EFFECTS OF POST-EXERCISE INFRARED SAUNA ON TRAINING ADAPTATIONS IN TEAM-SPORT ATHLETES

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ABSTRACT

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The aim of this study was to investigate the effects of post-exercise infrared sauna (IRS) on chronic training adaptations regarding physical performance, skeletal muscles, cardiovascular function, and haematological biomarkers in team-sport athletes.

23 female team-sport players were volunteered to participate and assigned to two groups to undertake a 6-week strength and power training programme with utilizing IRS recovery (IRS; n = 11) or without recovery implementation (CON; n = 12). The training program consisted of two or three complex resistance training sessions per week, with a 10-minute recovery period following each session. Before and after the 6-week training intervention, 20 m maximal sprint, maximal countermovement-jump, squat jump, and isometric leg press tests were performed to evaluate the adaptations in explosive physical performance. To assess the adaptations in skeletal muscle, body composition, cross-sectional area (CSA) and pennation angle of the vastus lateralis muscle were measured. Venous blood samples were collected pre and post-training intervention to analyse haematological parameters including red blood cells, haematocrit, and haemoglobin concentration.

Significant increases were found in isometric leg press performance, whole-body fat-free mass (FFM), leg FFM and CSA following 6-week strength and power training ($P < 0.05$). No significant effect of utilizing IRS (time*group) has been indicated in all variables compared to using passive recovery ($P > 0.05$). It concludes that IRS as a recovery strategy does not have a detrimental impact on adaptations to strength and power training in team sport athletes. Moreover, it could be considered a favourable recovery strategy when frequent and long-term utilization is required, as previous evidence has indicated the benefits of IRS in acute recovery.

Key words: infrared sauna, recovery, training adaptations, team sport

ABBREVIATIONS

ANS	autonomic nervous system
Aix_{aort}	aortic augmentation index
BV	blood volume
CK	creatin kinase
CMJ	countermovement jump
CSA	cross-sectional area
CV	coefficients of variation
CWI	cold water immersion
CWT	contrast water therapy
DOMS	delayed-onset muscle soreness
FFM	fat-free mass
FFM_{total}	whole body fat-free mass
FFM_{leg}	leg fat free mass
FIRs	far-infrared saunas
[Hb]	haemoglobin concentration
Hct	haematocrit
HR	heart rate
HR_{max}	maximal heart rate
HSPs	heat shock proteins
ICC	intraclass correlation coefficient
IR	infrared radiations
IRS	infrared sauna
LP	leg press
mTOR	mammalian target of rapamycin
PA	pinnation angle
PV	plasma volume
PWVao	aortic pulse wave velocity
RBC	red blood cells
RCV	red cell volume
RESTQ-Sport	Recovery-Stress Questionnaire for Sport

SD	standard deviation
SJ	squat jump
VL	vastus lateralis
1 RM	one repetition maximum

CONTENTS

1 INTRODUCTION

Team sports are popular worldwide with millions of participants. Athletes who compete in team sports require both good decision-making abilities under pressure and/or while fatigued and highly developed physical capacities due to the characteristics of the sports (Billaut et al. 2012; Bishop and Girard, 2013).

The utilization of recovery strategies is popular among team sports players (Crowther et al. 2017; Van Wyk and Lambert 2009), varies recovery strategies e.g., active recovery, massage, cold water therapy, contrast water therapy, sleep, and nutrition supplementation are used in team sport athletes daily training to avoid overreaching or overtraining and benefit training adaptations. Sleep and nutrition play central roles in both sports performance and recovery. By ensuring appropriate quality and quantity of sleep, coupled with adequate intake of nutrition, athletes can effectively obtain sufficient recovery from competitions and training. (Beck et al. 2022; Venter, 2012) For team sports athletes, sleep is critical for muscle protein accumulation, memory retention, and neural plasticity following exercise training which plays an essential role in acquiring training adaptations (Fullagar et al. 2015). Nevertheless, in cases where rigorous and demanding training schedules are implemented to speed up the process of gaining adaptations, it may be necessary to incorporate additional recovery strategies. Studies have evaluated the effectiveness of utilizing post-training cold water immersion (CWI) in team sports players, suggesting that implementation of CWI is beneficial for psychometric measures and does not have negative effects on players' physical performance (Elias et al. 2012; De Nardi et al. 2011). However, adverse effects of strength (Fröhlich et al. 2014) and muscle gains (Roberts et al. 2015) have been found in the studies that investigated the effects of CWI on long-term strength training adaptations. Similarly, acute intake of antioxidant supplements may bring benefits to physical performance for athletes while having detrimental effects on chronic muscle adaptations (Braakhuis and Hopkins 2015; Merry and Ristow 2016). Strategies that benefit athletes' recovery and do not interfere with chronic training adaptation should be further investigated.

Recently, there is an increasing interest in implementing heat intervention in sports settings to maximise the benefits of training in athletes (Bartolomé et al., 2021; Méline et al. 2021; Kirby et al. 2021; Perez-Quintero, 2021). Méline (2021) found that regular training with hot water baths maintains high performance in elite short-track speed skaters while inducing additional effects on maximal isometric strength and did not alter aerobic and anaerobic aptitudes and field performance on the ice. Exposures to sauna bath following exercise training has been found to improve exercise performance (Kirby et al., 2021); increased total blood volume (Scoon et al., 2007) and plasma volume (Stanley et al., 2015); and altered body composition (Bartolomé et al. 2021). Compared with traditional saunas, far-infrared saunas (FIRs) which utilize infrared elements to radiate heat with a ~10 μm wavelength of approximate heat to 40-60 °C seem to offer a more relaxing and comfortable experience. Additionally, a more vigorous sweat is developed in users of FIRs than in their sweating responses to traditional saunas since infrared heat penetrates more deeply than warmed air. (Beever, 2009) Studies have examined the effectiveness of utilizing infrared radiations (IR) as recovery modalities, suggesting favourable effects on the recovery of neuromuscular performance and perceived sensation (Hausswirth et al. 2011; Mero et al. 2015; Noponen et al. 2015).

To optimize the effects of athletic training, it is important to understand the characteristics of the sport, adaptations to training, and the recovery strategies that have been proposed to boost training adaptations. The following sections will introduce and focus on athletic training and recovery strategies in team sports.

2 CHARACTERISTICS OF TEAM SPORTS

2.1 Physical and physiological profiles during match play

Team sports matches generally consist of repeated short, maximal, or near-maximal efforts, interspersed with recovery intervals including rest to low-intensity activity to moderate-intensity activity over an extended period of 1-2 h. Elite athletes are not only required to possess superior decision-making abilities under pressure and/or while fatigued but also highly developed physical capacities. Demands for these athletes are complex, consisting of power, speed, strength, repeated sprint ability, agility, and endurance. (Billaut et al. 2012; Bishop and Girard, 2013)

For example, during a soccer game, ~10 km distance is covered by an elite female field player. Around 1500 changes of activity occur during a match, with ~125 high-intensity (18 $km \cdot h^{-1}$ - 25 $km \cdot h^{-1}$) runs and ~ 26 sprints ($\geq$ 25 $km \cdot h^{-1}$ or backward running $\geq$ 10 $km \cdot h^{-1}$) are performed. (Krustrup et al. 2005) For a high-level female basketball player, ~ 7 km total distance and ~ 1700 movements are performed during a game with ~ 300 runs (3.1-7.0 $m \cdot s^{-1}$) and ~ 100 sprints ($\geq$ 7.0 $m \cdot s^{-1}$) among these movements (Scanlan et al. 2012). Physiological responses of team sports players have been investigated in studies, with an average heart rate (HR) of 80-90% maximal HR (HR_{max}) during competitive matches reported (Barbero-Alvarez et al. 2007; Krustrup et al. 2005; Lythe and Kilding 2011; Scanlan et al. 2011). These findings suggest that competing in team sports requires both anaerobic and aerobic capacities. Athletes should undergo comprehensive training that focuses on developing both aspects to achieve optimal results during competitions.

2.2 Physiological determinants and performance tests

Body composition, aerobic fitness, and anaerobic power could discriminate team sports players among different competitive levels and playing positions, athletes who compete at higher-level tend to be leaner with possessing better aerobic fitness and anaerobic power (Ferioli et al. 2018; Reilly et al. 2000; Ostojic et al. 2006; Slimani and Nikolaidis, 2017). According to Delextrat and Cohen (2008), elite basketball players performed significantly better ($p < 0.05$) in the vertical jump test (+8.8%), agility T test (+6.2%), 1RM bench press (+18.6%), and peak torques developed by the knee extensors (+20.2%) compared to average-level athletes, suggesting superior anaerobic power in elite athletes. In addition, the study by Ferioli et al. (2018) found that higher-level basketball players were able to perform the high-intensity intermittent exercise with lower blood lactate accumulation, lower blood hydrogen ion concentration, and higher bicarbonate concentration than relatively lower-level players, which suggests a better ability to sustain the high-intensity intermittent efforts in higher-level basketball players. It also suggests that higher-level players tend to be more powerful and have more strength, which was evidenced by higher jump heights, greater peak power output, and peak force during countermovement jumps (CMJ) (Ferioli et al. 2018). Similar findings were documented in soccer players, elite athletes present higher maximal isometric force, vertical jump height, agility, aerobic power, tolerance of fatigue, and lower sprint time than non-elite athletes (Gissis et al. 2005; Reilly et al. 2000). Rodríguez-Rosell et al. (2017) have also examined the validity and reliability of using jump tests including CMJ, Abalakov jump, and sport-specific jumps in team sports athletes. They found high intraclass correlation coefficients (0.969–0.995) and low coefficients of variation (1.54 – 4.82%) of implementing these tests and the results of these jump tests were associated with sprint performance and leg strength (Rodríguez-Rosell et al. 2017). Based on these findings, jump tests, sprint tests, and muscle strength measurements are suggested to evaluate team sports athletes' anaerobic performance.

