial HA without significantly impacting the subject's daily training. This is the only study to the authors knowledge, that has measured TL (s-RPE x duration) concurrently with a HA intervention. Although these studies primarily used endurance-trained athletes and found beneficial adaptations through post-training sauna and

HWI, it does provide a practical option for a team preparing to play in a hot environment. The passive nature of the sauna/HWI will minimise any detrimental impact on team training quality in comparison to exercise-based HA protocols, making it more favourable for those teams with minimal time together before competition departure.

2.7.3 Other Methods & Considerations

Other approaches of HA have been recognised within the literature but given the lack of research, they should be considered as secondary options behind both active and passive (HWI/sauna) HA methods. Pre-cooling is a method that can temporarily decrease body temperature before competition or exercise, potentially improving capacity and performance in hot and/or humid conditions. Pre-cooling can occur in the form of wearing of ice-vests or cool towels and ingestion of ice-slurries (Siegel, Mate, Brearley, Watson, Nosaka & Laursen, 2010; Duffield, Coutts, McCall, & Burgess, 2013). Pre-exercise ice-slurries have shown to decrease T_c (-0.66°C) leading to an increase in exercise capacity in the heat (Siegel et al, 2010), showing the temporary benefits for an event/game. Given evidence that T_{sk} is a primary driver behind thermoregulatory behaviour (Schlader, Prange, Mickleborough, & Stager, 2009; Schlader, Simmons, Stannard, & Mündel, 2011; Schlader, Perry, Jusoh, Hodges, Stannard, & Mündel; 2013), the use of ice-vests and cold towels during a half-time period of a match may prevent T_{sk} induced reductions in exercise intensity in the second half. Using pre-cooling methods such as ice-slurries and cold towels/ice-vest could be an appropriate method for a one-off match but will not add any further benefits on top on HA (Castle, Mackenzie, Maxwell, Webborn, & Watt, 2011; Brade, Dawson, & Wlalman, 2013). Wearing additional clothing or ‘sweat clothing’ during normal training can potentially produce small physiological adaptations to improve thermoregulatory function and exercise performance in hot and/or humid conditions. By training in sweat clothing, it creates a humid heat microclimate around the body by limiting evaporation from the skin; this would be a more appropriate method during cooler environments for players who do not have access to a natural climatic heat stress (Dawson, 1994). Training outdoors during the hottest time of the day if air temperature reaches an appropriate temperature to induce heat stress, or training indoors where air temperatures can be adjusted. Using general household heaters to raise ambient temperatures in an enclosed area can create thermal stress, additionally when a misting spray is added to increase relative humidity could be used as a HA strategy (Pryor, Johnson, Roberts, & Pryor, 2018).

When training or exercising in the heat, hydration is extremely important as it can influence the level of physiological strain that can occur. Dehydration during exercise in the heat exacerbates thermal and cardiovascular strain (i.e. increase in T_c) and can further impair aerobic performance (Racinais et al, 2015), i.e. an inverse relationship between hydration and body temperature exists. The effects of hypohydration on physiological stability, function and exercise performance are more substantial when competing in the hot conditions compared to the same level of hypohydration imposed in more temperate environments (Maughan & Shirreffs, 2004). Changes in rectal T_c during exercise are directly related to the degree of fluid intake, and water intake equalling sweat loss results in the slowest temperature rises compared to *ad libidum* drinking and no water drinking. Hypohydration not only elevates T_c, but also can lessen Tc advantages (i.e. lower exercising/resting core temperature) produced by high aerobic fitness and HA further highlighting its importance for competition in the heat (Sawka et al, 2001). Figure 2.2 outlines the effects of hydration status on T_c. For further reading see review by Akerman, Tipton, Minson & Cotter, 2016.

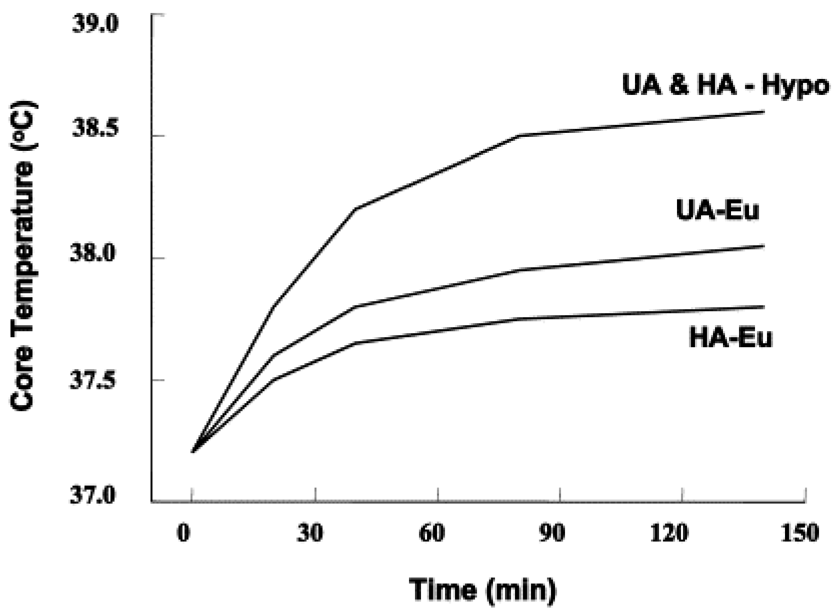


Figure 2.2. Core temperature responses during exercise-heat stress in euhydrated (Eu) and hypohydrated (Hypo) (5% BWL) persons both before (UA) and after (HA) being heat acclimated (Sawka Montain, & Latzka, 1998)

As previously stated, HA can produce large individual variations, factors such as genotype, body composition and fitness levels all can influence the rate of HA-induction an athlete experience. Racinais et al, (2012) identified the 'non-responders' (i.e. no changes in HR, T_c or T_{sk}) following a 6-day HA training camp and explained that they could just be 'slow-responders', and further days of acclimation may have produced similar results to those who displayed the greatest HA. They did identify the player who displayed the biggest decrement in total distance covered during the post-acclimatisation football match, was also the player showing adverse reactions to the acclimatisation camp, highlighting the importance of individual monitoring. Similar results by Buchheit et al, (2011) who found an average 7% improvement in Yo-YoIr1 running time following a week-long HA training camp, but the individual variation was large (-5.6 to +27.2%). The individual differences shown here for HA should be continuously monitored despite which HA method is being used to ensure every player is suitably adapted for the conditions and providing top-ups for slow responders. This is increasingly important for sporting teams where a number of players will come together prior to competition, the differing fitness levels may impact the induction of HA and should be closely monitored if possible, to ensure all players reach similar levels of adaption.

2.8 Practical Application

Sporting teams often face the reality of competing in hot and/or humid environments, this can provide both a physiological challenge to perform optimally and logistical challenges to appropriately prepare for the competition environment. The physiological challenges of exercising in the heat have been extensively reviewed in the past few decades giving researchers and practitioners a sound understanding of the detrimental effects they can have on exercise performance. The under-acknowledged logistical challenges that teams often face need to be investigated further and how they can impact the application of a HA protocol, as they can often dictate what is (un)available for a team and what other alternatives exist. No matter what team-sport is of focus, the coach will always implement strategies, tactics, plays and philosophies that they envision will lead to optimal performance and team success. Considering this, team-based trainings need to be performed at a high quality for players to become accustom to playing in a certain formation, set-plays or adhering to the coach's philosophy. Exercise based HA protocols may affect the quality of concurrent training due to the additional physical loading on the players. Athletes who are completing 1-2 team-based trainings during the day, along with, in some cases, strength and conditioning sessions, video sessions, media commitments, etc. and then must complete some heat training. This may overload athletes, and given the priority of team-based trainings, HA sessions may not be worth risking the quality of these sessions. Given this situation, a passive approach may be suitable to minimise any detrimental effects of HA may have on concurrent training quality/load. Post-training HWI/sauna is a viable option that is relatively cheap and easy to access for teams, it will have less impact on concurrent training quality vs. exercise-based protocols and can induce physiological adaptions comparable to that of traditional HA protocols (Scoon et al, 2007; Shin et al, 2013; Brazaitis & Skurvydas, 2014; Stanley et al, 2015; Zuralew et al, 2016; 2018). Although it will not induce physiological adaptation as significantly as an exercise-based HA protocol and may not completely prepare the team/athletes for the sensations and physiological responses to exercise in the heat, particularly at match intensity (Pryor et al, 2018). Despite this, it has shown improved exercise performance in the heat with minimal effects on concurrent TL to promote high training quality during the preparatory period for competition. Therefore, post-training HWI/sauna provides a practical HA strategy that is logistically friendly for both elite and sub-teams.

2.9 Conclusion

Sporting teams of both elite and sub-elite status should always look to acclimate when preparing for competition in hot and/or humid environments. The physiological challenge of exercising in the heat and the detrimental impact it can have on performance is well-understood within the literature. A shift in research is needed to focus towards the practical application of this knowledge and consideration for teams/athletes who face logistical challenges that can often dictate the type of method of HA they can employ. Passive HA approaches such as HWI/sauna are a practical method to induce physiological adaptions that can improve exercise performance in the heat whilst potentially minimising any detrimental effects on concurrent training. Further research is needed to understand the full benefits of alternative HA strategies and how to effectively implement them into and athletic setting during the preparatory stages prior to competition in hot and/or humid environments.

Chapter Three: Research Aim and Hypotheses

The research conducted in this thesis was built from undertaking a comprehensive review of the literature and the researcher's experiences within team-sport settings. It has been identified that passive HA approaches such as HWI/sauna require further investigation for inducing HA and the effects they may have on concurrent training load is under-acknowledged within the current literature. The first aim of this study was to investigate if 6-days of post-training HWI induces HA. The second aim was to investigate the effects of 6-days of post-training HWI on concurrent training load in moderately-trained team-sport athletes. The third aim was to investigate the effects of 6-days of post-training HWI on treadmill running in the heat.

The hypotheses for the current study are outlined below:

1. 6-days of post-training HWI will induce physiological adaptations indicative of partial HA
2. 6-days of post-training HWI will not detrimentally affect concurrent training load in moderately-trained team-sport athletes.
3. 6-days of post-training HWI will improve aerobic capacity in the heat.

Chapter Four. Methodology

4.1 Experimental Overview

Fifteen male, unacclimated subjects completed a 6-day intervention consisting of intermittent running that simulated a training week of a competitive sporting team. This was followed by 40-minutes of hot water immersion at a temperature of 38°C (HWI; n=7) or no intervention (CON; n=8). All participants completed a pre- and post-intervention RAMP test at a temperature of 33°C, 30% RH two-days before and two-days following the 6-day intervention. Figure 3.1 gives a general overview of the experimental protocol. This protocol was approved by the Massey University Human Ethics Committee.

4.2 Subjects

Fifteen active male team-sport athletes were recruited for this study. All subjects were currently participating in team-sports at a club level within the region and were defined as moderately trained. The subjects all had extensive sporting backgrounds (5-10 years of team-sport experience) ensuring they had suitable training history to cope with the load during the training intervention period. Participants were from a range of team-sport backgrounds e.g. football, hockey, rugby league and AFL, participant characteristics are displayed in Table 3.1. All participants had the risks and benefits of this investigation explained to them (Appendix 1), completed a pre-exercise health questionnaire (Appendix 2) and provided written informed consent (Appendix 3) prior to commencing the trials.

Table 4.1 Participant characteristics. Data presented as Mean ± SD

Characteristics	CON Group (n=8)	HWI Group (n=7)
Age (years)	22±1	21±3
Height (cm)	181±9	177±8
Weight (kg)	77.2±9.4	73.4±9.2
VO_{2peak} ($mL \cdot min^{-1} \cdot kg^{-1}$)	52.2±3.0	50.7±3.3