3 ADAPTATIONS TO TRAINING

3.1 Models explaining physiological effects of training stress

There are several models, for example, the general adaptation syndrome model, the stimulus-fatigue-recovery-adaptation model, and the fitness-fatigue model have been utilized to explain the physiological effects of an acute training stimulus.

In brief, the general adaptation syndrome model consists of four phases (alarm, resistance, supercompensation, overtraining) and proposes that the response to stress, which is considered a disruption of the body's homeostatic state is similar to all stressors. Supercompensation is experienced following the resistance phase and overtraining syndrome may be identified with too much stress and without adequate recovery. The stimulus-fatigue-recovery-adaptation model which includes five components (stimulus, fatigue, recovery, supercompensation, involution) suggests that the accumulation of fatigue in proportion to the magnitude and duration of a stimulus and supercompensation occurs following recovery from fatigue. The fitness-fatigue model proposes that fitness and fatigue occur concurrently and gains in fitness become apparent only when fatigue has dissipated. The cumulative effect of training load and fatigue, and recovery deficit explain responses to stress in this model. (McGuigan, 2017, 43-51; Turner, 2011) These models emphasize the importance of the recovery phase during exercise training to induce training adaptations and extensive fatigue should be avoided during the training.

3.2 Risk of overreaching/overtraining

Overreaching can be defined as a short-term reduction in performance capacity resulting from an accumulation of training and/or non-training stress, which may last for several days to several weeks. While overtraining refers to a long-term reduction in performance capacity due to stress accumulation and may last for several weeks or months. (Meeusen et al. 2013) With insufficient recovery following training stimulus, athletes may move along the fatigue continuum to a state where overreaching or overtraining occurs. Specifically, overreaching can be divided into functional overreaching and non-functional overreaching, which can be distinguished by the required time to recover as the former could be reversed with an adequate period of recovery of 1-3 weeks, and the latter requires more time ranging from 2 weeks to 6 months. (McGuigan, 2017, 51-64; Kreher and Schwartz, 2012) The overtraining syndrome represents the ultimate stage of the fatigue continuum and appears to be a maladapted response to excessive stress without sufficient recovery. This condition can disrupt various systems within the body, including the neurological, endocrinological, and immunological systems, as well as mood states. It is important to note that the consequences of overtraining extend beyond a decline in performance and can increase the risk of injuries and illnesses. (Angeli et al. 2004; McGuigan, 2017, 51-64; Kreher and Schwartz, 2012)

In short, exercise training should include adequate overload to induce adaptation but should also allow a sufficient recovery period from fatigue and prevent non-functional overreaching or overtraining that may lead to severe consequences. This suggests the importance of monitoring recovery during training and the potential benefits that may gain from the use of recovery strategies.

4 RECOVERY IN TEAM SPORT

4.1 Recovery monitoring

To ensure adequate recovery following exercise training to induce training adaptations, it is important to monitor fatigue/recovery status during training sessions. Several types of measurements consisting of performance tests, physiological parameters, and self-reported measures have been well-documented in studies for recovery monitoring.

The CMJ test which is simple and time-efficient has been widely adopted to monitor athletes' neuromuscular fatigue in team sports due to its robust reliability and validity (Coffey et al. 2020), with significant decreases in jump heights up to 72 h hours were reported following training or competitions (Coffey et al. 2020; Ramírez-López et al. 2020; Wiewelhove et al. 2015). However, it has been questioned due to its task-specific nature which may not be sensitive to assessing the fatigue generated by run-based training sessions or games that involves a lot of horizontal movements e.g., soccer (Buchheit et al. 2017), thence some studies suggested the utilization of running tests to measure neuromuscular fatigue in team sports players (Garrett et al. 2021; Leduc et al. 2019). In addition, a cycle-ergometer sprint test has also been proposed for neuromuscular fatigue monitoring as it examines the concentric component of force production decrement in muscle induced by fatigue that is likely to be overlooked by a CMJ test (Wehbe et al. 2015). Nevertheless, while these performance tests have been found to effectively assess neuromuscular fatigue in team sports athletes (Garrett et al. 2021; Wehbe et al. 2015; Wiewelhove et al. 2015), their implementation for the entire team can be laborious and pose a potential risk of injuries to players. Consequently, it becomes impractical to utilize them frequently during daily training sessions.

There are some biochemical markers such as creatine kinase (CK) (Buchheit et al. 2011; Coffey et al. 2020; Coutts et al. 2007; Wiewelhove et al. 2015), cortisol, and testosterone (Coutts et al. 2007; Elloumi et al. 2003; Nunes et al. 2014; Rowell et al. 2018) have been utilized to assess fatigue and recovery in team sports players. Among these biomarkers, CK is one of the most frequently used (Doeven et al. 2018) which increases following high-intensity interval training and decreases after 72 h of recovery period (Wiewelhove et al. 2015). However, according to Coffey et al. (2020), a high coefficient of variations at pre-exercise (25.6%) and 24 h following exercise (44.5%) were found in thirteen male college team sport athletes. In addition, the CK responses of soccer players to an in-season training camp were indicated to be varied based on training contents ($P < 0.001$), which fluctuated throughout a training camp with variations in training modalities (Buchheit et al. 2011). These findings question using CK measurements to monitor the fatigue and recovery status in the training of team sports which usually involve varied training contents. Studies suggested that changes in training load did not provoke changes in hormone responses including testosterone and cortisol (Coutts et al. 2007; Nunes et al. 2014). This is evidenced by no significant differences found in testosterone concentration, cortisol concentration, and testosterone to cortisol ratio of rugby league players following normal training and intensified training that intended to be overreached (Coutts et al. 2007). Additionally, it is supported by the baseline measures of salivary testosterone and cortisol concentrations of elite female basketball players that were not influenced by a 12-week periodized training program (Nunes et al. 2014).

The activity of the autonomic nervous system (ANS) is sometimes monitored during regular team sports training as it has been shown to associate with training adaptability (Buchheit et al. 2011; Buchheit et al. 2013; Cipryan et al. 2007) and to some extent reflect the adequacy of recovery. According to Buchheit et al. (2012), among highly trained young soccer players, decreased HR during exercise or increased heart rate variability (HRV) was associated with improved performance in incremental running tests to estimate maximal cardiorespiratory function and individual changes in HR recovery were found moderately associated with sprint ($r = 0.39$) and repeated-sprint ($r = -0.38$) performance. In addition, exercise HR was also found highly correlated ($r > 0.5$-0.7) with changes in Yo-Yo Intermittent recovery test level 1 in response to either sea-level training or altitude training camp in soccer players (Buchheit et al. 2013). Similarly, Cipryan et al. (2007) tracked the activity of ANS in ice hockey players and concluded that the ANS activity was affected by training quality and could reflect athletes' changes in adaptability. These findings suggest that the efficacy of monitoring ANS activity to track performance adaptability in team sports athletes.

It is well-documented that some self-report subjective measurements e.g., Recovery-Stress Questionnaire for Sport (RESTQ-Sport) (Coutts and Rcaburn, 2008; di Fronso et al. 2013); the profile of mood state questionnaire (Buchheit, 2014) and perceived ratings of wellness (Buchheit et al. 2013; Gastin et al. 2013; Thorpe et al. 2016) are suitable for monitoring stress and fatigue induced by exercise training in team sports players. Studies that examined the effectiveness of utilizing RESTQ-Sport indicated that only a few of the subscales from the questionnaire reflected the training stress changes (Coutts and Rcaburn, 2008; di Fronso et al. 2013). It was shown that only scores of three subscales i.e., fatigue, general stress, and disturbed breaks in semi-professional rugby players who completed normal training were different from the players that were administered intensified training with higher training loads than normal training (Coutts and Rcaburn, 2008). Additionally, it was found that twenty-eight amateur basketball players only recorded significantly different scores in fatigue and emotional stress in response to different training stress during the preseason and competition phases (di Fronso et al. 2013). These may suggest that the complete RESTQ-Sport questionnaire seems not to be necessary to be utilized to monitor players' training stress and fatigue level, more time-efficient measurements with fewer subscales might be more appropriate. For instance, indicators such as perceived fatigue, sleep quality, and delayed-onset muscle soreness (DOMS) have been observed to exhibit sensitive responses among elite soccer players in relation to variations in training load. These measures can be regarded as effective and practical tools for monitoring team sports, as they demonstrate a significant reduction (35-40%) in post-match compared to pre-match levels and a gradual increase during the subsequent recovery period. (Thorpe et al. 2016)

Based on the findings above, it suggests that performance tests such as CMJ tests, running tests, and cycle-ergometer sprint tests could be used for monitoring fatigue status on a routinely based rather than daily in team sports (for example, once a week). The use of biochemical markers for monitoring team sports athletes should be cautious as variations may occur in responses to different types of exercises that could be involved in their training programme. Monitoring ANS activity is promising to track the performance adaptability of these athletes. In addition, simple self-report measurements such as perceived fatigue, sleep quality, and DOMS seems to be effective in monitoring recovery status in the settings of team sports.

4.2 The use of recovery strategies

A mixed-method survey study conducted by Crowther et al. (2017) that investigated three hundred and thirty-one team sports athletes’ perceptions and use of recovery strategies found that 57% of athletes from the study reported performing a recovery after competition and/or training. According to Van Wyk and Lambert (2009), among fifty-eight medical staff from elite rugby teams, 48% reported having been utilizing recovery strategies for 0-5 years. These suggest that recovery strategies are commonly used in team sports settings.