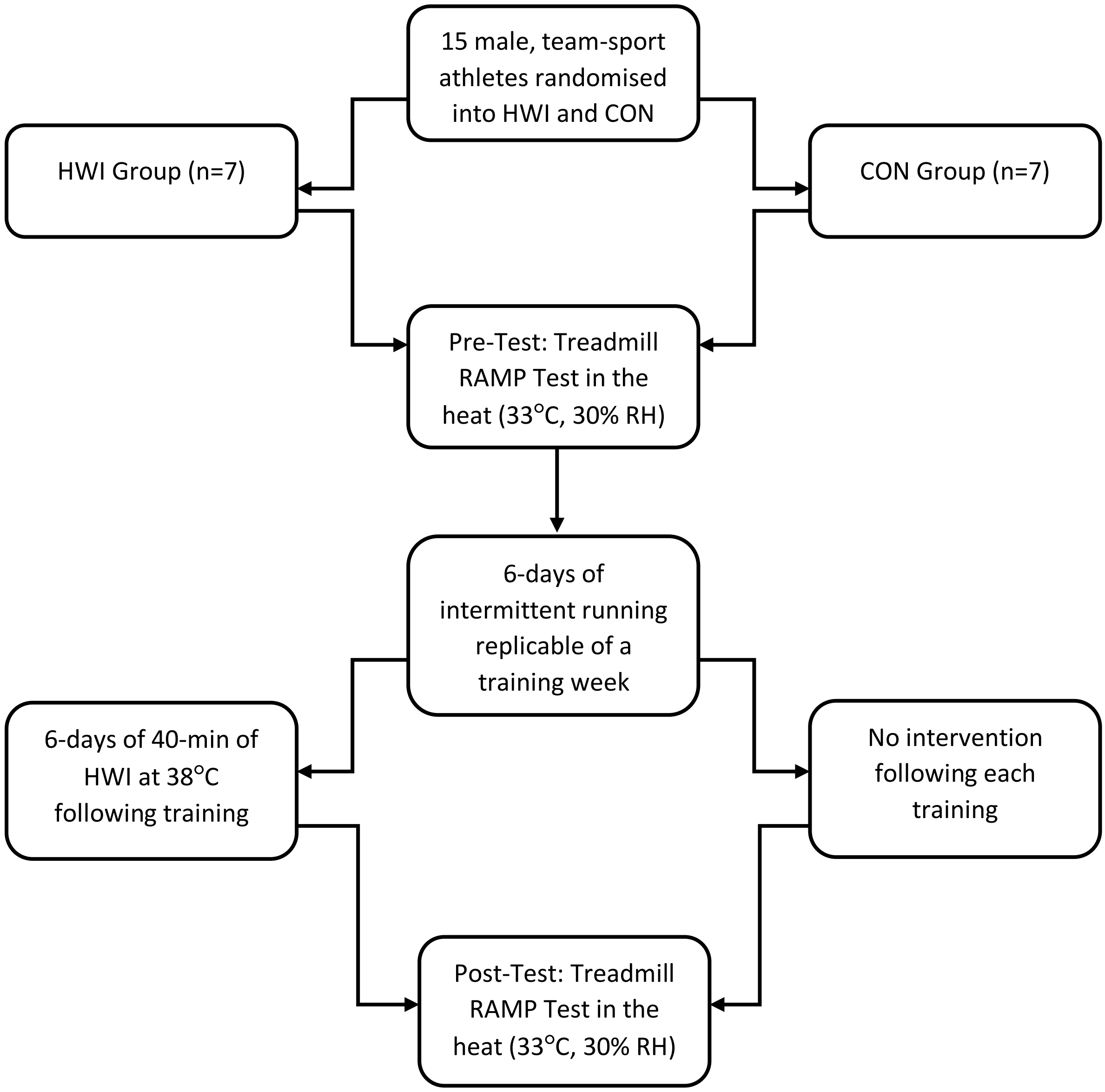


Figure 4.1 General outline of the experimental protocol

4.3 Pre- and Post-Test

All subjects completed a treadmill running test in the heat (33°C, 30% RH) two-days before and two-days following the 6-day training intervention, this temperature was based upon Zuralew et al, (2016) who used a similar temperature (33°C, 40% RH). The exercise protocol was an incremental RAMP based test that began at 9.0 km$\cdot$h^{-1} and increased at 0.5 km$\cdot$h^{-1} every minute until volitional exhaustion (Buchheit & Mendez-Villanueva, 2013). The treadmill was on a 1% gradient as this most commonly reflects the energetic cost of running outdoors (Jones & Doust, 1996). Participants were informed to run until volitional exhaustion to safely end the test. No warm-up was used as the first few stages of the treadmill test are light, submaximal intensity to elicit a warm-up preceding to higher intensity stages.

4.3.1 Procedure

Subjects arrived individually at the Exercise Science laboratory at Massey University, Albany for baseline measurements and treadmill testing having maintained a normal diet without supplementation, alcohol or caffeine intake in the previous 24 hours. They were instructed the previous night to have swallowed the core temperature pill (Core Body Temperature Sensor, HQ Inc. Wireless Sensing Systems and Design, Forida, USA) 10 hours prior to exercise, participants who noted they had hypermotility in the pre-exercise health screening questionnaire were asked to ingest the pill later (e.g. 6 hours before presenting to the laboratory). All subjects were asked to present in a euhydrated state. Upon entering the laboratory, core temperature (T_c) was measured to ensure that the pill was working and accurately recording, if giving faulty readings or the pill had passed, subjects T_c was not measured throughout the treadmill test.

Subjects provided a verbal thirst rating based on a thirst scale (Appendix 4) and asked to void their bladder and provide a small urine sample to assess hydration status. Urine specific gravity (USG) was measured using a hand-held refractometer (Sur-Ne, Atago Co. Ltd., Japan). Following this, participants were restricted from any further fluid consumption until test completion. Subjects mass and height were recorded, height was measured using a stadiometer, subjects were instructed to place the backs of their heels in contact with the wall and stand upright before a measurement was recorded. Mass was measured using scales that were accurate to 0.1 kg (A & D Weighing, HV-200KGL, Australia), subjects were instructed to remove shoes before body mass and height measurements. Subjects were fitted with a heart rate monitor (Polar S610i, Polar Electro, Finland) and were seated in a chair for a period of 10-minutes to allow for even distribution of fluids before resting measures and blood samples were collected. Following this 10-minute seated period, resting heart rate (HR) and resting T_c were recorded. Participant's placed their non-dominant hand under running hot water to enhance blood flow to the finger tips from which blood would be drawn, capillary blood samples were collected from the ring finger. The finger was cleansed with an alcohol wipe, dried and a sterile lancet was used to draw blood. Three capillary tubes were filled up with blood. Blood was spun down in a centrifuge (MF-50 Hanil Science Industrial) at a speed of 100 RPM for 3-minutes. If one of the samples leaked or was found to be broken after being spun down in the centrifuge, only the two remaining samples were used. Resting thermal comfort (ThC; Appendix 5), thermal sensation (ThS; Appendix 6) and feelings scale (Appendix 7) were recorded before entering the heat.

The environment was heated to 33.3±0.2°C, 30±4% RH and the subjects proceeded to begin the RAMP-based treadmill test, during which HR and VO_2 measurements were recorded automatically using a Garmin HR monitor (Garmin HRM3-SS, Taiwan) and the gas analysis system (Quark CPET, Omnia 1.6.5, COSMED, Italy), respectively. T_c was measured every 2-minutes, blood lactate (BLa) measurements from the finger were measured every 3-minutes (Akray Lactate Pro 2, Japan), subjective measures of RPE, ThS, ThC and feelings were measured every 2-minutes. Only four BLa measurements were taken and recorded during the treadmill test as following 12-minutes of running and the fourth BLa measurement, participants were running at a speed of 14.5 $km \cdot h^{-1}$ and became dangerous for them to quickly step off to provide the small blood sample and then safely step back to continue running. Following completion of the test, the subjects exited the heat immediately, they removed their sweaty running shirt for body mass measurements to be recorded, subjects were then given fluids to consume.

4.3.2 Core Temperature Pill Calibration

To ensure all core temperature pills would accurately measure body temperature they were first calibrated using a food scale water bath. Although factory calibrated, some may have been perhaps damaged in shipping or slightly misreading temperature. All pills were placed in the water at a temperature of 35°C and were tested to see if they each recorded the water temperature at 35°C. If any of the pills displayed a different temperature reading, it was noted, and when analysing core temperature responses, it would be adjusted for appropriately. This was repeated for temperatures of 36, 37, 38, 39, 40 and 41°C (human temperature range). Pills that gave off no reading or extremely faulty readings were not used in this experiment and were safely disposed of.

4.4 Training Intervention

The intervention period was 6-days of varied intermittent running that replicated the intensity of a typical training week, this was either followed by 40-minutes of HWI or no intervention (CON) as outlined on Figure 3.1. The duration of HWI in the present study was informed by the findings of Zuralew et al, (2016; 2018) who observed physiological adaptations that improved exercise performance in the heat following 6-days of HWI. The intervention took place during the winter months (June-August) in Auckland, New Zealand with an average daily outside temperature of 15.4 ± 4.1°C and 74 ± 12% RH.

4.4.1 Loughborough Intermittent Shuttle Test

The Loughborough Intermittent Shuttle Test (LIST) is a valid protocol that simulates the activity pattern of football movements (Nicholas, Nuttall, & Williams, 2000), i.e. intermittent and varying running speeds, a common characteristic of team-sports. The LIST is formulated of 15-min blocks of exercise followed by 3-min of recovery (to total 90-min of exercise with 15-min of recovery to simulate the duration of a football match). In brief, the LIST requires subjects to run between two lines, 20m apart, at various speeds dictated by an audio signal and based on velocities corresponding to their individual VO_{2max}, refer to Nicholas et al, (2000) for more information regarding the LIST. As the goal was to replicate a team-training, ensuring subjects were running at the speeds based on their individual VO_{2max} was logistically impossible. Therefore, all subjects ran the LIST that was applicable for athletes with a VO_{2max} of $50 ml \cdot kg^{-1} \cdot min^{-1}$, this was based upon the mean VO_{2peak} values measured during the pre-test. Ensuring all subjects were able to run together and create competition as they would in a typical team training session. Variations of 15-min blocks of intermittent running have been used to simulate an easily quantifiable training load suitable for team-sport athletes. Nicholas et al, (2000) used 5 x 15-min blocks and then a Part B of the LIST which involved open ended running at alternating intensities, other studies have used 6 x 15 blocks only (Backhouse, Ali, Biddle, & Williams, 2007; Gant, Foskett, & Ali, 2010). The current investigation was seeking to simulate a training session, therefore a 30-minute LIST protocol (2 x 15-min blocks) was used on days1-5, on day-6 only one 15-min block was used for the intervention. Subjects ran the LIST at the same time each day (early afternoon), if unable to make the specified time due to external commitments (e.g. work, university) a morning session was additionally run to cater for those who could not commit to the afternoon session.

On days 2,3 and 4 subjects would complete a Part B of the LIST which is an open-ended run (Nicholas et al, 2000). This open-ended run consisted of alternating running and jogging to an audio signal until volitional exhaustion or the subject had been running for 10-minutes and they would be asked to stop. The structure of the training intervention was based on a typical training week for a professional team which included a lighter training day at the beginning of the week (day-1), higher intensity training days during the middle of the week (day 2-4), followed by a taper (day 5-6). The structure is displayed on Table 3.2

Table 4.2. Training protocol for the 6-day intervention

Day	Training Protocol
1	2 x 15-min blocks of intermittent running
2	2 x 15-min blocks of intermittent running followed by alternating running and jogging until exhaustion
3	2 x 15-min blocks of intermittent running followed by alternating running and jogging until exhaustion
4	2 x 15-min blocks of intermittent running followed by alternating running and jogging until exhaustion
5	2 x 15-min blocks of intermittent running
6	1 x 15-min blocks of intermittent running

4.4.2 LIST Procedure

Subjects arrived at the training ground at the specified time each day of the intervention, they were asked for a verbal thirst rating based upon the thirst scale (Appendix 4). They provided a small (5-20mL) urine sample which was later analysed for hydration status. Body mass was recorded, after which they were given a named drink bottle which had been previously weighed allowing them to drink *ad libitum* throughout each training session as they would normally during training. All subjects were fitted with a polar HR monitor and GPS unit (VX Sports) unit to record HR and total running distance performed each day. A 5-10-minute standardised warm-up led by the researcher was completed each day and consisted of light jogging, dynamic movements/stretches, higher intensity running/movements. Subjects proceeded to line up in their respective running lanes to begin the LIST. During each walking stage of the LIST, HR and RPE were recorded, following the completion of the LIST, a 5-minute cool-down was completed led by the researcher. Body mass and individual fluid consumption were recorded after the session. Session-RPE and session duration (min) was recorded to calculate the composite measure of training load. Subjects were also asked to provide a training log of additional training completed outside of the experiment and were advised to keep any heavy loading to a minimum due to the physical demands of the training intervention.

4.4.3 Hot Water Immersion

Following training completion subjects in the HWI group proceeded to the spa located next door to the training field. Time between finishing training and entering the spa was within 15-min. Subjects stripped down to their shorts and body mass was measured and recorded before entering the water, they were informed to submerse themselves to cover most of their body up to their chest. The temperature of the water was set and kept constant at 38°C, this temperature did not fluctuate during the HWI. Subjects were able to drink *ad libitum* whilst in the spa, water intake was recorded and adjusted for when calculating sweat rate and changes in body mass. Starting and finishing drink bottle mass was measured, if subjects finished the water provided, they were refilled and re-weighed before continued consumption. HR was recorded every four-minutes, subjective measures ThS, ThC and feelings were recorded every five-minutes. Following 40-minutes of HWI, subjects exited the spa and dried themselves off with a towel before body mass measurements were recorded.

4.5 Data Analysis

Four subjects (HWI=2; CON=2) missed one or more days of the 6-day training intervention and were not included in the data analysis. This resulted in 12 participants (HWI=6; CON=6) completing all 6-days of training and only these participants' data were analysed for all results pertaining from the 6-day training intervention. Two subjects could not make the post-intervention session due to illness (CON group) and the other subject from the HWI group withdrew from the investigation on day-3 of the training intervention, their data were not included in the final analysis. The subjects who missed one day or had pulled out during one of the training intervention days still completed the post-test analysis, this resulted in data from 14 participants (HWI=7; CON=7) being analysed for all results from the pre- and post-test. The variance in running times in the pre- and post-RAMP test made analysis of the results difficult, therefore, given that all participants completed the first 10-minutes of the test for both pre- and post-intervention this time-point was split (<10-min and >10-min). This allowed for equal comparison for <10-min, and all results >10-min were averaged to adjust for the varied end-exercise times that occurred. Core temperature results are displayed as <9-min and >9-min due to the timing of the measures during testing. Oxygen consumption was recorded as VO_{2peak} in place of VO_{2max} based on observations that participants did not necessarily reach maximal oxygen consumption as no plateau occurred during the pre-test.

Sweat rate was calculated by: Post Exercise BM – Pre-Exercise BM + (fluid intake).

4.6 Statistical Analysis

One-way ANOVA for repeated measures was used compare all within group changes for both groups across the 6-day training intervention and the RAMP treadmill test, post-hoc pairwise Bonferri adjustments were used when significant differences were found. Two-way ANOVA for repeated measures were used comparing results of the LIST between groups during the 6-day training intervention and the RAMP treadmill test, post-hoc pairwise Bonferri adjustments were used when significant differences were found. Cohen's *d* effect sizes were used to calculate the magnitude of any statistical differences found and were defined as 0.2=small, 0.5=moderate, and 0.8=large (Cohen, 2013)

All data were analysed using SPSS statistical software (Version 24, Chicago, IL, USA), with statistical significance set at $p<0.05$. All data are reported as mean ± standard deviation of mean (SD) for fifteen participants, unless otherwise stated.

Chapter Five: Results

5.1 Hot Water Immersion

5.1.1 Heart Rate

Heart rate (HR) during the 40-min of immersion decreased by 14±10 b·min^{-1} (-12%) across 6-days of HWI. A main effect of time occurred ($p=0.03$; ES=0.30), figure 5.1.1 shows that HR decreases with every HWI exposure with a significant difference ($p=0.02$; ES=1.80) occurring on day-6 vs. day-1.