The common recovery modalities that are adopted by team sports players include active recovery, massage, cold water therapy, contrast water therapy, sleep, and nutrition supplementation (Cross et al. 2019; Field et al. 2021; Van Wyk and Lambert, 2009; Venter 2014; Crowther et al. 2017). Studies suggest that the use of recovery strategies is affected by sports type (Cross et al. 2019; Venter et al. 2010) and competitive level (Crowther et al. 2017), which may be explained by the perceptions of recovery strategies (Crowther et al. 2017; Venter 2014). The study by Cross et al. (2019) found that the most frequently used strategy was CWI in 35 practitioners from professional collision (Australian rules football, rugby league, and rugby union) or non-collision (soccer) sports teams following match play while following training, the most frequently used strategy for collision teams was active recovery and for non-collision teams was the massage. In addition, according to Venter et al. (2010), active cool-down was ranked as the most frequently used post-match recovery strategy in hockey, netball, and soccer players while rugby players used rehydration most frequently. Regarding the players that compete at different levels, it was found by Crowther et al. (2017) that massage was the most frequently utilized recovery strategy among international-level team sport athletes, and the active-stretching was the most frequently used by other competition levels' (national, state, regional, and local) players. However, it is worth noting that the numbers of players competing at different levels were not evenly distributed in that study, therefore, it should be cautious to interpret the data from the study for some athletes (e.g., only 2% were international-level players which suggested a small sample size) (Crowther et al. 2017).

4.3 The effects of recovery strategies

The effects of recovery strategies may be varied based on different modalities as the potential mechanisms underlying seems to be varied. The following sections will introduce the potential mechanism briefly and the effects of three common recovery strategies (i.e., active recovery, cold water therapy, and contrast water therapy) that have been utilized in team sports.

Active recovery may involve continuous low-intensity exercise for a duration of around 10-20 min, which is a practical strategy to be implemented in team sports. The potential mechanism underlying active recovery is increasing the blood flow that elevates the removal of metabolic byproducts such as blood lactate (Calleja-González et al. 2016; Monedero and Donne, 2000; Nédélec et al. 2013; Taoutaou et al. 1995). However, Nédélec et al. (2013) argued that the faster lactate removal may not be the criterion utilized to examine the quality of recovery strategies as quicker removal of lactate does not necessarily induce better subsequent exercise performance. Studies found that even with an improved blood lactate removal induced by active recovery, the subsequent exercise performance was not enhanced (Weltman et al. 1979;

Ouergui et al. 2014). King and Duffield (2009) implemented four different recovery interventions (passive recovery, active recovery, CWI, contrast water therapy) following simulated team sport, intermittent-sprint exercise in ten trained netball players and found that active recovery even evoke greater muscle soreness 24 h post-exercise than the other recovery interventions and the exercise performance performed in the following day was maintained regardless of recovery strategies. While according to Rey et al. (2012), compared with passive recovery, the muscle contractile properties using tensiomyography and perceived muscle soreness did not differ after using active recovery in professional soccer players. These findings suggest that although active recovery is a practical strategy for team sports players and may be beneficial for metabolic byproducts removal, it may not be able to promote better recovery in subsequent performance and could provoke detrimental effects on perceived muscle soreness sometimes instead.

The physiology underpinning cold therapy is that under cold stress, it leads to a reduction in body (skin, core, tissue, and muscle) temperature (White and Wells, 2013) therefore causing vasoconstriction which is likely to decrease swelling and acute inflammation from muscle damage (Gregson et al. 2011). Additionally, decreased tissue temperature induced by cold therapy may reduce nerve conduction properties and decrease muscle spasms and pain. The hydrostatic effects specifically related to CWI may also benefit to improve metabolic waste removal. (Tavares et al. 2018) Numerous studies have examined the effectiveness of implementing post-match CWI in team sports, the benefits including but are not limited to promoting better physical performance restoration (Delextrat et al. 2012; Elias et al. 2013; Montgomery et al. 2008; Rowsell et al. 2011); improving perceptual measures (e.g., lower perceived fatigue and muscle soreness) (Ascensão et al. 2011; Delextrat et al. 2012; Elias et al. 2013; Pointon and Duffield, 2011; Rowsell et al. 2009; Rowsell et al. 2011); enhancing muscle contractile properties (Pointon and Duffield, 2011); and reducing muscle damage (Ascensão et al. 2011). There are some studies that evaluated the effectiveness of utilizing post-training CWI in team sports players, suggesting that implementation of CWI is beneficial for psychometric measures and does not have negative effects on players' physical performance (Elias et al. 2012; De Nardi et al. 2011). However, these studies only investigated the acute responses to CWI as a recovery strategy for short-term training (~1 week), the effects of CWI on long-term training adaptations in team sports remain unclear. Adverse effects of strength (Fröhlich et al. 2014) and muscle gains (Roberts et al. 2015) have been found in the studies that investigated the effects of CWI on long-term strength training adaptations. The blunt adaptations provoked by CWI may be explained by the attenuated acute changes in the satellite cell numbers and activity of kinase regulating muscle hypertrophy related to CWI (Roberts et al. 2015).

Contrast water therapy (CWT) that alternating hot-cold water has been proposed to generate a "pumping" action by alternating blood vessels' vasodilation and vasoconstriction in response to temperature change, thence increasing blood flow and improving the metabolic byproducts removal (King and Duffield, 2009). This is supported by the findings of Gill et al. (2006)'s study, that is when compared with passive recovery, CWT led to a significantly higher percentage of recovery after a rugby match after 84 h as assessed by interstitial creatine kinase activity (39.0% vs. 85.0%, $p < 0.05$). However, when compared with CWI, studies found that post-match and post-training CWT presented less effectiveness in restoring physical performance and psychometric measures in professional Australian footballers (Elias et al. 2012; Elias et al. 2013). The studies that investigated utilizing CWT on training adaptations in team sports athletes are limited, future studies should further investigate.

In summary, among the three common recovery strategies mentioned above, CWI seems to be the most effective one for recovery following a single exercise session. However, some evidence suggests that CWI might blunt some training adaptations such as strength and muscle size gain in response to strength training. Recently, there is a novel finding indicating that implementing heat stress following training sessions is beneficial for muscle strength improvements in elite athletes (Méline et al. 2021), which suggests the potential benefits of utilizing heat interventions in sports training.

4.4 Heat Interventions in sport

4.4.1 Mechanisms of heat interventions

The potential mechanisms of heat interventions may associate primarily with the effects of heat stress on the human body which is mostly mediated by the thermoregulatory control system. Figure 1 illustrates the human thermoregulatory control system schematically. Numerous core and peripheral receptors and nerves sense temperatures peripherally and throughout the body, which sends thermal information to some central integrators. Under heat stress, it is likely to trigger a thermal command signal to alter sweating and cutaneous vasodilatation when there are deviations between the regulated variable i.e., body temperature, and a reference variable e.g., set-point temperatures. (Sawka et al. 2011) Consequently, an increase in blood flow occurs due to cutaneous vasodilatation (Fiscus et al. 2005) that may enhance the removal of metabolic byproducts and speed up oxygen, nutrients, and hormones supply to fatigued muscles (Versey et al. 2013).

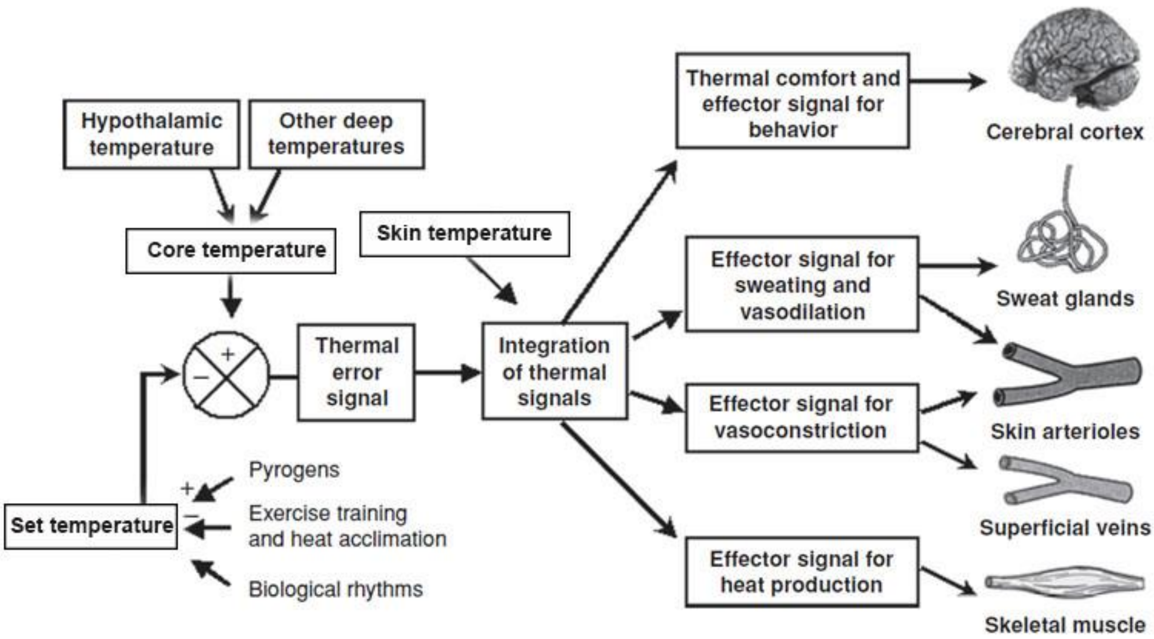

FIGURE 1. Scheme of human thermoregulation control system (Sawka et al. 2011).

Potential molecular mechanisms underlying the effects that attenuate muscle injury, performance decrements, and recovery improvement elicited by heat stress include heat shock proteins (HSPs), kinases in the mammalian target of rapamycin (mTOR) pathway, and genes associated with muscle hypertrophy/atrophy (McGorm et al. 2018). HSPs are produced by cells in response to exposure to stressful conditions. It is suggested that HSP plays a major role in immune regulation and cell protection during exercise and in the efficiency of regeneration and reparation processes. During long-term training, HSP is involved in preconditioning and adaptation processes that might also be important for disease prevention and therapy. (Krüger, Reichel and Zeilinger 2019) Evidence was found that implementing heat interventions increases the level of HSPs in human skeletal muscles (Ogura et al. 2007; Touchberry et al. 2007). mTOR signalling plays an important role in regulating muscle group through increasing protein synthesis (Bodine 2005). Since heat stress also has been indicated to enhance mTOR signalling in human skeletal muscles following resistance exercise, it may suggest that post-exercise heat interventions could provide benefits on muscle hypertrophy (Kakigi et al. 2011).

4.4.2 Modalities of heat interventions

There are various modalities of heat interventions including the modalities that could heat up the whole body such as using heated environmental chambers, hot water immersion (HWI), and sauna; and the modalities that are typically utilized locally in the human body such as wearing heat/steam sheets and microwave diathermy (Figure 2, McGorm et al. 2018). The effects of heat treatment have been suggested to be not limited to one specific mode of heating, and a key factor that mediates the effects of heating is the muscle temperature as it affects the expression of HSPs in muscle (McGorm et al. 2018).

Heated environmental chambers have been utilized as the environmental conditions (i.e., temperature and relative humidity) can be well-controlled. Compared with other modalities, HWI may have additional benefits due to the effects of hydrostatic pressure which is likely to elevate cardiac output, increase muscle blood flow, and diffusion of metabolic by-products from muscle to the blood (Versey et al. 2013). Regarding saunas, traditional saunas usually utilize either wood stoves or 220-V heaters to heat the air to ~85 °C and then heat up the human body mainly via convection (Beever 2009). When implementing heat intervention in team sports, the costs and the accessibility of the equipment should be taken into consideration, with HWI and saunas seeming to be practical methods due to their relatively low costs and great accessibility.

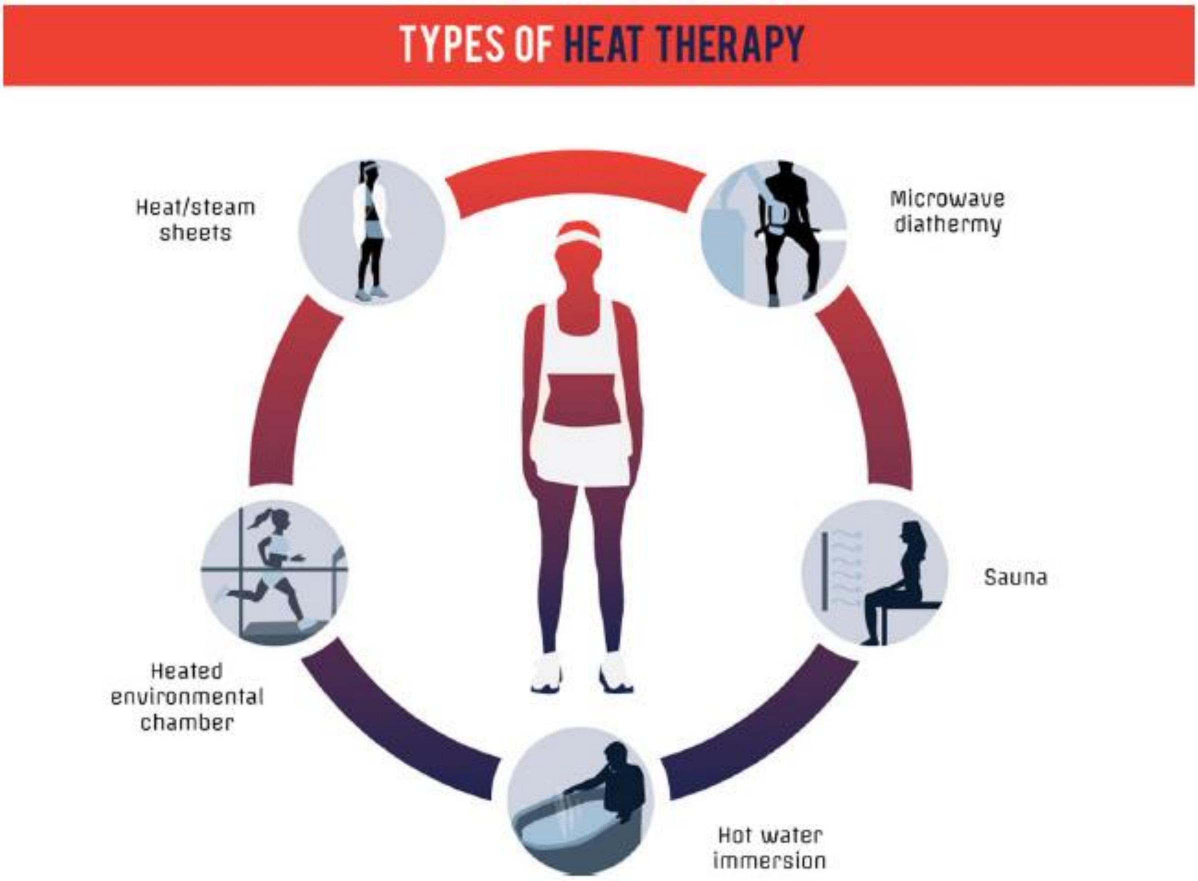

FIGURE 2. Modalities of heat interventions (McGorm et al. 2018).

4.4.3 Effects of heat interventions

The general effects of implementing heat stress on skeletal muscles include smaller loss of muscle strength and jump power, greater range of motion, and decreased soreness and swelling (McGorm et al. 2018). In addition, there is an increasing interest in the research utilizing post-exercise passive heating as heat acclimation strategies recently e.g., HWI (Zurawlew et al. 2016 & Zurawlew et al. 2018 & Zurawlew et al. 2019) and sauna exposure (Bartolomé et al., 2021; Kirby et al. 2021; Perez-Quintero, 2021; Scoon et al. 2007; Stanley et al. 2015). The general adaptation of heat acclimation strategies includes lowered body temperature, decreased cardiovascular strain, improved sweat rate, and enhanced aerobic performance (Périard et al., 2015). These effects may be influenced by various factors such as the intensity of heat stress i.e., temperature; the duration of exposure; the number of exposure sessions to heat stress, etc. For example, to induce heat acclimation, 30 min sauna (90-100 °C) for ten exposures is suggested (Bartolomé et al., 2021; Kirby et al. 2021; Perez-Quintero, 2021; Scoon et al. 2007; Stanley et al. 2015). However, this is unlikely applied in daily training sessions due to the time constraints and may lead to thermal discomfort during the intervention. Regarding the acute effects of utilizing heat stress on recovery, the study by Lee et al. (2012) found that whole-body hot water immersion (40 ℃) and mist sauna following fatigue exercise-induced higher skin blood flow and oxygenated haemoglobin concentration compared to shower and no bathing conditions which suggests that whole-body water immersion and mist sauna are effective for recovery from muscle fatigue. However, according to Skorski et al. (2019), a greater decrease in swimming performance was indicated by implementing a sauna bath after an intense swimming training session than under a placebo condition. The effects of heat interventions on recovery may depend on the type of exercise performed and may be partially explained by placebo effects.

There are limited studies that investigated the effects of applying heat interventions as recovery strategies on chronic adaptations to training. The study by Méline et al. (2021) compared the effects of post-training hot baths (40.3 ± 0.6 ℃, 92% RH) and passive recovery for 20 min in elite short-track speed skaters. They found that utilizing hot baths following training improved the isometric strength of the knee extensor and flexor muscles and maintained 1.5-lap all-out exercise performance without altering the aerobic capacity during incremental peak power output test (Méline et al. 2021). These findings suggest that regular training with hot water baths maintains high performance in these elite athletes while at the same time inducing additional effects on maximal isometric strength and did not alter aerobic and anaerobic aptitudes and field performance on ice (Méline et al. 2021). More studies are needed to further examine the effects of post-exercise heat interventions on training adaptations.

4.4.4 Far-infrared sauna

Compared with traditional saunas, far-infrared radiation could radiate heat with a ~10 μm wavelength approximately heat to 40-60 ℃ seems to offer a more relaxing and comfortable experience (Beever, 2009). A more vigorous sweat is developed in users of FIRs than in their sweating responses to traditional saunas since infrared heat penetrates more deeply (~3-4 cm into fat tissue and the neuromuscular system) than warmed air (a few millimetres) (Beever, 2009; Mero et al. 2015). The cardiovascular demand to maintain thermoregulatory homeostasis when implementing FIRs light, similar to that induced by walking at a moderate pace (Beever, 2009). Significant lower HR was observed by using FIRs (71 ± 7 bpm) than applying traditional sauna (92 ± 13 bpm) with similar temperatures (35–50 ℃) for 30 min in physically active men, which is likely due to the higher relative humidity during traditional sauna (traditional sauna:

60–70% vs. FIRs: 25–35%) bath by throwing water on the hot rocks of the sauna heater (Mero et al. 2015).