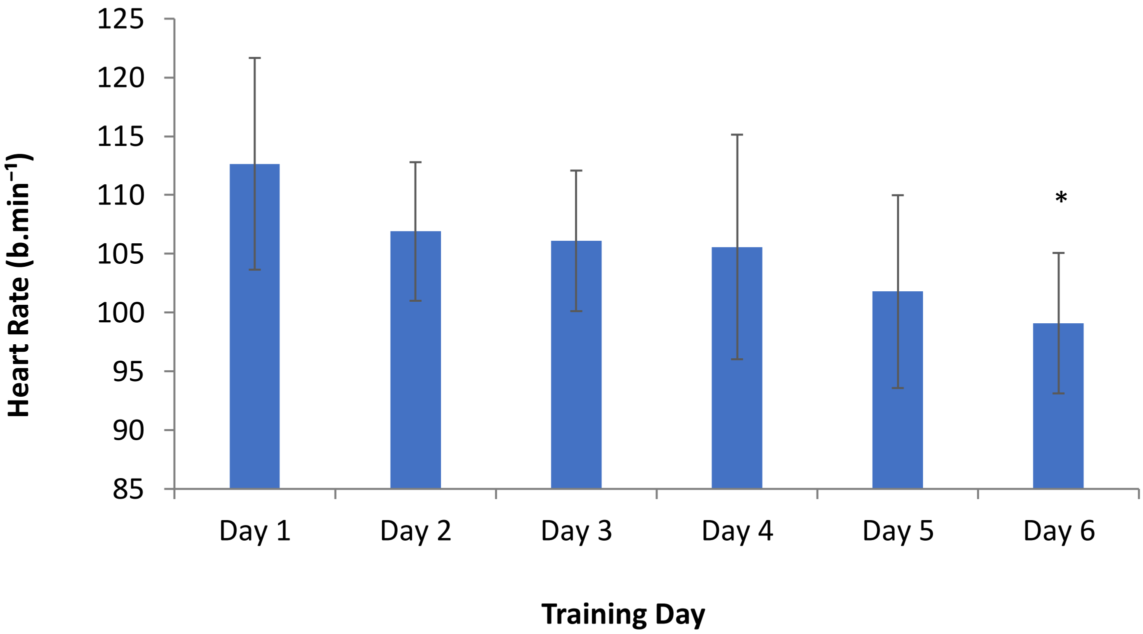


Figure 5.1.1 Effects of 40-min of HWI on HR across the 6-day intervention period. Values are mean ± SD for the HWI group (n=7)

* $p < 0.05$ vs day-1

5.1.2 Sweat Rate and Subjective Responses

Sweat rate (SR) and subjective responses of thermal comfort (ThC), thermal sensation (ThS) and feelings did not significantly change during the HWI period, they did however show a trend for improvement.

Table 5.1.1 Mean responses during 40-min of HWI during the 6-day intervention period.

	HWI (n=7)					
	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**
SR (L/h)	0.13±0.4	0.33±0.4	0.48±0.6	0.36±0.3	0.44±0.4	0.47±0.6
ThS	1.8±0.5	1.6±0.8	1.7±0.7	1.8±0.6	1.6±0.8	1.5±0.6
ThC	2.2±1.1	1.8±1.9	1.8±1.5	2.0±1.6	2.5±1.3	2.6±1.2
Feelings	2.6±0.9	2.2±1.9	2.2±1.5	2.4±1.9	3.2±1.6	3.5±1.5*

Values are mean ± SD. SR, Sweat Rate. ThS, Thermal Sensation. ThC, Thermal Comfort.

* $p < 0.05$ vs. day-1 for feelings

A main effect for time occurred for subjects' feelings (p=0.002; ES=0.45) across the 6-days of post-training HWI, with a significant improvement (p=0.05; ES=0.71) occurring on day-6 vs. day-1. No significant changes were found for sweat rate (p=0.70; ES=0.10), thermal sensation (p=0.98; ES=0.02) and thermal comfort (p=0.86; ES=0.05). Despite no significant changes occurring in these variables they all displayed a drift of improvement with thermal comfort and sweat rate recording the highest values on day-6 and thermal sensation recording its lowest value on day-6.

5.2 Effects on Concurrent Training

5.2.1 Total Distance

Total running distance across the 6-day training intervention for the HWI and CON groups accumulated to 27050±2471m and 27180±1926m, respectively. Running distance during the 6-day training intervention was fixed on day 1, day 5 and day 6, the other training days the running was variable, therefore, ANOVA analysis was performed for total distance for the three days where running distance was variable (day 2,3 and 4). No significant difference (p=0.91; ES=0.003) was found between groups for total running distance.

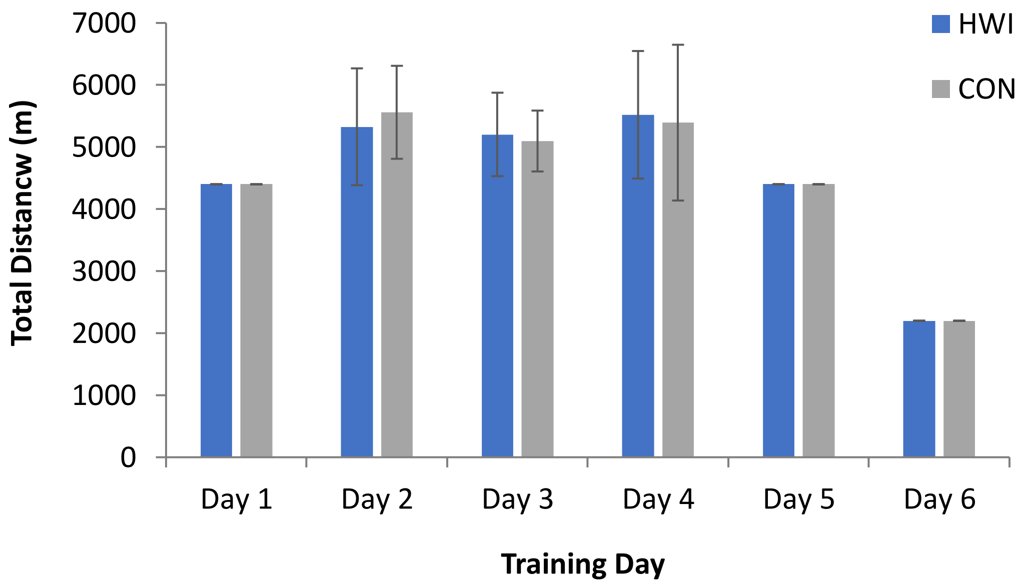


Figure 5.2.1 Total distance run on each day of the 6-day training intervention. Values are mean ± SD (Day 2-4; varied running distance) for the HWI (n=6) and CON (n=6) group.

5.2.2 Session-RPE

Session-RPE (sRPE) across the 6-day training intervention averaged to 12.9±1.4 AU for the HWI group and 11.6±2.0 AU for the CON group. Mean s-RPE was higher in the HWI group each day during the 6-day intervention compared to the CON group but did not reach significance ($p=0.07$; ES=0.53) across the 6-day training intervention.

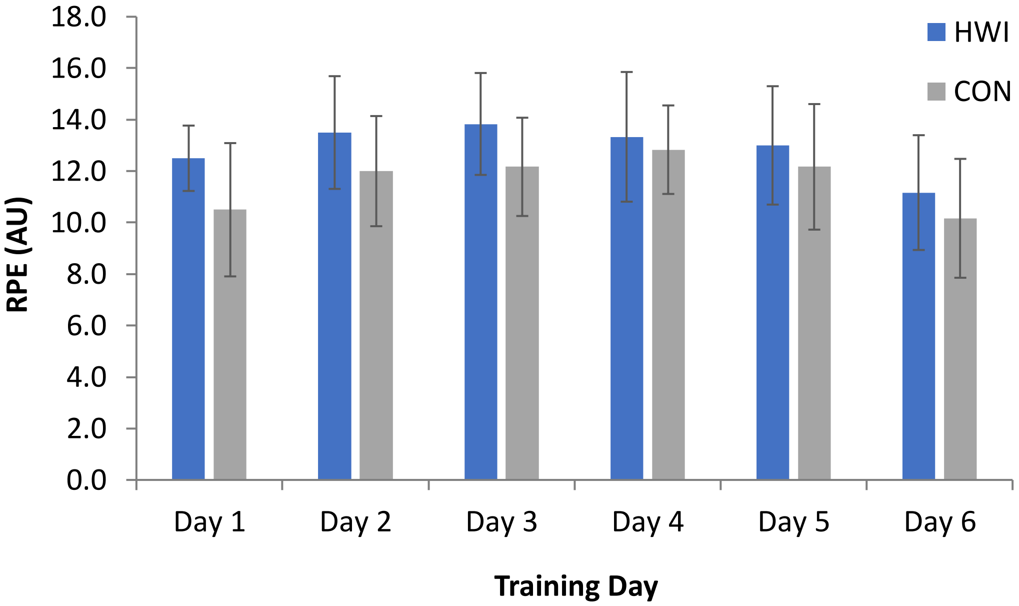


Figure 5.2.2 Daily session RPE during the 6-day training intervention. Values are mean ± SD for HWI (n=6) and CON (n=6) group.

5.2.3 Training Load

Total weekly training load for the 6-day training intervention accumulated to 2669±293AU for HWI and 2402±358AU for CON group. There was no significant difference ($p=0.1$; ES=0.45) in training load between the HWI and CON group across the 6-days.

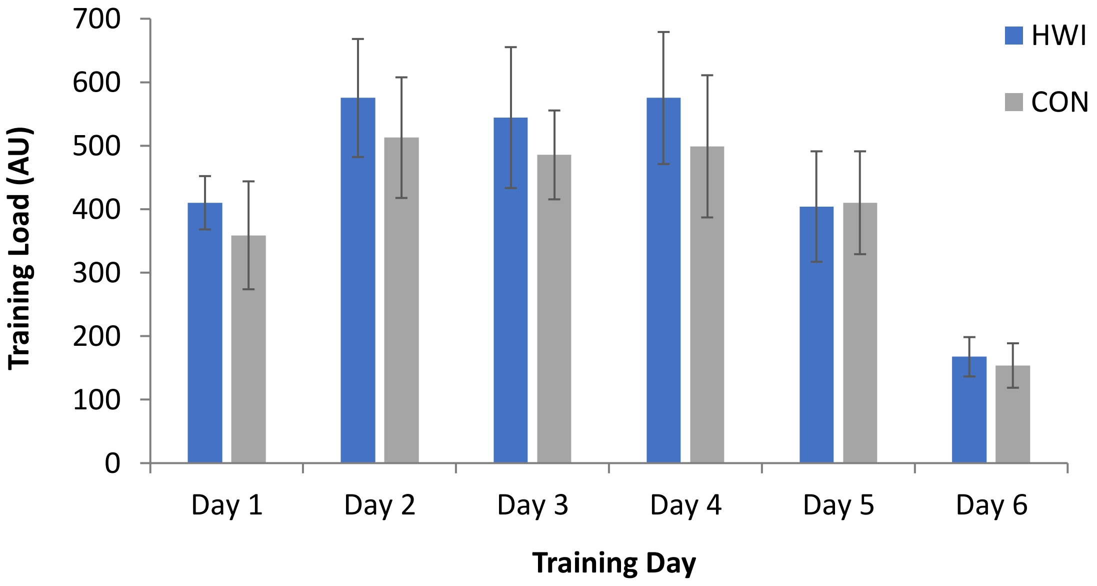


Figure 5.2.3 Daily training load during the 6-day intervention. Values are mean ± SD for the HWI (n=6) and CON (n=6) group.

5.3 Training Intervention

5.3.1 Heart Rate

The HWI group displayed significantly higher HR values during the 6-day training intervention compared to the CON group. Main effects revealed a time ($p<0.01$; ES=0.62) and group*time ($p=0.01$; ES=0.43) interaction. The HWI group showed a significant decrease in HR on day-4 ($p=0.01$; ES=0.86) and day-5 ($p=0.02$; ES=0.86) compared to day-1, with an overall decrease of -12±5 b·min^{-1} from day 1 vs. day 6. The CON group showed no change in HR across the 6-day training intervention (0±6 b·min^{-1}).

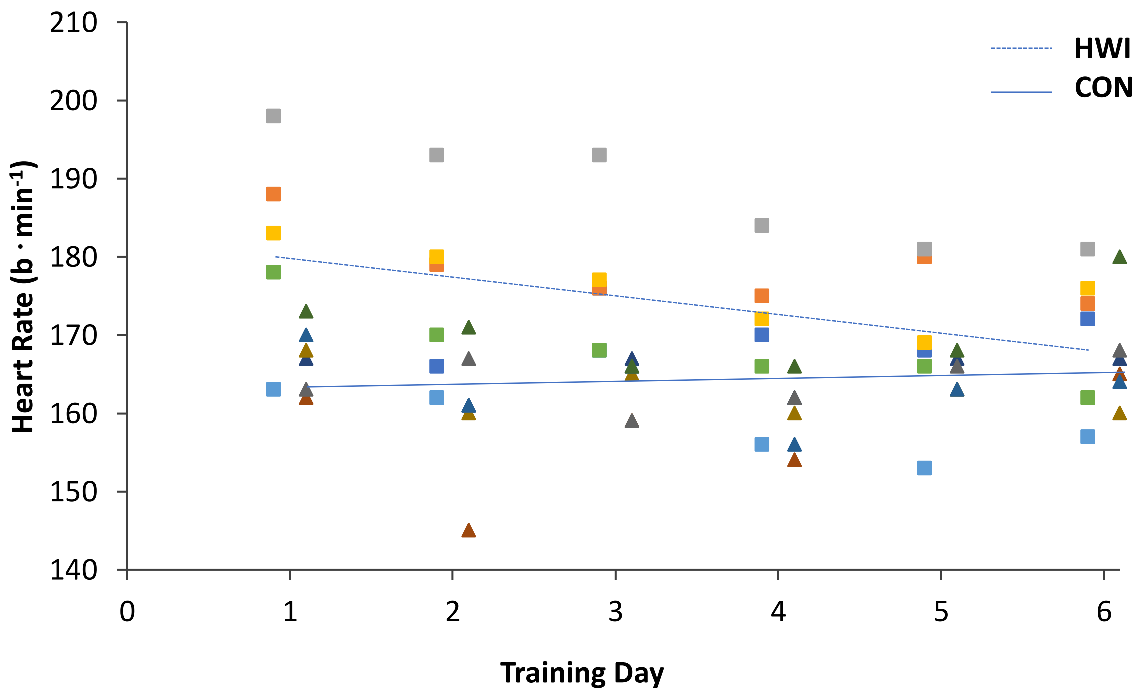


Figure 5.3.1 Individual HR responses during each day of the training intervention. The HWI group (n=6) are represented by the square symbols, the CON group (n=6) are represented by the triangles. The lines represent mean HR responses during each training day.