Several studies have examined the effectiveness of utilizing IR as a recovery modality, suggesting favourable effects on the recovery of neuromuscular performance and perceived sensation (Hausswirth et al. 2011; Mero et al. 2015; Noponen et al. 2015). Mero et al. (2015) utilized FIRs under mild temperature (35–50 °C) and light humidity conditions (25–35%) for 30 min in ten healthy physically active males and found higher CMJ after FIRs (0.34 ± 0.09 m) than after passive recovery (0.32 ± 0.08 m) following 34–40 min maximal endurance training session, suggesting FIRs is beneficial for the recovery of neuromuscular system from maximal endurance exercise. Furthermore, the study by Noponen et al. (2015) indicated that applying IR (50 °C) for 40 min following five-day strength, power, and technique training in ten trained power athletes led to significantly greater peak power during the Wingate test (pre: 13.09 ± 0.96; post: 13.46 ± 0.84) which was also different from the peak power in the control group (13.29 ± 0.85, $p \leq 0.05$). In addition, they also found a significant interaction effect between the IR and control condition in CMJ performance and a greater change in the testosterone/cortisol ratio in the IR condition than in the control condition (Noponen et al. 2015). These findings further support the beneficial effects of IR on neuromuscular performance recovery. According to Hausswirth et al. (2011), maximal muscle strength and perceived sensations in nine well-trained runners following muscle damage exercise were recovered within 24 h when implementing 30 min exposure to IR (4-14 µm, 45 °C) while the recovery was not attained by passive recovery strategy. Nevertheless, it took a shorter time (within an hour) to recover when using whole-body cryotherapy, suggesting a slower acute effect on post-exercise recovery of IR compared to whole-body cryotherapy (Hausswirth et al. 2011). Studies that examined the effects of IR on the cardiovascular system are scarce and mostly target clinical populations (Beever 2009). Theoretically, it could have some beneficial effects on the cardiovascular system such as increased plasma volume, decreased blood pressure, and reduced arterial stiffness which has been found by using traditional saunas (Hannuksela and Ellahham 2011; Laukkanen et al. 2018; Stanley et al. 2015). These should be further investigated in future research.

5 PURPOSE OF THE STUDY

To date, there is no available data assessing whether implementing post-exercise infrared sauna (IRS) is beneficial for training adaptations in team-sport athletes. As such the aim of this study is to examine the effects of post-exercise IRS on training adaptations regarding physical performance, skeletal muscles, and blood variables in team-sport athletes. The research questions and hypothesis are:

Question 1. Does post-exercise IRS exposure as a recovery strategy affect adaptations to 6-week strength and power training on physical performance, such as 20 m sprint, isometric leg press, squat jump (SJ), CMJ in team sport athletes?

Hypothesis 1. Post-exercise IRS exposure does not impair or even benefit the training adaptations on on physical performance in team sport athletes.

Question 2. Does post-exercise IRS exposure as a recovery strategy affect adaptations to 6-week strength and power training on muscles, such as muscle thickness, muscle cross-sectional areas, pennation angles in team sport athletes?

Hypothesis 2. Post-exercise IRS exposure does not impair or even benefit the training adaptations on muscles compared with the control group in team sport athletes.

Question 3. Does post-exercise IRS exposure affect haematological adaptations such as plasma volumes, blood pressure, and arterial stiffness to 6-week strength and power training in team sport athletes?

Hypothesis 3. Post-exercise IRS exposure does not impair or even improve haematological adaptations, for example, it may increase plasma volumes, reduce blood pressure, and decrease arterial stiffness in team sport athletes.

6 METHOD

6.1 Participants

The participants were 23 female team sports players who were competing in local teams or university teams and the characteristics of the players that participated in this study were presented in Table 1. Participants were assigned to two groups based on their age, physical performance, and sports: an infrared sauna group (IRS) and a control group (CON). Participants were informed about the study's purposes and test procedures before attending experimental sessions. Written informed consent was obtained and ethical approval was provided by the Ethics Committee of the University of Jyväskylä.

TABLE 1. Characteristics of participants in this study (mean ± SD)

Group	Age(year)	Height(cm)	Body mass(kg)	N	Sports
Infrared Sauna	20±4	169±7	65.2±5.6	11	Basketball: n=7; Ice hockey: n=2; Futsal: n=2
Control	22±4	169±7	67.0±12.1	12	Basketball: n=7; Ice hockey: n=2; Futsal: n=3

6.2 Study design

A randomized controlled study design was utilized to determine the effects of the IRS exposure as a recovery strategy following strength and power training (Figure 3). Experimental trials were completed one week before (PRE) and after (POST) the 6-week strength and power training. Training sessions were implemented two or three times per week and each training session was followed by either a 10-min recovery in an IRS chamber (50 °C) or without any recovery protocol implemented. Physical performance tests, arteriography measurements, ultrasound measurements, and blood samples analysis were conducted during experimental

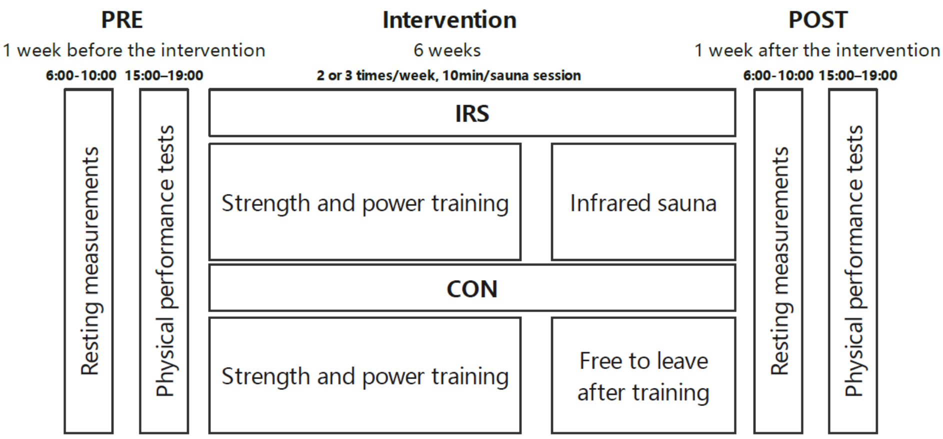

FIGURE 3. Schematic of study design.

trials and the temperature and humidity in the sauna chamber were monitored throughout the intervention.

6.3 Procedures

6.3.1 Experimental trials

Experimental trials were performed within 7 days prior to the training programme. A menstrual cycle questionnaire was completed by each participant and fluid intake was recorded 24 h prior to the first experimental trial. Three days of food diaries were completed during the week before the intervention and the last week of the intervention. All participants were instructed to not consume any alcohol, diuretics, or caffeine, and to refrain from any additional exercise 24 h prior to the experimental trials and on the day of experimental trials.

On the day of the experimental trials, participants were reported to the laboratory in the early morning (6:00–10:00) for the resting measurements which included anthropometric measurements, ultrasound measurements, arteriography measurements, and blood samples collection. Firstly, the height and weight of each participant were measured using a stadiometer and a digital platform scale (Seca, Hamburg, Germany), respectively. Body composition was measured by dual-energy X-ray absorptiometry (DXA). After anthropometric measurements, the participant rested in a supine position for 10 minutes while the marking of the imaging position was conducted simultaneously. Ultrasound imaging was taken for approximately 20 min and the blood pressure, aortic pulse wave velocity (PWVao), and aortic augmentation index (Aix_{aort}) were measured by arteriography device (TensioMed Ltd., Budapest, Hungary) after the imaging. Blood samples were collected either prior to ultrasound imaging or immediately following the ultrasound measurements in a standardised biochemistry laboratory. Physical performance tests were performed in the afternoon (15:00–19:00) during the same day. A standardized warm-up, including a 5-min aerobic warm-up and 5 min dynamic stretching and activations, was performed before the tests. Participants conducted the tests in the following order: 1) 20 m sprint; 2) jump tests; 3) isometric leg press. The rest intervals between different exercise tests were at least 3 min.

6.3.2 Training program

Throughout the 6-week training period, participants completed a training diary (types, frequency, duration, session perceived exertion, the use of recovery strategies, possible days of injury and illness) and a menstrual diary (the dates of menstruation, the possible use of hormonal contraception). Participants were instructed to avoid using other recovery strategies (foam rolling, massage, compression clothing, NSAIDs) apart from the one used in the study. In addition, a food diary at Meal Logger was completed for three days during the week before the start and the last week of the intervention. Participants were also instructed to keep consistent with their diet during the study period.

The training program aimed to improve strength and power. A standardized warm-up was performed at the beginning of each session (~10 min). The types of exercises were based on the physical demands of the sports that participants were involved in (Table 1). The majority of exercises were required to be performed with explosive power. Each session lasted for approximately 45-60 min and three sessions were performed per week. An example of the training programme was presented in Appendix 1.

6.3.3 Recovery modalities

Following each training session, the participants in the IRS group undertook a 10-min IRS for recovery, while the participants in the control group were free to leave.

For the IRS group, participants sat in the IRS chamber quietly for 10 min with wearing sports bras and shorts. Two chambers (the first one: VitaMy, Sentiotec GmbH, Vöcklabruck, Austria; the second one: Infrared Cabin, Spectrum Small, Harvia) were in different places and participants went to the nearest one to their training place. The room was heated up for about 10-20 min before participants entered and the temperature of the sauna chamber was set at 50 ℃. The actual temperature and relative humidity of the chamber at the end of recovery (~10s) were recorded.

6.4 Measurement

6.4.1 Physical performance tests

Three 20 m sprints on an indoor track were performed by participants after the warm-up with wearing sports shoes. The length of the rest period was 3 min in between each sprint. Infrared timing gates (University of Jyväskylä) were used to assess time to 5 and 20 m running. Participants were started in a standing position and instructed to run as fast as they could with verbal encouragement.

Jump tests were performed in a force plate (Hurlabs, FP8, Tampere, Finland) with a 3-min break between different jump exercises. Participants started the CMJ tests from a standing position with hands on hips throughout the jump and then squat down followed by a maximal effort vertical jump immediately to jump as high as possible. For the SJ tests, participants started the jump in a squat position with knees bending in a position based on participants' own preference and then jump vertically as high as possible with hands on hips. Three maximal efforts (4 or 5 attempts were performed when the participant improved on the third attempt) for both CMJs and SJs were undertaken, and the highest value of jump height was the main outcome measured for analysis. Data were collected and analysed in (Hurlabs, Tampere, Finland) by using flight time to estimate jump height. The previous study has reported the reliability of the SJ test with an intraclass correlation coefficient (ICC) of 0.97 and coefficients of variation (CV) of 3.3%, and the CMJ test with an ICC of 0.98 and CV of 2.8%, respectively (Markovic et al., 2004).