5.3.2 RPE

RPE in the HWI group was higher during each training day, although no significant difference (p=0.08; ES=0.49) between groups was found. The HWI group showed a decrease of -1.2±0.7 AU compared to the CON group who showed an increase of 0.5±1.6 AU. Within group differences showed no significant differences across the 6-day training intervention for the both the HWI group (p=0.55; ES=0.12) and the CON group (p=0.85; ES=0.06).

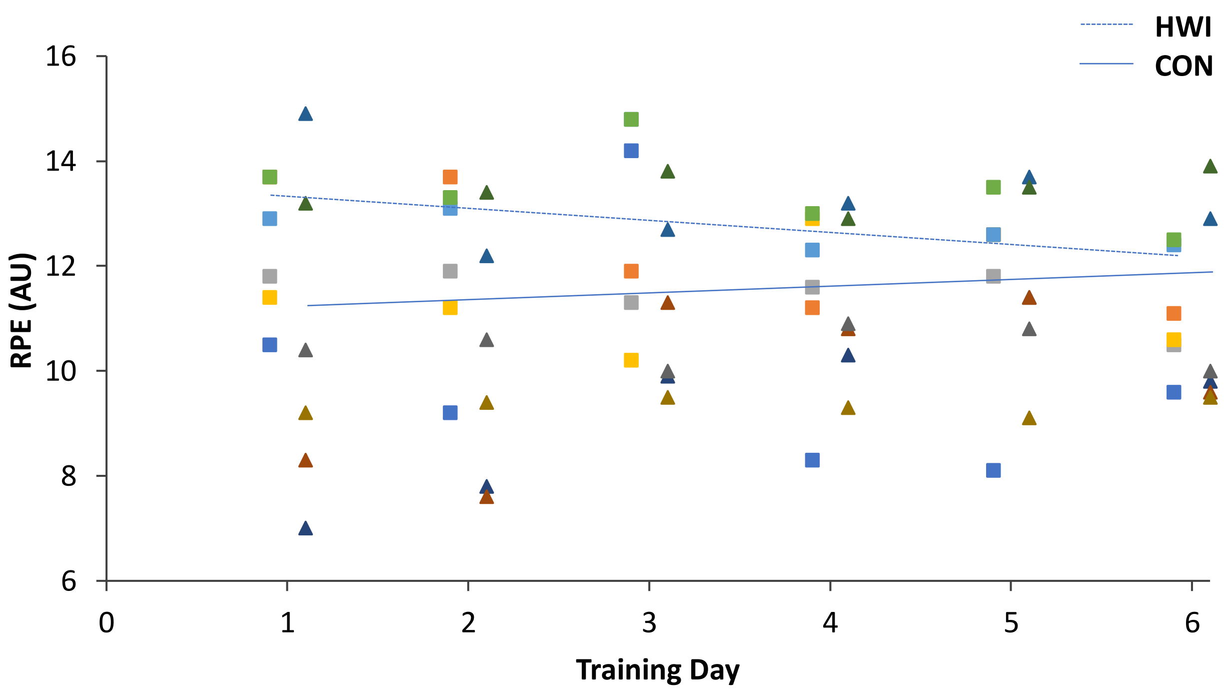


Figure 5.3.2 Individual RPE responses during each day of the training intervention. The HWI group (n=6) are represented by the square symbols, the CON group (n=6) are represented by the triangles. The lines represent mean HR responses during each training day.

5.4 Pre- & Post-Intervention RAMP Test

5.4.1 VO_{2peak}

No significant difference was found for VO_{2peak} between the HWI and CON groups ($p=0.44$; $ES=0.1$). Within group changes showed the HWI group significantly ($p=0.003$; $ES=1.8$) improved VO_{2peak} (50.7±3.3 vs 52.8±4.1 $ml \cdot kg^{-1} \cdot min^{-1}$), whereas no significant difference ($p=0.88$; $ES=0.04$) was found in the CON group (52.2±3.0 vs 52.4±5.4 $ml \cdot kg^{-1} \cdot min^{-1}$). This resulted in the HWI having a greater percentage increase in VO_{2peak} from pre- to post-training, compared to the CON group (4.2±2.2% vs 0.5±8.0%, respectively). 6 out of 7 subjects in the HWI group improved VO_{2peak} as shown in figure 5.4.1, whereas the CON group showed mixed responses following 6-days of post-training HWI.

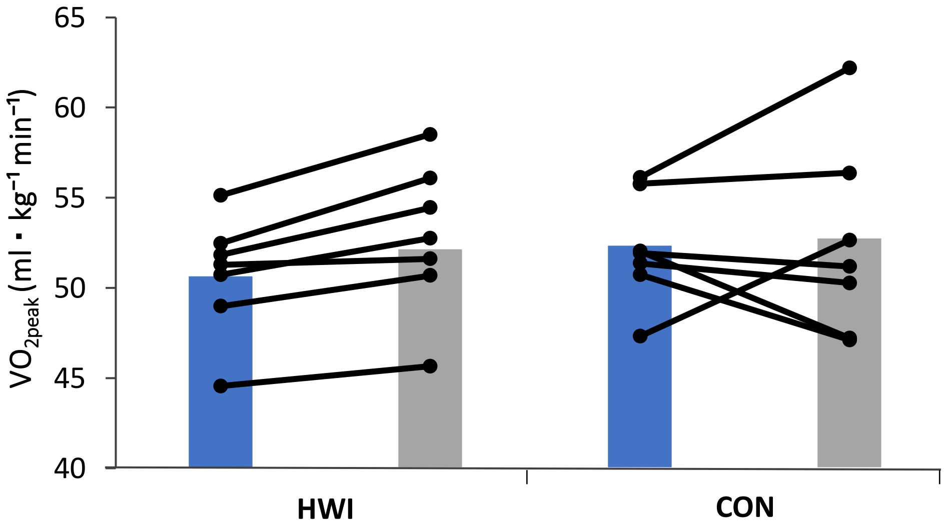


Figure 5.4.1 Effects of a 6-day training protocol on VO_{2peak}. Values are mean ± SD for the HWI group (n=7) and the CON group (n=7).

* $p < 0.05$ vs. Pre-Test

Table 5.4.1 Mean differences between pre- and post-intervention for HWI and CON groups.

	HWI Group (n=7)		CON Group (n=7)	
	Pre-Test	**Post-Test**	**Pre-Test**	**Post-Test**
Run Time (min:ss)	12:37	12:41	13:24	13:28
Weight (kg)	76.8±12.4	77.4±12.4	79.0±10.1	76.8±9.1
Resting HR ($b \cdot min^{-1}$)	72±12	72±7	77±7	70±4
Max HR ($b \cdot min^{-1}$)	199±10	195±10	195±9	192±7
Resting T_c	37.48±0.26	37.39±0.18	37.37±0.16	37.18±0.23
Max T_c	38.34±0.63	38.15±0.41	38.14±0.37	38.04±0.44

Values are mean ± SD. HR, Heart Rate; T_c, Core Temperature

Table 5.4.1 illustrates resting and maximal HR and T_c during the pre- and post-test for the HWI and CON groups. The RAMP test running times showed small improvements in both the HWI group (4±57 sec) and the CON group (4±68 sec). Resting HR showed a significant change from the pre vs. post-test for the CON (n=7; p=0.02; ES=0.65) but not the HWI group (n=7; p=0.96; ES=0). T_c measures showed improvements in both groups but did not reach a level of significance in both resting T_c (CON; p=0.55; ES=0.06, HWI; p=0.84; ES=0.004) and max T_c (CON; p=0.20; ES=0.26, HWI; p=0.43; ES=0.06).

5.4.2 Core Temperature

Figure 5.4.2 displays core temperature (T_c) responses during the first 9-minutes of the treadmill run to exhaustion test, thereafter it illustrates the mean time in which participants exhausted from the run and mean T_c during this period. No significant differences were found pre- and post-intervention for both the HWI (n=6; p=0.61; ES=0.03) and CON (n=5; p=0.33; ES=0.12) groups during the first 9-minutes of the treadmill test. The HWI produced a mean decrease of -0.36°C >9-min compared to an increase of 0.15°C for the CON group.

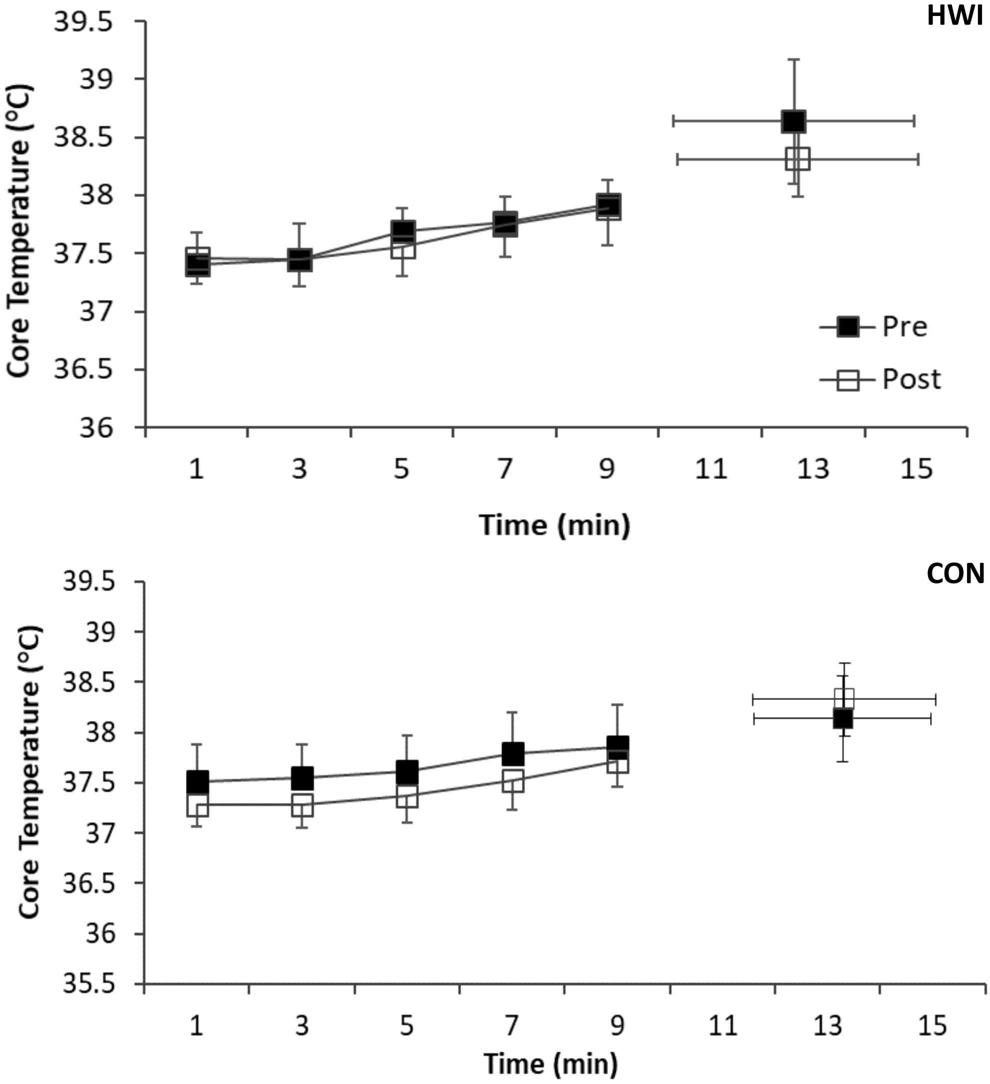
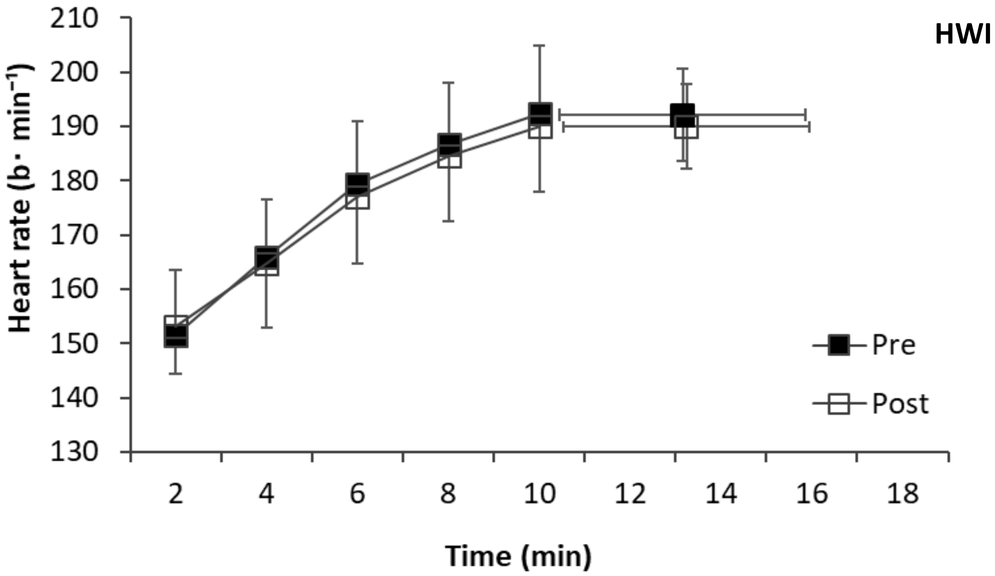


Figure 5.4.2 Core temperature responses during the pre- and post-maximal treadmill run to exhaustion in the heat. Values are mean ± SD for the HWI (top panel) and CON (bottom panel) group. The horizontal error bars represent the SD for time to exhaustion during the treadmill test.