A leg extension dynamometer (University of Jyväskylä) was utilized to measure maximal isometric force. The contractile characteristics of the participants' isometric muscle force of bilateral leg extensors (hip, knee, and ankle extensors) were measured in a sitting position, with the knee angle 107°. A goniometer was used to determine the joint angles. During the maximal voluntary isometric contraction, the back chair was fixed to support the trunk and keep the predetermined angular position of the hip and knee with participants holding handles attached to the dynamometer. 3-5 attempts were made by each participant, and each contraction was sustained for approximately 3-5 s separated by 60 s intervals. The participants were instructed to exert maximal effort as quickly as possible. Strong verbal encouragement was given during the tests. Data were recorded and analysed using the monitor that was attached to the leg press device (University of Jyväskylä, Finland). The maximal isometric leg press was determined as the highest value of weights during each effort. The previous study has reported that the reliability of the testing protocol with CV ranges from 17.44% - 26.87% (Ivanovic´ and Dopsaj, 2013).

6.4.2 Ultrasound measurements

Morphological parameters were determined via images obtained from the diagnostic ultrasound system (Ultra ALOKA, Alpha 10, Zug, Switzerland). Participants were rested in a supine position comfortably with their vastus lateralis (VL) muscle of the right legs being imaged. At PRE, measuring tape and permanent markers were used to identify the midpoint between the greater trochanter and the superior aspects of the patella on the mid-sagittal plane of the thigh.

After marking, a polystyrene foam was placed under the participant's calves to slightly lift the thigh and a cuboid-shaped polystyrene foam was placed between the feet with a band to fix the position. A straight line parallel with the transverse axis of the thigh was extended from the midpoint that had been marked. The probe was placed above the line (transversally to the longitudinal axis of the thigh) which formed a 90 ° angle to the skin surface to gain the cross-sectional area (CSA) image. To obtain the pennation angle image, the probe was placed in parallel with the longitudinal axis of the thigh and vertically to the marked straight line as well as forming a 90° angle to the skin surface. The distance between the probe for the pennation angle (PA) image and the marked midpoint was recorded. A short line identifying the position of the probe when taking the images of PA was marked for future scanning (POST). Ultrasound images were analysed with ImageJ. The reliability of using ultrasound examination protocol to quantify the VL muscle was reported with an ICC of 0.87 in PA (Raj et al., 2012) and an ICC of 0.727 in CSA (Betz et al., 2021) previously.

6.4.3 Blood sample collection and analysis

Venous blood samples were collected from the antecubital veins via catheters. All blood samples were analysed within 1 hr of collection under standard laboratory conditions and analysis were performed in accordance with the manufacturer's specifications using routine laboratory procedures. An automated haematology analyser (Sysmex XP-300™, Norderstedt, Germany) was used to perform a complete blood count analysis and the following parameters were analysed: red blood cells (RBC), haematocrit (Hct), and haemoglobin concentration ([Hb]). Changes in plasma volume (PV; %), red cell volume (RCV; %), and blood volume (BV; %) from PRE to POST were estimated by using the method proposed by Dill and Costill's (1974). Equations were as follows:

$$BV_{POST} = BV_{PRE} ([Hb_{PRE}] / [Hb_{POST}])$$

$$RCV_{POST} = BV_{POST} (Hct_{POST})$$

$$PV_{POST} = BV_{POST} - RCV_{POST}$$

$$\Delta BV (\%) = 100 (BV_{POST} - BV_{PRE}) / BV_{PRE}$$

$$\Delta RCV (\%) = 100 (CV_{POST} - RCV_{PRE}) / RCV_{PRE}$$

$$\Delta PV (\%) = 100 (PV_{POST} - PV_{PRE}) / PV_{PRE}$$

6.5 Statistical analysis

Data in results were presented as mean ± standard deviation (SD) and analysed using IBM SPSS version 28.0. The level of significance for all data was set up at $p < 0.05$. The normal distribution of the data was checked by the Shapiro-Wilk test. For data that were not normally distributed, including SJ and HR, an appropriate logarithmic transformation was performed to make the values normally distributed. Between-group and within-group changes of the measurements (i.e., sprint time, maximal leg press, countermovement jump height, cross-sectional area and pennation angle of VL, FFM, blood pressure, RBC, Hct, [Hb], arterial stiffness) following training programme were determined through a two-factor (time*group) repeated measures ANOVA. A Bonferroni correction was used as a post hoc test. Correlations between changes in variables were analysed by the Pearson correlation coefficient.

7 RESULTS

7.1 Physical performance

No significant effect of training was shown regarding physical performance variables apart from the isometric leg press. There were no significant changes in 20 m sprint time, CMJ height, and SJ height following the 6-week strength and power training in IRS and CON ($P = 0.311$-0.851) (Table 2). Increases in isometric leg press were found after 6-week training with IRS (9.3%, 29 ± 48 kg, 95%CI [-2, 61]) and training without recovery strategy implementation (12.5%, 39 ± 34 kg, 95%CI [17, 61]) (main effect time; $F = 15.857$, $P < 0.001$). However, no time*group effect was observed in the increases of isometric leg press ($F = 0.038$; $P = 0.567$). (Table 2, Figure 4).

TABLE 2. Comparison of the training adaptations following the 6-week training in physical performance, muscle morphological characteristics, cardiovascular function, and haematological variables between the infrared sauna group and control group (mean ± SD)

Group	Infrared Sauna			Control		
	PRE	POST	Changes	PRE	POST	Changes
Physical performance						
20m sprint (s)	3.51±0.13	3.53±0.13	0.02±0.06	3.53±0.20	3.54±0.16	0.01±0.10
CMJ (cm)	26.4±2.8	26.2±2.5	-0.2±1.8	28.0±5.0	27.4±4.5	-0.5±1.9
SJ (cm)	27.8±3.9	28.9±3.1	1.1±5.5	30.1±6.5	28.8±5.9	-1.3±3.5
Leg Press (kg)	332±46	362±60*	29±48	347±92	386±89*	39±34
Muscle morphological characteristics						
CSA (cm^2)	21.64±2.69	23.44±2.39*	1.80±0.76	22.38±1.85	23.47±2.08*	1.09±1.35
PA (°)	14.2±3.9	14.6±2.8	0.3±3.4	13.1±2.4	13.5±3.1	0.4±3.9
FFM_{total}(kg)	47.8±4.1	48.4±4.5*	0.6±1.0	46.8±6.9	47.4±6.8*	0.6±1.5
FFM_{leg} (kg)	16.5±1.9	16.9±2.0*	0.4±0.5	16.4±2.6	16.7±2.5*	0.3±0.5
Cardiovascular functions						
SBP (mmHg)	110±6	108±7	-2±5	114±8	111±9	-3±9
DBP (mmHg)	61±9	58±7	-3±4	63±7	63±8	0±5
HR_{rest} (bpm)	58±9	56±12	-1±9	58±11	53±9	-5±8
Aix_{aort} (%)	18.8±7.0	21.0±10.3	2.2±9.7	21.6±11.9	20.3±8.3	0.0±8.1
PWV_{ao} (m/s)	6.3±0.7	6.6±0.7	0.3±0.6	6.3±0.6	6.0±0.6	-0.2±0.4
Haematological variables						
RBC(million/mm^3)	4.51±0.38	4.57±0.27	0.06±0.20	4.38±0.38	4.34±0.31	-0.04±0.20
HGB (g/dl)	135±10	137±8	2±6	127±10	126±11#	-1±4
Hct (%)	40.6±2.6	41.4±2.3	0.8±1.7	38.6±2.7	38.5±2.9#	-0.1±2.1
PV (%)	N/A	N/A	0.85±1.73	N/A	N/A	0.36±2.05

*P< 0.05 PRE vs. POST; # P < 0.05 IRS vs. CON, changes are absolute values.

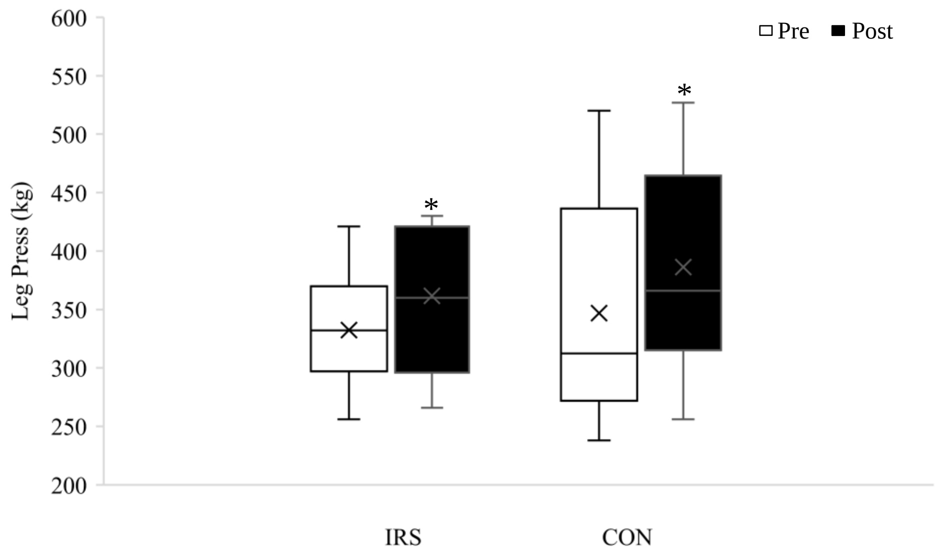

FIGURE 4. Comparison of leg press performance between before and after the 6-week intervention; *P < 0.05 PRE vs. POST, x indicates the mean values, the line inside the box indicates the median values, and the error bars indicate the standard deviation.