5.4.3 Heart Rate

Figure 5.4.3 below shows HR during the first 10-minutes of the treadmill test, thereafter it illustrates the mean time in which participants exhausted from the run and mean HR during this period. No significant differences were found pre- and post-intervention for both the HWI ($p=0.87$; ES=0.002) and CON ($p=0.47$; ES=0.05) groups during the first 10-min of the treadmill test. Beyond 10-min, the HWI group showed a decrease in HR from 193±8 to 191±7 b·min^{-1}, the CON showed a decrease of 194±9 to 189±7 b·min^{-1}.



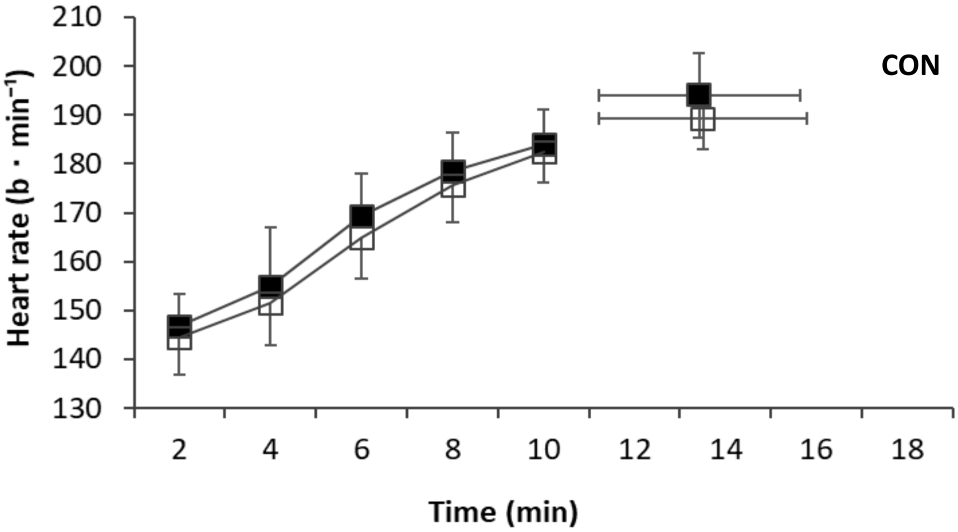


Figure 5.4.3 Heart rate during the pre- and post-maximal treadmill run to exhaustion in the heat. Values are mean ± SD for the HWI (top panel) and CON (bottom panel) group.

Table 5.4.2 Subjective responses during the pre- and post-treadmill test in the heat at <10-min and >10-min

	<10-min				**>10-min**			
	HWI		**CON**		**HWI**		**CON**	
	Pre	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
RPE	12.6±3.3	11.7±2.8	13.1±2.2	12.4±2.3	17.7±2.0	16.0±2.0	17.6±1.7	17.3±2.1
ThC	0.1±2.3	1.6±1.9*	-0.1±1.7	-0.2±1.7	-2.3±2.3	-0.8±1.9	-2.0±1.7	-2.9±1.3
ThS	1.7±0.7	1.7±0.8	2.0±0.7	1.9±0.8	3.0±0.0	2.4±0.5	2.8±0.4	2.8±0.4
Feelings	-0.1±2.7	2.0±2.4	1.2±1.7	0.5±1.7	-3.0±2.4	-1.0±2.2	-2.1±1.8	-2.7±1.5

Values are mean ± SD. RPE, Rating of Perceived Exertion. SR, Sweat Rate. ThS, Thermal Sensation. ThC, Thermal Comfort.

* $p < 0.05$ vs. pre-test for ThC

ThC <10-min improved significantly in the HWI group (p=0.05; ES=0.9) but not the CON group (p=1.0; ES=0), beyond 10-min no significant changes occurred in both groups. RPE, ThS and Feelings all showed improved at both <10-min and >10-min for both the HWI and CON group as shown on table 5.4.2, but none of which reached a significant level.

Chapter Six: Discussion

The purpose of this study was to investigate post-training hot water immersion (HWI) as a practical heat acclimation (HA) strategy for moderately-trained team-sport athletes when preparing for competition in hot and/or humid environments and analyse its effects on concurrent training load (TL). The results showed that 6-days of post-training HWI for 40-minutes at 38°C induced partial HA and had no detrimental impact on concurrent TL. We observed evidence that subjects in the HWI group induced partial HA as characterised by significant improvements in VO_{2peak} and thermal comfort (ThC) during the treadmill run in the heat. This was accompanied by a significant decrease in HR and an improvement in feelings during the HWI intervention. Six-days of post-training HWI showed no detrimental effects on concurrent daily and weekly TL, illustrating that this controlled strategy does not interfere with the quality of field-based training sessions. This was demonstrated by no significant differences ($p>0.05$) between the HWI and CON groups for total distance and training load (s-RPE x duration) completed each day.

6.1 Six-days of post-training HWI induced partial HA

Physiological and subjective responses to the pre- and post-intervention maximal aerobic capacity test

Changes in VO_{2max} or VO_{2peak} are not featured adaptions of HA, nor are they frequently measured in HA studies, but they are important components of aerobically dominant sports (i.e. team-sports). In the current study, there was no significant difference in VO_{2peak} between groups following 6-days of post-training HWI, although a larger effect size was found ($p=0.44$; ES=0.1). The results did show the HWI group significantly improvement VO_{2peak} with a large effect size ($p=0.003$; ES=1.8), whereas the CON group showed no significant improvement accompanied by a low effect size ($p=0.877$; ES=0.04). Zuralew et al, (2018) found a significant improvement in mean VO_{2max} in recreationally active subjects following 6-days of post-training HWI. A previous study (Zuralew et al, 2016) found no changes in VO_{2max} following 6-days of post-training HWI. This lack of change could have been due to the higher initial VO_{2max}

($60.5\pm6.8 ml \cdot kg^{-1} \cdot min^{-1}$) and the endurance-based training history of the subjects whereby changes in VO_{2max} become harder to attain, compared to the lower initial VO_{2peak} in the team-sport athletes used in the current study and recreational subjects used in the later study by Zuralew et al, (2018). ThC improved significantly ($p=0.03$) in the HWI group over the first 10-min of the treadmill run compared to the CON group. Similar findings have previously been shown following exercise-based HA intervention in team-sports athletes (Sunderland et al, 2008; Petersen et al, 2010; Kelly et al, 2016). Enhanced ThC is an important element associated with optimal performance in the heat as it removes psychological reservations of high-intensity exercise allowing for proper pacing strategies during competition (Pryor et al, 2018). Previous research has found that perception of effort i.e. RPE, thermal comfort/sensation responses can mediate behavioural thermoregulation during exercise in the heat (Schlader, Stannard, & Mundel, 2010. Schlader, Simmons, Stannard, and Mundel, (2011) investigated the effects of temperature and thermal perception as thermoregulatory behaviours. They found that in the absence of temperature changes (T_c and T_{sk}) non-thermal cooling and warming produced thermal sensory and discomfort sensations like those observed during thermal cooling and warming. Both temperature and thermal perception were capable modulators of exercise work output. The HWI group in the current study significantly improved ThC following 6-days of post-training HWI. Based on the evidence of ThC as a potential controller for thermoregulatory behaviour, the HA strategy in the current study could minimise reductions in exercise intensity during team-sport competition in the heat (Aughey et al, 2014; Nassis et al, 2015)

A lower T_c during exercise in the heat is a featured physiological adaptation following HA, it allows for greater distribution of blood to exercising muscles due to a reduced requirement of peripheral blood flow to dissipate metabolically produced heat. Across the first 9-min of the treadmill running test T_c showed no difference between pre- and post-intervention for both groups ($p>0.05$) but following 9-min when T_c was averaged until the point of exhaustion, a decrease in T_c occurred in the HWI (-0.36°C) but not the CON group (0.15°C). This suggests that if the test was of a longer duration, greater changes in T_c may have presented in the HWI group as reported in previous studies. Zuralew et al, (2016) showed that subjects decreased end-exercise T_c (-0.36°C) following a 40-min treadmill run at 65% VO_{2max} in the heat (33°C) following 6-days of post-training HWI. Exercise-based HA regimes using team-sport athletes have found conflicting results, Kelly et al, (2016) found no change in T_c of AFL players following 5-days of HIIT cycling in the heat, like Peterson et al, (2010) following 4-days of HA in cricket players, compared to other team-sport STHA protocols that produced significant improvements in T_c (Sunderland et al, 2008; Brade et al, 2013). Exercise-induced T_c elevations to 38.5°C for approximately 60-min is the minimal thermal impulse for effective HA, during the training days in the current study, T_c was on average 38.5°C and 38.0°C for the HWI and CON group, respectively. The HWI group spent approximately 20-minutes above 38.5°C during the training session, compared to the CON group who did not reach 38.5°C for a substantial amount of time. During HWI, subjects displayed an average T_c of 38.2°C, this may not have been enough of a stimulus to drive T_c adaptations to improve exercise capacity in the heat (Taylor, 2000). This lack of thermal impulse may be a reason why there was no decrease in T_c in the HWI group in the current study, in agreement with previous reports (Peterson et al, 2010; Kelly et al, 2016). Due to the expensive nature of ingestible temperature pills, T_c was only recorded on one training day during the intervention, and of those used, only two and four subjects were able to be analysed from the CON and HWI group, respectively. It is important to note that T_c measurements during the training intervention included a very small sample size (HWI; 4, CON; 2) and only one day was recorded, therefore these data should be taken with caution.

Physiological and subjective responses during the 6-day training intervention

The HWI group produced higher HR values during each day during the training intervention compared to the CON group (Fig. 5.3.1.), with significant differences occurring on days 2-4, this was surprising to the researcher given the similar training history/background of the subjects and no significant differences in VO_{2peak} between groups. No differences were found in RPE between groups despite the higher HR values in the HWI group, therefore although they may have found it physiological harder compared to the CON group, they did not perceive it to be harder. Over the course of 6-days, the HWI group decreased mean HR during training by -12 b·min^{-1} (182±13 to 170±9 b·min^{-1}) where no change in HR occurred in the CON group (167±4 to167±7 b·min^{-1}). Following 6-days of post-training HWI, Zuralew et al, (2016) showed that during the fifth day of training subjects produced a significant decrease ($p<0.05$) in HR vs. day-1 (142±13 vs. 139±12 b·min^{-1}), similar to Zuralew et al, (2018) whereby subjects produced a significant difference ($p<0.01$) in end-exercise HR on day-6 (143±9 b·

min^{-1}) compared to day-1 (154±7 b·min^{-1}) . Although the HR changes in the Zuralew et al (2016) study are smaller than the HR changes in the current study, their subjects were endurance trained and had a higher fitness levels and initial VO_{2max}, whereby HR changes become harder to achieve. Similar, moderate reductions in HR have been observed in exercise–based HA protocols in team-sports athletes (Peterson et al, 2010; Kelly et al, 2016). RPE showed no differences between groups during the training intervention, despite differing HR values, all subjects perceived the training to be of a similar intensity, highlighting the similar fitness levels/training backgrounds of the subjects.

Physiological responses during HWI

Subjects showed early improvements in HR during HWI as decreases occurred on just the second day (although not significant until day-6), this trend continued and led to an overall decrease of -14 b·min^{-1} following 6-days of HWI (Fig. 5.1.1). Similar HR changes have previously been shown by Brazaitis & Skurvydas, (2010) where subjects displayed a significant decrease in HR (139±5 vs. 127±3 b·min^{-1}), following seven sessions of HWI across 2-weeks where a mean decrease of 12 b·min^{-1} occurred. Cardiovascular changes in response to heat stress are usually the first to occur during heat adaptation (Tyler et al, 2016), which may explain the early improvement on the second day of HWI in the current study. These changes are complex and occur due to varying mechanisms such as improved skin cooling and redistribution of blood volume, PV expansion, increased venous tone from cutaneous and non-cutaneous vascular beds and reduced skin and core temperature (Periard et al, 2015). Subjective responses produced meaningful changes across the 6-days of post-training HWI as feelings significantly improved and ThC and ThS produced their highest/lowest values on day-6, this may have been related to the significant decrease in HR observed. A reduced perceived physiological strain is a common adaption with heat exposure and given the role the CNS can have in regulating exercise intensity through motor unit recruitment (Tucker, Marle, Lambert, & Noakes, 2006) this can be an important factor for performance in the heat. These results show that 6-days of post-training HWI is an effective method to induce partial acclimation in moderately trained team-sport athletes.

6.2 Effects on Concurrent Training Load

Training Load (TL) is a measure that is frequently used within elite sporting environments, typically combining both internal and external metrics that is specific and relevant to the respective sport to calculate TL. HA is typically implemented during the preparatory stages for competition in hot and/or humid environments, however, the effects of HA on concurrent TL has rarely been reported within the literature. The results from the current study have shown that 6-days of post-training HWI for 40-minutes at 38°C had no detrimental impact on concurrent TL and exercise capacity in team-sport athletes (Fig. 5.2.3). To the best of the researcher's knowledge only one study has measured TL during a HA intervention. Stanley et al, (2015) used the same s-RPE method to measure TL during 10-days of post-exercise sauna bathing in elite cyclists. They also found it had no substantial effect on concurrent TL in the cyclists, however, they did find 'moderate' reductions in training duration and TL during the sauna bathing period. The subjects completed their own training; therefore, duration or intensity of training can be altered easily, compared to the current study whereby subjects had a set amount of intermittent running to complete as they would during a typical team-sport training session, hence, alterations in intensity and duration were limited. Scoon et al, (2007) did not measure TL during post-training sauna bathing but did compare intensity, duration and frequency of training during the control period (3-weeks) and sauna period (12 sessions across 3-weeks). During the control period, training sessions lasted 53±8-min and were performed 7.7±2.3 times per week, with 53% of the total training time spent at a 'hard' or 'very hard' intensity. During the sauna period subjects trained for 52±7 min and spent 45% of total training time at hard or very hard intensity but were less frequent (6.7±2.2 times per week). These data suggest that alternate days of post-training sauna influenced training frequency and training intensity in trained endurance runners. It is important to note that the two studies mentioned used endurance athletes compared to team-sports athletes in the current study, TL and training intensity between these two modes of exercise are extremely different and should be considered when drawing comparisons. All subjects completed a training log to record any external training they completed throughout the testing process (pre-test to post-test), as most subjects were still playing a team-sport they had other training commitments. There was no difference in the number of external trainings completed as the HWI group completed 3±2 trainings vs. the CON group who completed 3±4 trainings through the testing period. The results from the current study offer useful information not only for sport scientists, but also coaches when complying with the implementation of a HA protocol such as post-training HWI. A coach's main concern is the potential effects any intervention may have on the more important field-based training. Using a simple measure such as s-RPE x duration can be easily implemented into any elite and sub-elite team-sport setting, it is cheap and can provide a scientific explanation for changes in performance (Halson, 2014). Increasingly so for sub-elite teams, as a lack of resources is often the main challenge when seeking tools such as the monitoring of TL. Therefore, it should be used during the implementation of a HA regime to measure the effects it may have on concurrent TL, allowing changes to be made if necessary. Future studies that implement a HA concurrently with the subjects/athletes normal training should also look to use some measure of TL to gather more data surrounding its potential effects on TL and training quality.

6.3 Treadmill RAMP Test

The pre- and post- intervention treadmill RAMP test produced a large variance in times between groups. The HWI group improved run to exhaustion time by 4±57 sec, like the CON group who improved by 4±68 sec, i.e. no difference between groups. Garett et al, (2009) used a similar RAMP-based protocol (2% PPO every 30 sec until volitional exhaustion) following a submaximal (40% PPO) cycle for 90-min in the heat (35°C, 60% RH). Following five consecutive days of exercise-based HA, subjects improved exercise performance capacity by 106 sec (59 to 152 sec; $p = 0.001$), significantly greater than the results found in the current study. This significant improvement in exercise capacity may be specific to the exercise used during HA as subjects spent 5-days cycling in the heat and then went to perform a cycling test in the heat two-days following the intervention. The absence of improvement in the run to exhaustion test in the current study could have been due to the lack of heat training in which they were exposed. Subjects completed 6-days of intermittent running in temperate conditions followed by 40-min of HWI, this is dissimilar to the sensations they would feel exercising in the heat during the pre- and post-intervention treadmill test. Scoon et al, (2007) used a similar run to exhaustion test (best 5km run time) for endurance trained subjects following 12 sauna sessions, subjects produced a 32% (21-43%) improvement in running time which was equivalent to a 1.9±0.7% change in time for a 5km time-trial. The greater extent of heat exposure (12-days vs. 6-days) may explain differences observed in run to exhaustion times. Further exposure may have produced greater physiological adaptation such as the noted PV and blood volume adaptions measured. The subjects used were trained endurance athletes who had extensive running backgrounds making them very familiar with the running protocol used in this study. Subjects in the current study were unfamiliar with the RAMP-based treadmill run, which may have affected run times both pre- and post-intervention. The test was of short duration due to the RAMP-based nature and perhaps not long enough to reveal differences within and between groups. A longer test may have shown greater differences as indicated by diverging T_c data following 9-min for the HWI group (figure 5.4.2.)

6.4 Limitations

The pre- and post-performance test was not team-sport specific, the RAMP protocol used in this investigation is similar to field-based tests such as the Yo-Yo Intermittent Recovery (Yo-YoIR) tests due to its similar incremental conditions, but by no means is a valid performance measure for team-sport performance in the heat. The RAMP-based treadmill run was a continuous test, which is not specific to the intermittent nature of team-sport, the ability to accelerate and decelerate are critical to performance in team-sports, the Yo-Yo IR1 tests are commonly used because of the intermittent running, accelerations and deceleration involved. Heating a large room to a specific temperature and running a field-based test such as the Yo-Yo IR1 or the LIST (Sunderland et al, 2008) would have given a better indication of the impact the HA protocol would have on team-sport performance in the heat. This was piloted during the early stages of this study, but a suitable temperature was unable to be reached that would've provided an appropriate stimulus to replicate a hot environment. Therefore, the more controlled laboratory-based exercise protocol was used that allowed for simulation of a hot environment.

Some subjects had commitments outside of the testing protocol such as club trainings, strength and conditioning sessions, etc. which would have added to their respective weekly load. Although this was considered through their self-reported training logs, it may have impacted their running performance, especially during the days where the run to exhaustion test was performed (part B of the LIST). We could not control outside training sessions, only consider them when discussing the results. Two participants core temperature pills were not reading, and so they were given two more to ingest and come back the following day for re-testing. The temperature of the HWI was set at 38°C, previous reports have used temperatures between 40-44°C, the spa we had access to could only reach 38°C. This does not adhere to data from previous research (Brazaitis & Skurvydas, 2010; Shin et al, 2013; Zuralew et al, 2016) and may explain why only few physiological adaptations occurred, compared to previous reports (Zuralew et al, 2016). However, this type of logistical issue would also typically be encountered by teams depending on facilities available to them. This study had a low initial sample size which decreased further as subjects missed training sessions or dropped out of the study altogether, this reduces the validity of the results from the study.

6.5 Future Recommendations

Utilising a professional team-sport squad and integrating the HA strategy into their trainings would have improved validity and practical application of this study. Analysing how post-training HWI affects physical training quality through analysis of GPS (different running parameters, accelerations, jumps, etc.) and subjective measures. Additionally, investigating the effects of post-training HWI on skill performance e.g. pass accuracy, duals won, etc. would provide greater confidence for coaches when looking to implement it during the preparatory period prior to competition. Further investigation is also needed on post-training HWI and post-training sauna as practical HA methods. This is the first study to use team-sport athletes after previous studies that have typically used endurance trained subjects. Given the significant differences in physical demands along with the differing logistical challenges they can face when looking to acclimate prior to competition, more research needs to focus on implementing HA protocols within a team-sport setting. Other parameters such as duration of immersion, length of protocol, depth level of HWI needs to be investigated to optimally prescribe a suitable protocol for a given team/athlete. Permissive dehydration needs to be investigated as it could potentially lead to enhanced physiological strain i.e. greater adaptation as shown in exercise-based HA protocols (Garrett, Goosens, Rehrer, Patterson, Harrison, Samnut, & Cotter, 2014). This should be taken with caution as to prevent fluid intake following training can delay recovery for the subsequent training sessions. Integrating both HWI and exercise-based HA together should be looked into for future studies, the HWI could be implemented on days where training intensity is relatively heavy, and the exercise-based HA could be completed on the lighter training days to avoid high training loads. This would allow greater physiological adaption and prepare athletes for the sensations and responses they would face during competition.

6.6 Practical Application

The results of the present study provide evidence that 6-days of post-training HWI induces partial HA and has no detrimental impact on concurrent TL in moderately-trained team-sport athletes. This is a practical HA method for teams who do not have access to an environmental chamber, or the time to implement an exercise-based HA protocol. Most teams will have access to a spa pool or a sauna, it is relatively cheap, and is suitable for larger numbers, therefore will not be time-consuming. For example, a NZ age-group football team typically comes together 6-7 days before departing to the Pacific Islands for World Cup Qualifying tournaments. The Pacific Islands have relatively high air temperatures and high humidity that can impact football performance, given limited time before competition departure, on-field training will be needed to be completed at the highest quality, so the coach can implement his/her style of play. Along with video sessions, recovery sessions and other external commitments, leaves minimal time for specific exercise-based HA. Post-training HWI provides a practical alternative that will induce physiological adaption that will offset environmentally induced impairments in performance in the heat with no detrimental effects on concurrent TL.

6.7 Conclusion

6-days of post-training HWI is a practical method of HA for team-sport athletes that will not impact concurrent TL negatively. Challenges faced during preparation for team-sport competition in the heat can influence what is (un)available for teams to optimally prepare for these disadvantageous environmental conditions. Post-training HWI provides an easy alternative that is cheap, accessible for teams of differing competition level with no detrimental effects on concurrent TL.

References

Akerman AP, Tipton M, Minson CT, & Cotter JD. (2016). Heat stress and dehydration in adapting for performance: good, bad, both, or neither? *Temperature* **3**, 412-436.

Aldous JW, Chrismas BC, Akubat I, Dascombe B, Abt G, & Taylor L. (2016). Hot and hypoxic environments inhibit simulated soccer performance and exacerbate performance decrements when combined. *Frontiers in Physiology* **6**, 421-435

Alghannam AF. (2012). Metabolic limitations of performance and fatigue in football. *Asian Journal of Sports Medicine* **3**, 65-73

Aragón-Vargas LF, Moncada-Jiménez J, Hernández-Elizondo J, Barrenechea A, & Monge-Alvarado M. (2009). Evaluation of pre-game hydration status, heat stress, and fluid balance during professional soccer competition in the heat. *European Journal of Sport Science* **9**, 269-276.

Armstrong LE, & Maresh CM. (1991). The induction and decay of heat acclimatisation in trained athletes. *Sports Medicine*, **12**, 302-312.

Aughey RJ, Goodman CA, & McKenna MJ. (2014). Greater chance of high core temperatures with modified pacing strategy during team sport in the heat. *Journal of Science and Medicine in Sport* **17**, 113-118.

Austin D, Gabbett T, & Jenkins D. (2011). The physical demands of Super 14 rugby union. *Journal of Science and Medicine in Sport* **14**, 259-263.

Backhouse SH, Ali A, Biddle SJH, & Williams C. (2007). Carbohydrate ingestion during prolonged high-intensity intermittent exercise: impact on affect and perceived exertion. *Scandinavian Journal of Medicine & Science in Sports* **17**, 605-610.

Balsom PD, Wood K, Olsson P, & Ekblom B. (1999). Carbohydrate intake and multiple sprint sports: with special reference to football (soccer). *International Journal of Sports Medicine* ***20,*** 48-52.

Bangsbo J. (2014). Physiological demands of football. *Sports Science Exchange* **27**, 1-6.

Bangsbo J, Mohr M, & Krustrup P. (2006). Physical and metabolic demands of training and match-play in the elite football player. *Journal of Sports Sciences* **24**, 665-674.

Barengo NC, Meneses-Echávez JF, Ramírez-Vélez R, Cohen DD, Tovar G, & Bautista JEC. (2014). The impact of the FIFA 11+ training program on injury prevention in football players: a systematic review. *International Journal of Environmental Research and Public Health* **11**, 11986-12000.

Barnes C, Archer DT, Hogg B, Bush M, & Bradley PS. (2014). The evolution of physical and technical performance parameters in the English Premier League. *International Journal of Sports Medicine* **35**, 1095-1100.

Bonner RM, Harrison MH, Hall CJ, & Edwards R.J. (1976). Effect of heat acclimation on intravascular responses to acute heat stress in man. *Journal of Applied Physiology* **41**, 708-713

Brade C, Dawson B, & Wallman K. (2013). Effect of precooling and acclimation on repeat-sprint performance in heat. *Journal of Sports Sciences* **31**, 779-786.

Brazaitis M, & Skurvydas A. (2010). Heat acclimation does not reduce the impact of hyperthermia on central fatigue. *European Journal of Applied Physiology* **109**, 771-778.

Buchheit M, Voss SC, Nybo L, Mohr M, & Racinais S. (2011). Physiological and performance adaptations to an in-season soccer camp in the heat: Associations with heart rate and heart rate variability. *Scandinavian Journal of Medicine & Science in Sports* **21**, 477-485.

Buchheit M, & Mendez-Villanueva A. (2013). Supramaximal intermittent running performance in relation to age and locomotor profile in highly-trained young soccer players. *Journal of Sports Sciences* **31**, 1402-1411.

Cahill N, Lamb K, Worsfold P, Headey R, & Murray S. (2013). The movement characteristics of English Premiership rugby union players. *Journal of Sports Sciences* **31**, 229-237.

Casadio JR, Kilding AE, Cotter JD, & Laursen PB. (2016). From lab to real world: heat acclimation considerations for elite athletes. *Sports Medicine* **47**, 1-10.

Casadio JR, Kilding AE, Siegel R, Cotter JD, & Laursen PB. (2016). Periodizing heat acclimation in elite Laser sailors preparing for a world championship event in hot conditions. *Temperature* **3**, 437-443.

Casamichana D, Castellano J, Calleja-Gonzalez J, San Román J, & Castagna C. (2013). Relationship between indicators of training load in soccer players. *The Journal of Strength & Conditioning Research* **27**, 369-374.

Castle P, Mackenzie RW, Maxwell N, Webborn AD, & Watt PW. (2011). Heat acclimation improves intermittent sprinting in the heat, but additional pre-cooling offers no further ergogenic effect. *Journal of Sports Sciences* **29**, 1125-1134.

Chalmers S, Esterman A, Eston R, Bowering KJ, & Norton K. (2014). Short-term heat acclimation training improves physical performance: a systematic review, and exploration of physiological adaptations and application for team sports. *Sports Medicine* **44**, 971-988.

Chen TI, Tsai PH, Lin JH, Lee NY, & Liang MT. (2013). Effect of short-term heat acclimation on endurance time and skin blood flow in trained athletes. *Journal of Sports Medicine* **4**, 161-170.

Cohen, J. (2013). *Statistical power analysis for the behavioural sciences*, Routledge.

Coughlan GF, Green BS, Pook PT, Toolan E, & O'Connor SP. (2011). Physical game demands in elite rugby union: a global positioning system analysis and possible implications for rehabilitation. *Journal of Orthopaedic & Sports Physical Therapy* **41**, 600-605.

Coutts AJ, Reaburn PRJ, Murphy AJ, Pine MJ, & Impellizzeri FM. (2003). Validity of the session-RPE method for determining training load in team sport athletes. *Journal of Science and Medicine in Sport*, **6**, 525.

Coyle EF. (2004). Fluid and fuel intake during exercise. *Journal of Sports Sciences* **22**, 39-55.

Cunniffe B, Proctor W, Baker JS, & Davies B. (2009). An evaluation of the physiological demands of elite rugby union using global positioning system tracking software. *The Journal of Strength & Conditioning Research* **23**, 1195-1203.