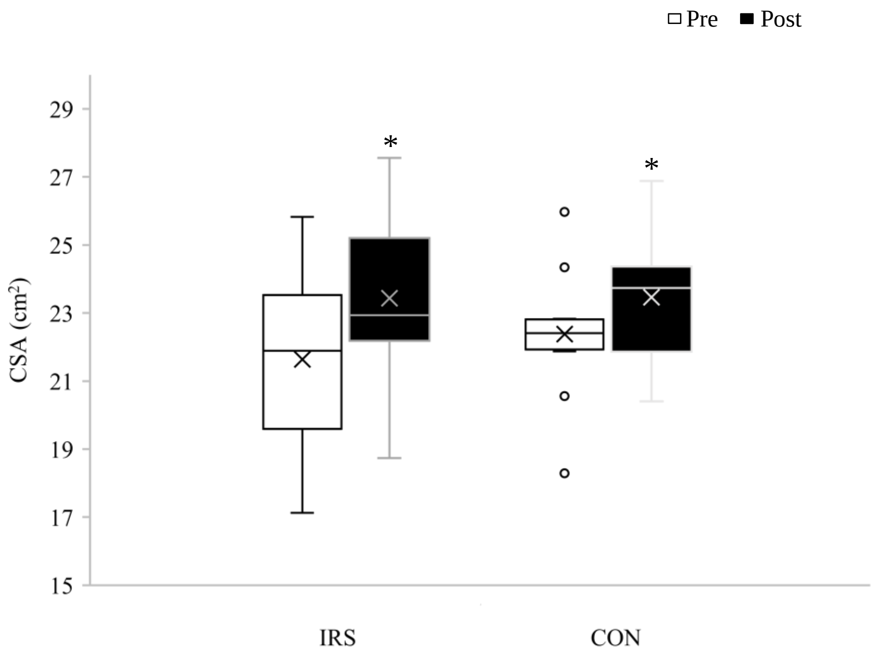

FIGURE 5. Comparison of cross-sectional area of the vastus laterlis muscle between before and after the 6-week intervention; *P < 0.05 PRE vs. POST, x indicates the mean values, the line inside the box indicates the median values, and the error bars indicate the standard deviation.

7.2 Muscle morphological characteristics

The CSA of VL significantly increased in both IRS (8.6%, 1.80 ± 0.76 cm^2, 95%CI [1.29, 2.31]) and CON (5.0%, 1.09 ± 1.35 cm^2, 95%CI [0.23, 1.95]) following the 6-week training (main effect time; F = 38.781, P < 0.001) (Table 1, Figure 5). In addition, significant increases were found in whole body fat-free mass (FFM_{total}) from PRE to POST in IRS (1.1%, 0.6 ± 1.0, 95%CI [-0.1,1.2]) and CON (1.4%, 0.6 ± 1.5, 95%CI [-0.4, 1.6]) (main effect time; F = 4.728, P = 0.041). Similarly, the leg fat-free mass (FFM_{leg}) increased in both groups (IRS: 2.6%, 0.4 ± 0.5 kg, 95%CI [-0.4, 0.5]; CON: 2.2%, 0.3 ± 0.5 kg, 95%CI [-0.3, 0.5]) (main effect time; F = 13.257; P = 0.002) (Figure 6). However, no time*group effect was found in increases of CSA, FFM_{total}, and FFM_{leg} (P = 0.140-0.924). There was no significant change in PA from PRE to POST (P = 0.638) and no time*group effect was observed (F = 0.004, P = 0.949) (Table 1)

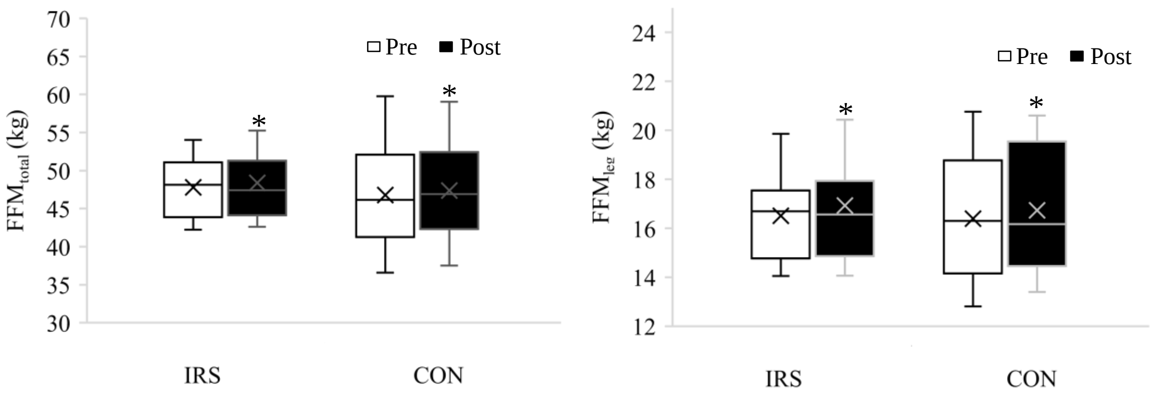

FIGURE 6. Comparison of whole body fat-free mass and fat-free mass in the leg between before and after the 6-week intervention; *P < 0.05 PRE vs. POST, x indicates the mean values, the line inside the box indicates the median values, and the error bars indicate the standard deviation.

In IRS, a modest correlation (r = 0.644, P = 0.033) was found between the relative changes in CSA (ΔCSA) and the relative changes in SJ height (ΔSJ) after the 6-week training (Figure 7a) while no significant correlation was observed in CON (P = 0.331) (Figure 7b). In CON, a modest correlation (r = 0.617, P = 0.033) was observed between ΔCSA and the relative changes in the maximal isometric leg press (ΔLP) while ΔCSA was not significantly correlated with ΔLP in IRS (P = 0.183) (Figure 7c; Figure 7d).

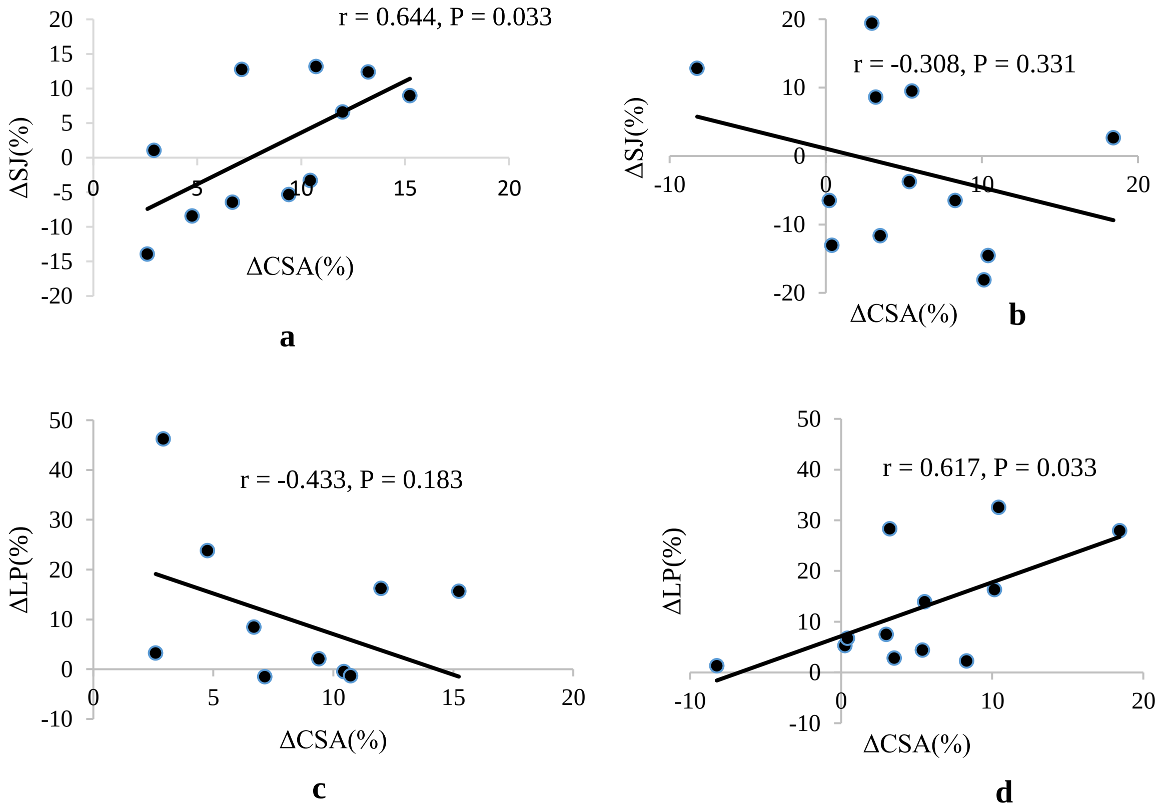

FIGURE 7. Correlations between relative changes in squat jump height, isometric leg press, and relative changes of cross-sectional area; a) correlations between relative changes in squat jump height and relative changes of cross-sectional area in IRS; b) correlations between relative changes in squat jump height and relative changes of cross-sectional area in CON; c) correlations between relative changes in isometric leg press and relative changes of cross-sectional area in IRS; d) correlations between relative changes in isometric leg press and relative changes of cross-sectional area in CON.

7.3 Cardiovascular functions

There were no significant differences reported in variables relate to cardiovascular functions including SBP, DBP, HR_{rest}, Aix_{aort}, and PWV_{ao} following the 6-week training (P = 0.084-0.591), and no time*group effect was found in these variables (P = 0.052-0.680; Table 2).