Dawson B, Pyke FS, & Morton AR. (1988). Improvements in heat tolerance induced by interval running training in the heat and in sweat clothing in cool conditions. *Journal of Sport Sciences* **7**, 189-203

Dawson B. (1994). Exercise training in sweat clothing in cool conditions to improve heat tolerance. *Sports Medicine* **17**, 233-244.

Dellal A, Chamari K, Wong DP, Ahmaidi S, Keller D, Barros R, Bisciotti G, & Carling C. (2011). Comparison of physical and technical performance in European soccer match- play: FA Premier League and La Liga. *European Journal of Sport Science* **11**, 51-59.

Drust B, Rasmussen P, Mohr M, Nielsen B, & Nybo L. (2005). Elevations in core and muscle temperature impairs repeated sprint performance. *Acta Physiologica* **183**, 181-190.

Duffield R, Coutts AJ, & Quinn J. (2009). Core temperature responses and match running performance during intermittent-sprint exercise competition in warm conditions. *The Journal of Strength & Conditioning Research* **23**, 1238-1244.

Duffield R, Coutts A, McCall A, & Burgess D. (2013). Pre-cooling for football training and competition in hot and humid conditions. *European Journal of Sport Science* **13**, 58-67.

Febbraio MA, Snow RJ, Stathis CG, Hargreaves M, & Carey MF. (1994). Effect of heat stress on muscle energy metabolism during exercise. *Journal of Applied Physiology* **77**, 2827-2831.

Flouris AD, & Schlader ZJ. (2015). Human behavioral thermoregulation during exercise in the heat. *Scandinavian Journal of Medicine & Science in Sports* **25**, 52-64.

Gant N, Ali A, & Foskett A. (2010). The influence of caffeine and carbohydrate coingestion on simulated soccer performance. *International Journal of Sport Nutrition and Exercise Metabolism* **20**, 191-197.

Garrett AT, Goosens NG, Rehrer NG, Patterson MJ, & Cotter JD. (2009). Induction and decay of short-term heat acclimation. *European Journal of Applied Physiology* **107**, 659-670

Garrett AT, Creasy R, Rehrer NJ, Patterson MJ, & Cotter JD. (2012). Effectiveness of short-term heat acclimation for highly trained athletes. *European Journal of Applied Physiology* **112**, 1827-1837.

Garrett AT, Goosens NG, Rehrer NJ, Patterson MJ, Harrison J, Sammut I, & Cotter JD. (2014). Short-term heat acclimation is effective and may be enhanced rather than impaired by dehydration. *American Journal of Human Biology* **26**, 311-320.

Givoni B, & Goldman RF. (1972). Predicting rectal temperature response to work, environment, and clothing. *Journal of Applied Physiology* **32**, 812-822.

Halson SL. (2014). Monitoring training load to understand fatigue in athletes. *Sports Medicine* **44**, 139-147.

Horowitz M. (2002). From molecular and cellular to integrative heat defense during exposure to chronic heat. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology* **131**, 475-483.

Iaia FM, Ermanno R, & Bangsbo J. (2009). High-intensity training in football. *International Journal of Sports Physiology and Performance* **4**, 291-306.

Impellizzeri FM, Rampinini E, Coutts AJ, Sassi ALDO, & Marcora SM. (2004). Use of RPE-based training load in soccer. *Medicine & Science in Sports & Exercise* **36**, 1042-1047.

Jones AM, & Doust JH. (1996). A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. *Journal of Sports Sciences* **14**, 321-327.

Kelly M, Gastin PB, Dwyer DB, Sostaric S, & Snow RJ. (2016). Short duration heat acclimation in Australian football players. *Journal of Sports Science & Medicine* **15**, 118-125

Krustrup P, Mohr M, Steensberg A, Bencke J, Kjær M, & Bangsbo J. (2006). Muscle and blood metabolites during a soccer game: implications for sprint performance. *Medicine and Science in Sports and Exercise* **38**, 1165-1174.

Lacome M, Piscione J, Hager JP, & Bourdin M. (2014). A new approach to quantifying physical demand in rugby union. *Journal of Sports Sciences* **32**, 290-300.

Leppäluoto J, Tuominen M, Väänänen A Karpakka J, & Vuor J. (1986). Some cardiovascular and metabolic effects of repeated sauna bathing. *Acta Physiologica* **128**, 77-81.

Lieberman HR. (2007). Hydration and cognition: a critical review and recommendations for future research. *Journal of the American College of Nutrition* **26**, 555-561.

Lythe J, & Kilding AE. (2011). Physical demands and physiological responses during elite field hockey. *International Journal of Sports Medicine* **32**, 523-528.

Maughan R, & Shirreffs S. (2004). Exercise in the heat: challenges and opportunities. *Journal of Sports Sciences* **22**, 917-927.

Maughan RJ, Shirreffs SM, Ozgünen KT, Kurdak SS, Ersöz G, Binnet MS, & Dvorak JİRİ. (2010). Living, training and playing in the heat: challenges to the football player and strategies for coping with environmental extremes. *Scandinavian Journal of Medicine & Science in Sports* **20**, 117-124.

Maxwell NS, Castle PC, & Spencer M. (2008). Effect of recovery intensity on peak power output and the development of heat strain during intermittent sprint exercise while under heat stress. *Journal of Science and Medicine in Sport* **11**, 491-499.

Mohr M, Krustrup P, & Bangsbo J. (2003). Match performance of high-standard football players with special reference to development of fatigue. *Journal of Sport Sciences* **21**, 519-528

Mohr M, Nybo L, Grantham J, & Racinais S. (2012). Physiological responses and physical performance during football in the heat. *PloS one* **7**, e39202.

Montain SJ, Latzka WA, & Sawka MN. (1995). Control of thermoregulatory sweating is altered by hydration level and exercise intensity. *Journal of Applied Physiology* **79**, 1434-1439.

Nassis GP, Brito J, Dvorak J, Chalabi H, & Racinais S. (2015). The association of environmental heat stress with performance: analysis of the 2014 FIFA World Cup Brazil. *British Journal of Sports Medicine* **49**, 609-613

Neal RA, Corbett J, Massey HC, & Tipton MJ. (2016). Effect of short-term heat acclimation with permissive dehydration on thermoregulation and temperate exercise performance. *Scandinavian Journal of Medicine & Science in Sports* **26**, 875-884.

Nicholas CW, Nuttall FE, & Williams C. (2000). The Loughborough Intermittent Shuttle Test: a field test that simulates the activity pattern of soccer. *Journal of Sports Sciences* **18**, 97-104.

Nielsen BODIL. (1996). Olympics in Atlanta: a fight against physics. *Medicine and Science in Sports and Exercise* **28**, 665-668.

Pandolf KB, Burse RL, & Goldman RF. (1977). Role of physical fitness in heat acclimatisation, decay and reinduction. *Ergonomics* **20**, 399-408.

Pandolf KB. (1998). Time course of heat acclimation and its decay. *International Journal of Sports Medicine* **19**, S157-S160.

Périard JD. (2013). Cardiovascular determinants involved in pacing under heat stress. *Sports Medicine* **43**, 643-645.

Périard JD, Racinais S, & Sawka MN. (2015). Adaptations and mechanisms of human heat acclimation: applications for competitive athletes and sports. *Scandinavian Journal of Medicine & Science in Sports* **25**, 20-38.

Petersen CJ, Portus MR, Pyne DB, Dawson BT, Cramer MN, & Kellett AD. (2010). Partial heat acclimation in cricketers using a 4-day high intensity cycling protocol. *International Journal of Sports Physiology and Performance* **5**, 535-545.

Pethick WA, Stellingwerff T, Lacroix MA, Bergstrom C, & Meylan CM. (2017). The effect of a team-sport specific heat acclimation protocol on plasma volume in elite female soccer players. *Science and Medicine in Football* **2**, 16-22.

Pryor JL, Minson CT, & Ferrera MS. (2018) Heat Acclimation. In *Sport and Physical Activity in the Heat* (pp. 33-58). Springer, Cham.

Racinais S, Mohr M, Buchheit M, Voss SC, Gaoua N, Grantham J, & Nybo L. (2012). Individual responses to short-term heat acclimatisation as predictors of football performance in a hot, dry environment. *British Journal of Sports Medicine* **46**, 810-815.

Racinais S, Buchheit M, Bilsborough J, Bourdon PC, Cordy J, & Coutts AJ. (2014). Physiological and performance responses to a training camp in the heat in professional Australian football players. *International Journal of Sports Physiology and Performance* **9**, 598-603.

Racinais S, Alonso JM, Coutts AJ, Flouris AD, Girard O, González-Alonso J, Hausswirth C, Jay O, Lee JK, Mitchell N, and Nassis GP. (2015). Consensus recommendations on training and competing in the heat. *Scandinavian Journal of Medicine & Science in Sports* **25**, 6-19.

Sawka MN, Wenger CB, & Pandolf KB. (2011). Thermoregulatory responses to acute exercise-heat stress and heat acclimation. *Comprehensive physiology*.

Schlader ZJ, Prange HD, Mickleborough TD, & Stager JM. (2009). Characteristics of the control of human thermoregulatory behavior. *Physiology & Behavior* **98**, 557-562.

Schlader ZJ, Simmons SE, Stannard SR, & Mündel T. (2011). Skin temperature as a thermal controller of exercise intensity. *European Journal of Applied Physiology* **111**, 1631-1639.

Schlader ZJ, Perry BG, Jusoh MRC, Hodges LD, Stannard SR, & Mündel T. (2013). Human temperature regulation when given the opportunity to behave. *European Journal of Applied Physiology* **113**, 1291-1301.

Scoon GS, Hopkins WG, Mayhew S, & Cotter JD. (2007). Effect of post-exercise sauna bathing on the endurance performance of competitive male runners. *Journal of Science and Medicine in Sport* **10**, 259-262.

Shin YO, Lee JB, Min YK, & Yang HM. (2013). Heat acclimation affects circulating levels of prostaglandin E 2, COX-2 and orexin in humans. *Neuroscience Letters* **542**, 17-20.

Shirreffs SM, Aragon-Vargas LF, Chamorro M, Maughan RJ, Serratosa L, & Zachwieja JJ (2005). The sweating response of elite professional soccer players to training in the heat. *International Journal of Sports Medicine* **26**, 90-95.

Siegel R, Mate J, Brearley MB, Watson G, Nosaka K, & Laursen PB. (2010). Ice slurry ingestion increases core temperature capacity and running time in the heat. *Medicine & Science in Sports & Exercise* **42**, 717-725.

Stanley, J., Halliday, A., D'Auria, S., Buchheit, M., & Leicht, A. S. (2015). Effect of sauna-based heat acclimation on plasma volume and heart rate variability. *European Journal of Applied Physiology* **115**, 785-794.

Stølen T, Chamari K, Castagna C, & Wisløff U. (2005). Physiology of soccer. *Sports medicine* **35**, 501-536.

Sunderland C, & Nevill ME. (2005). High-intensity intermittent running and field hockey skill performance in the heat. *Journal of Sports Sciences* **23**, 531-540.

Sunderland C, Morris JG, & Nevill ME. (2008). A heat acclimation protocol for team sports. *British Journal of Sports Medicine* **42**, 327-333.

Taylor, N. (2000) Principals and practises of heat adaption. *Journal of the Human-Environmental System* **4**, 11-22

Taylor NA, & Cotter JD. (2006). Heat adaptation: guidelines for the optimisation of human performance. *International SportMed Journal* **7**, 33-57.

Taylor L, Thornton HR, Lumley N, & Stevens CJ. (2018). Alterations in core temperature during World Rugby Sevens Series tournaments in temperate and warm environments. *European Journal of Sport Science **19***, 432-441.

Tyler CJ, Reeve T, Hodges GJ, & Cheung SS. (2016). The effects of heat adaptation on physiology, perception and exercise performance in the heat: a meta-analysis. *Sports Medicine* **46**, 1699-1724.

Waldron M, Twist C, Highton J, Worsfold P, & Daniels M. (2011). Movement and physiological match demands of elite rugby league using portable global positioning systems. Journal of Sports Sciences **29**, 1223-1230.

Weller AS, Linnane DM, Jonkman AG, & Daanen HA. (2007). Quantification of the decay and re-induction of heat acclimation in dry-heat following 12 and 26 days without exposure to heat stress. *European Journal of Applied Physiology* **102**, 57-66.

Williams C, & Rollo I. (2015). Carbohydrate nutrition and team sport performance. *Sports Medicine* **45**, 13-22.

Wisbey B, Rattray B, & Pyne D. (2008). Quantifying changes in AFL player game demands using GPS tracking: 2008 AFL season. *Florey (ACT): FitSense Australia*.

Zurawlew MJ, Walsh NP, Fortes MB, & Potter C. (2016). Post-exercise hot water immersion induces heat acclimation and improves endurance exercise performance in the heat. *Scandinavian Journal of Medicine & Science in Sports* **26**, 745-754.

Zurawlew MJ, Mee JA, & Walsh NP. (2018). Heat Acclimation by Post- exercise Hot-Water Immersion: Reduction of Thermal Strain During Morning and Afternoon Exercise-Heat Stress After Morning Hot-Water Immersion. *International Journal of Sports Physiology and Performance* **13**, 1281-1286.

Zurawlew MJ, Mee JA, & Walsh NP. (2018). Post-exercise hot water immersion elicits heat acclimation adaptations in endurance trained and recreationally active individuals. *Frontiers in Physiology* **9**, 18-24

Appendices

Participant Information Sheet

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Massey University Auckland
Private Bag 102904
North Shore
Auckland
0745
New Zealand

The Effects of Passive Heat Acclimation on Running Performance in the Heat and Concurrent Training Quality

Information for Participants

You are invited to participate in a study that is analysing the effects of a short-term heat acclimation protocol (6-days of post-running hot water immersion) on running performance in the heat and the quality of concurrent training. If you do not want to take part in this study, you do not have to give a reason. This Participant Information Sheet will provide you the details to help you decide if you would like to take part in this study. It contains why we are performing this study, what your participation involves, the benefits and risks that you may experience, and what will happen at the conclusion of this study.

Why are we doing this study?

Many New Zealand sporting teams frequently travel from our cooler shores to warmer climates to compete (e.g. Australia, Pacific Islands), placing them at a performance disadvantage and risk of developing a heat illness due to the detrimental effects of this heat stress. Optimal preparation for such travel involves short-term (<7 days) adaptation to the heat (heat acclimation, HA) alongside their routine training, with this typically being achieved by consecutive days of moderate exercise in a heat chamber. However, whilst previous research has investigated the mechanisms by which this occurs there is little sport-specific knowledge and studies have neglected the impact this additional physical strain places on athletes and how it might compromise their (more important) team/tactical trainings. Therefore, the focus of this study will be to analyse the effects of a more practical method of HA (post-training hot water immersion) on intermittent running performance that is similar to football movement patterns and how this HA affects the quality of concurrent intermittent running quality.

What would your participation involve?

This study will be conducted in 3 parts across 8 consecutive days. We invite you to participate in this study:

Part 1. This pre-testing will occur in the morning during which time suits you to come in and participate. You will come into the Massey University, School of Sport and Exercise Laboratory to record resting measures. Part 1 will involve measuring resting heart rate using a polar heart rate monitor strapped around your chest, core temperature in which a thermometer pill will be swallowed, and we would like to obtain a small amount of blood through a small finger prick to measure changes in plasma volume. These measures combined should take no longer than 30-minutes to complete. In addition, we would like to measure height and weight, in which will only take 1-2 minutes. Following this, you are free to leave. This same procedure will be repeated following the intervention period on Day 8.

Part 2. This will involve completing an intermittent running performance test on a treadmill in a heated room in the School of Sport and Exercise laboratory. You will complete this protocol after all resting measures have been recorded. The room will be heated to 30-32°C, you will complete a standardised warm-up on the treadmill, then begin the performance test. You will be able to drink *ad libitum* (as desired) throughout the protocol. During this protocol, core temperature, heart rate, thermal comfort, thermal sensation and RPE will be measured at regular intervals until exhaustion.

Part 3. This involves all participants completing 6 consecutive days of standardised intermittent running. During these sessions, GPS tracking devices will be given to you to measure running activity throughout these trainings, ratings of perceived exertion (training intensity) will also be asked of you. The participants will be split into a control group and acclimation group, the control group will be able to head home following each training session. The acclimation group will complete a post-training hot water immersion for a period of 40 minutes at a temperature of 38°C, during which heart rate, sweating rate, thermal comfort and thermal sensation will be measured. Following the spa bath, participants may then exit, rehydrate and have access to showers.

Summary of approximate time to complete all tests and procedures across the 8-days

Day 1 and 8 (morning)	
Test	*Time*
Resting heart rate Resting core temperature Bloods Height/weight Brief about heat test Total approximate time for pre-tests	10 minutes 5 minutes 5 minutes 1 minute 5 minutes 26 minutes
Day 1 and 8 (evening)	
Heat Test	
Warm-up Performance test (including recovery) Total approximate time for heat test	5 minutes 30 minutes 35 minutes
Days 2-7 (Intermittent Running and Intervention)	
Procedures	*Time*
Briefing and GPS setup at the training ground Warm-up Intermittent Running Warm-down Travel to Spa location Equipment setup Pre-spa Weight Spa session Post-spa weight Total approximate time	10 minutes 10 minutes 40 minutes 5 minutes 10 minutes 5 minutes 3 minutes 30 minutes 3 minutes 1 hour and 56 minutes

What will happen to the data upon completion?

The data will be used only for the purposes of this project and will be coded so that no individual can be identified. Only the investigators of the study will have access to personal information and this will be kept secure and strictly confidential. Additionally, while your identity may be known to other participants in this study, your individual results from all test will remain confidential and will be kept in a locked office at Massey University. Summary results of this project may be published or presented at conferences or seminars, and disseminated in scientific research journals, but no individual will be able to be identified. At the end of the study you will receive a brief report summarizing the main findings of the research as well as your own individual results if wanted.

What are the benefits of participating in this research?

The benefit to you as an individual will be a copy of your final results if you wish to obtain them. This will show any physiological changes that occur throughout the duration of this project. It will also have benefits to your physiological fitness, as the predicted physiological changes will help improve physical performance not only in warmer conditions but also temperate/cooler conditions. It will also have benefits for the footballing community that face the challenge of going to compete in hot and/or humid climates, the information from this study will provide valuable recommendations to help appropriately equip these teams with the methods to cope with these stressful playing conditions.

What are the risks of participating in this research?

Exercise in the heat can place stress on the body, during the performance test participants may experience physical discomfort but given that this is a test until voluntary exhaustion, participants can pull-out at anytime they need to. Similar discomfort may be experienced during the spa bathing sessions, if there is ever a point throughout these sessions that a participant feels discomfort or feelings of “nausea” or “sickly”, they can exit the spa and be given water and any care deemed appropriate.

Although participants will be experienced football players, given potential fatigue effects from the concurrent spa baths and heat tests, physical strain that may be greater than usual and be experienced throughout the football trainings. As with all football trainings, the risk of injury is always present, but medical assistance will be on-hand if an injury is sustained.

Minor discomfort may be experienced from the finger prick in which to measure changes in plasma volume, however, this will be very minor and will not affect the participants activities following this test.

Participants rights

You are under no obligation, but if you participate in this study you have the right to:

- *Decline to answer any particular question*
- *Withdraw from the study at any time*
- *Withdraw from any testing session at any time*
- *Ask any questions about the study at any time*
- *Provide information on the understanding that your name will not be used*
- *Be given access to a summary of the project findings and individual data when it is concluded*

Where can you go for more information about the study, or to raise concerns or complaints?

This research is being conducted by Mr Josh Stewart, Master student of Massey University, School of Sport and Exercise. Co-supervisor Dr Andrew Foskett, who has extensive experience with NZ Football teams and other team-sport athletes. Co-supervisor Dr Toby Mundel, who has widespread knowledge and experience regarding heat research and its effects.

Contacting the researchers

Josh Stewart Principal Investigator *Phone:* [redacted] *Email:* [redacted]	Dr Andrew Foskett Co-Supervisor *Phone:* 414 0800 ext 43412 *Email:* A.Foskett@massey.ac.nz	Dr Toby Mundel Co-Supervisor *Phone:* (06) 356 9099 ext 84538 *Email:* T.Mundel@massey.ac.nz

Confidentiality

All information gathered from the study will remain confidential. Individual participants will have their data that is obtained during the research study, individually stored in a locked cabinet in a secure office. Individual data will be known only to the participant and the researchers. The analysed data will in no way be traceable to the names of the original participants. No participants will be named in the final summaries/reports which will feature only group data and results.

Compensation for Injury

If physical injury results from your participation in this study, you should visit a treatment provider to make a claim to ACC as soon as possible. ACC cover and entitlements are not automatic, and your claim will be assessed by ACC in accordance with the Accident Compensation Act 2001. If your claim is accepted, ACC must inform you of your entitlements, and must help you access those entitlements. Entitlements may include, but not be limited to, treatment costs, travel costs for rehabilitation, loss of earnings, and/or lump sum for permanent impairment. Compensation for mental trauma may also be included, but only if this is incurred as a result of physical injury.

This project has been reviewed and approved by the Massey University Human Ethics Committee: Southern A, Application 17/70. If you have any concerns about the conduct of this research, please contact Dr Lesley Batten, Chair, Massey University Human Ethics Committee: Southern A, telephone 06 356 9099 x 85094, email humanethicsoutha@massey.ac.nz .

Thank you for your consideration with participation in this study

Health Screening Questionnaire

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Massey University Auckland
Private Bag 102904
North Shore
Auckland
0745
New Zealand

Pre-Exercise Health Questionnaire

Name: ____

Address: ____

Phone: ______________________

Age: ________

This questionnaire has been designed to identify the small number of persons (15-69 years of age) for whom physical activity might be inappropriate. The questions are based upon the Physical Activity Readiness Questionnaire, originally devised by the British Columbia Dept of Health (Canada), as revised by Thomas et al. (1992) and Cardinal et al. (1996), with the added requirements of the Massey University Human Ethics Committee. The information provided by you on this form will be treated with the strictest confidentiality.

You should be aware that even amongst healthy persons who undertake regular physical activity there is a risk of sudden death during exercise. Though extremely rare, such cases can occur in people with an undiagnosed heart condition. If you have any reason to suspect that you may have a heart condition that will put you at risk during exercise, you should seek advice from a medical practitioner before undertaking an exercise test.

Please read the following questions carefully. If you have any difficulty, please advise the exercise specialist who is conducting the exercise test. Please answer all of the following questions by ticking only one box for each question:

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

Yes ☐ No ☐

2. Do you feel a pain in your chest when you do physical activity?

Yes ☐ No ☐

3. In the past month have you had chest pain when you were not doing physical activity?

Yes ☐ No ☐

4. Do you lose your balance because of dizziness or do you ever lose consciousness?

Yes ☐ No ☐

5. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

Yes ☐ No ☐

6. Do you have a bone or joint problem that could be made worse by vigorous exercise?

Yes ☐ No ☐

7. Do you know of any other reason why you should not do physical activity?

Yes ☐ No ☐

8. Have any immediate family had heart problems prior to the age of 60?

Yes ☐ No ☐

9. Have you been hospitalized recently?

Yes ☐ No ☐

10. Do you exercise 3 or more days per week?

Yes ☐ No ☐

Safe use of the Core Temperature Pill

The following questions ensure that it is safe for you to ingest the core temperature pill

11. Do you weigh less than 80 lbs (36.2 kg)?

Yes ☐ No ☐

12. Do you have any known or suspected obstructive disease of the gastrointestinal (GI) tract, including but not limited to diverticulitis and inflammatory bowel disease?

Yes ☐ No ☐

13. Do you have a history of disorders or impairment of the gag reflex?

Yes ☐ No ☐

14. Have you had previous GI surgery?

Yes ☐ No ☐

15. Do you know if you have any problems with your oesophagus or stomach?

    Yes ☐ No ☐

16. Will you undergo Nuclear Magnetic Resonance (NMR) or MRI scanning during the period that the core temperature pill is within the body?

    Yes ☐ No ☐

17. Do you have hypo motility disorders of the GI tract including but not limited to lleus?

    Yes ☐ No ☐

18. Do you have any hyper motility disorders of the GI tract?

    Yes ☐ No ☐

19. Do you have a cardiac pacemaker or other implanted electro medical device?

    Yes ☐ No ☐

20. Do you have a swallowing disorder?

    Yes ☐ No ☐

I have read, understood and completed this questionnaire.

Signature: ____ Date: ___________________

References

Thomas S, Reading J and Shephard RJ. (1992) Revision of the Physical Activity Readiness Questionnaire (PAR-Q). *Can J Sport Sci* 17(4): 338-345.

Cardinal BJ, Esters J and Cardinal MK. (1996) Evaluation of the revised physical activity readiness questionnaire in older adults. *Med Sci Sports Exerc* 28(4): 468-472

HQ Inc. CorTemp™ Ingestible Core Body Temperature Sensor, Intended Use/Contraindications

Consent Form

MASSEY UNIVERSITY
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UNIVERSITY OF NEW ZEALAND

Massey University Auckland
Private Bag 102904
North Shore
Auckland
0745
New Zealand

The Effects of Passive Heat Acclimation on Running Performance in the Heat and Concurrent Training Quality

Participant Consent Form

Declaration by participant:

I have read, or have had read to me in my first language, and I understand the Participant Information Sheet. I have had the opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this study

I have been given a copy of the Participant Information Sheet and Consent Form to keep

By consenting in this study, I allow the researcher permission to use the data collected for this study.

Participant's name: ____

Signature: ____________________________ Date: ________________

Declaration by member of research team:

I have given a verbal explanation of the research project to the participant and have answered the participant's questions about it.

I believe that the participant understands the study and has given informed consent to participate.

Researcher's name: ____

Signature: ____________________________ Date: ________________

Thirst Rating

Value	Thirst Rating
1	Not Thirsty At ALL
2	
3	A Little Thirsty
4	
5	Moderately Thirsty
6	
7	Very Thirsty
8	
9	Very, Very Thirsty

Thermal Comfort

How comfortable are you feeling with the temperature of your body??

Value	Rating
Very Comfortable	+4
	+3
	+2
Just/slightly comfortable	+1
	0
Just/slightly uncomfortable	-1
	-2
	-3
Very uncomfortable	-4

Thermal Sensation

Value	Sensation
+3	Hot
+2	Warm
+1	Slightly Warm
0	Neutral
-1	Slightly Cool
-2	Cool
-3	Cold

Feelings

Value	Feeling
+5	Very Good
+4	
+3	Good
+2	
+1	Fairly Good
0	Neutral
-1	Fairly Bad
-2	
-3	Bad
-4	
-5	Very bad

RAMP Protocol

Table 4.2*:* The RAMP protocol used as the performance test before and after the intervention period.

Stage	Speed ($km \cdot h^{-1}$)	Grade (%)	Time (min)
1	9	1	1
2	9.5	1	1
3	10	1	1
4	10.5	1	1
5	11	1	1
6	11.5	1	1
7	12	1	1
8	12.5	1	1
9	13	1	1
10	13.5	1	1
11	14	1	1
12	14.5	1	1
13	15	1	1
14	15.5	1	1
15	16	1	1
16	16.5	1	1
17	17	1	1
18	17.5	1	1
19	18	1	1
20	18.5	1	1

Ethics Approval Letter

MASSEY UNIVERSITY
TE KUNENGA KI PŪREHUROA
UNIVERSITY OF NEW ZEALAND

Date: 05 April 2018

Dear Josh Stewart

Re: Ethics Notification - **SOA 17/70** - **The Effects of Passive Heat Acclimation on Intermittent Running Performance in the Heat and Concurrent Training Quality**

Thank you for the above application that was considered by the Massey University Human Ethics Committee: **Human Ethics Southern A Committee** at their meeting held on **Friday, 6 April, 2018**.

Approval is for three years. If this project has not been completed within three years from the date of this letter, reapproval must be requested.

If the nature, content, location, procedures or personnel of your approved application change, please advise the Secretary of the Committee.

Yours sincerely

Dr Brian Finch

Chair, Human Ethics Chairs' Committee and Director (Research Ethics)