7.4 Haematological biomarkers

No statistically significant changes were found in haematological variables for both groups from PRE to POST, including RBC, HGB, and Hct (P = 0.379-0.834). Additionally, no time*group effect was reported in RBC, HGB, and Hct (P = 0.229-0.335) There were no significant between-group differences for the baseline measures of these haematological variables (P = 0.056-0.449). However, significant differences were reported between IRS and CON in some post-training haematological biomarkers, for measures of: HGB_{post} (P = 0.014) and Hct_{post} (P = 0.011). HGB_{post} and Hct_{post} were significantly higher in IRS than in CON. PV increased in both groups following the 6-week training (IRS: 0.85 ± 1.73 L; CON: 0.36 ± 2.05 L), however, the increases were not different between groups (P = 0.544). (Table 2)

8 DISCUSSION

The present study investigated the effects of using post-exercise IRS exposure on training adaptations in team-sport athletes. The present study showed that 6-week strength and power training improved isometric leg press performance, induced muscle hypertrophy, and increased fat-free mass in team sport athletes. In addition, implementing 10-min IRS three times a week following exercise sessions during the 6-week training had no detrimental effects on training adaptations regarding physical performance, muscle morphological characteristics, cardiovascular functions, and haematological variables compared to using passive recovery. Since previous evidence has shown that IRS provides benefits on acute recovery (Ahokas et al. 2023), it suggests that IRS may be considered as a favourable recovery strategy that can be implemented for long-term exercise training while does not diminish the training adaptations.

8.1 Adaptations induced by 6-week strength and power training programme

In the present study, no significant changes were reported in physical performance indicators following the 6-week strength and power training except for the isometric leg press. This is likely due to the relatively short duration of the training program (i.e., 6 weeks) as at least 7-week strength and power training have been found to induce enhancement in physical performance in adults team sports players previously (Brito et al. 2014; Faude et al. 2013; Ronnestad et al. 2008). In addition, the results may be affected by the variability of the testing protocols as the CV of SJ, CMJ, and isometric leg press tests were reported as 3.3%, 2.8%, and 17.44% - 26.87%, respectively (Ivanovic´ and Dopsaj 2013; Markovic et al. 2004). While in this study, the relative changes in SJ height were found as 1.6 ± 9.7% in IRS and -1.8 ± 12.1% in CON, and CMJ height was observed as 2.7 ± 6.7% in IRS and -0.4 ± -7.3% in CON which suggest that the changes in physical performance indicators may be too trivial to be detected by the current testing protocols. It is worth noting that even though a 12.5 ± 11.3% increase in isometric leg press was indicated, the changes should be interpreted with caution due to the large variability of the testing protocol and a high standard deviation of the results. Furthermore, the alterations of LP varied between individuals. The variation between testing subjects may be due to the varied familiarization of participants to conduct the tests, the training status, the previous training experience, etc.

Significant increases in CSA of VL and in FFM_{leg} were found in both IRS and CON, suggesting hypertrophic adaptations occur in the lower limbs in response to the 6-week training programme. An 8.6 ± 4.2 % increase in the CSA of VL was reported in IRS and a 5.0 ± 6.6 % increase was reported in CON in the present study. While greater extend of increases in the CSA of VL were found in a previous study with a 16.7 ± 12.7 % increase following 7-week traditional strength training and 23.4 ± 17.9 % increase following inter-repetition rest strength training in men (Scott et al. 2021). Similarly, a ~18.7% increase was observed following an 8-week strength training in sixteen men (Sterczala et al. 2019). This is likely due to the gender differences regarding hypertrophic responses of skeletal muscle in response to resistance training (Martel et al. 2006; Rissanen et al. 2021) as the participants recruited in this study were female athletes. In consistency with previous findings, no significant changes were observed in the PA of VL in the present study following 6-week strength and power training in team sports athletes (Scott et al. 2021). Various factors including targeted muscles, the range of motion/joint position during the intervention, the type and velocity of contractions, and the training mode have an impact on the extent of the alterations of muscle architecture (Timmins et al. 2016). According to the results, the training programme in the present study involved a complex training model that consisted of 3-4 dynamic resistance exercises and 1-2 plyometric exercises per training session (Appendix 1) may be considered an effective training mode to induce muscle hypertrophy, enhance muscle strength, and have the potential to induce improvement in other physical performance with longer duration since positive correlations have been indicated between ΔCSA and ΔSJ in IRS.

8.2 Influence of using IRS on exercise training programme

In consistency with the findings from the previous study that utilized post-exercise hot-water therapy on adaptations to 4-week training (Méline et al. 2021), in this study, utilizing heat therapy (IRS) following exercise training had no significant effects on the performance of jump tests including CMJ and SJ tests. Interestingly, additional benefits were shown on leg isometric strength while no effects on the body composition and predicted leg CSA of using hot-water immersion were found by Méline et al. No effects of using IRS were observed in increases in isometric leg press, CSA of VL, FFM_{total}, and FFM_{leg} compared to passive recovery in the present study. The effects of heat therapy on muscle hypertrophy and function are inconsistent in previous studies (Fuchs et al. 2020; Kim et al. 2020; Stadnyk et al. 2018). According to Kim et al. 2020, 8-week local heat therapy (90min, 5 days/wk, thigh) enhanced muscle strength of the knee extensors. However, the studies by Stadnyk et al. (2018) suggested that supplemental heating of muscle during and after resistance training did not provide additional benefits on training-induced hypertrophy or function, since no significant differences were observed in the changes of quadricep’s lean mass and peak isokinetic torque following 12-week resistance training between the intervention group (thigh heating, during and 20 min after each training session) and the control group. This is further supported by the study of Fuchs et al. (2020) which investigated the acute responses of protein synthesis during hot water immersion following resistance training and found that myofibrilla protein synthesis rates remained unchanged by local hot-water immersion (legs) compared to the control group after a single session of resistance training. These findings may suggest that the effects of heat therapy may be influenced by the duration and exposure area of heat therapy implementation. Long duration, and large exposure area (e.g., whole body) may be required to induce benefits on muscle hypertrophy and function to enhance physical performance.

Previous studies have also investigated the acute effects of using heat therapy on recovery of physical performance (Mero et al. 2015; Pournot et al. 2010; Vaile et al. 2007; Viitasalo et al. 1995). No differences were observed in the isometric bench press, isometric leg press, and CMJ between the group using IRS as a recovery strategy (30 min; 35-50°C) and the control group using the passive recovery following a strength training session in the previous study by Mero et al. (2015), which are in support of our findings that implementing IRS following strength and power training does not have additional effects on physical performance. While higher CMJ height was found after using IRS following endurance training sessions than using passive recovery in the same study (Mero et al. 2015), suggesting IRS may be a favourable recovery strategy for the neuromuscular system after maximal endurance training. According to Pournot et al. (2010), lower body temperate water immersion (15 min; 36°C) did not enhance the recovery of physical performance including maximal isometric voluntary contraction, maximal 30-s rowing test and CMJ after exhaustive intermittent (20 min) exercise. However, the study carried out by Vaile et al. (2007) found that hot water immersion (14 min; 38°C) improved recovery in isometric force following DOMS-inducing exercise which involved maximal strength training (5 *10 eccentric bi-lateral leg press contractions with a load of 120% of 1-RM followed by 2*10 at a load of 100% 1-RM) compared to passive recovery while had no effect on SJ. These findings may suggest that the acute effects of using heat therapy may be determined by the type of exercise that was performed prior to the recovery, implementing IRS seems not to be effective for performance recovery following strength training that did not use maximal strength as workload and exhaustive intermittent exercise.

In the present study, no group*time effect was indicated in the variables related to cardiovascular functions including SBP, DBP, HR_{rest}, Aix_{aort}, and PWV_{ao} following 6-week strength and power training using either IRS recovery or without recovery implementation. This suggests that using 10 min IRS exposure following exercise training does not provide additional benefits in cardiovascular functions. The long-term heat interventions that presented beneficial effects on arterial stiffness and blood pressure from previous studies involved a long duration of heat exposure per session (45-60 min) (Brunt et al. 2016; Gryka et al. 2020; Pokora et al. 2021). A significant decrease was found in resting SBP (from 138 ± 19 mmHg to 126 ± 6 mmHg) following 10 sauna exposures (90 ± 2 ℃) in elite cross-country skiers (Pokora et al. 2021). The study by Brunt et al. (2016) indicated that 8 weeks of repeated hot water immersion (45℃, 60 min) could enhance cardiovascular health since flow-mediated dilatation, superficial femoral dynamic arterial compliance were increased, and aortic pulse wave velocity (from 7.1 ± 0.3 m/s to 6.1 ± 0.3m/s), carotid intima media thickness, and mean arterial blood pressure (from 83 ± 1 mmHg to 78 ± 2 mmHg) were decreased following the 8-week therapy in sedentary people. The improvements in arterial stiffness and hemodynamic are likely due to the increase in nitric oxide production induced by heat therapy which may result in improved vascular relaxation and blood flow (Gryka et al. 2020).

The acute effects of using short-duration heat therapy on arterial stiffness and haemodynamic have also been investigated previously (Podstawski et al. 2020; Sugawara et al. 2021). According to Podstawski et al. (2020), 10-min sauna exposure (90-91°C; humidity: 14-16%) and following 20-min rowing ergometer training significantly decreased blood pressure in former elite athletes with hypertension (from 145.2 ± 3.5 / 95.4 ± 3.3 mmHg to 135.6 ± 3.9 / 84.3 ± 3.5 mmHg). In addition, decreases were found in brachial diastolic blood pressure (from 69 ± 7 mmHg to 67 ± 6 mmHg) and heart rate (from 55 ± 5 mmHg to 53 ± 6 mmHg) by 5-min hot water exposure in healthy males (Sugawara et al. 2021). 5-min hot water exposure was also indicated to decrease aortic and leg PWV by 7.5 and 3.1%, increase femoral arterial blood flow by 45.9% and reduce leg vascular resistance by 29.1% (Sugawara et al. 2021). Combining the findings from previous studies and the findings from the present study, implementing short-term (~5-10 min) heat therapy may induce acute effects on arterial stiffness and hemodynamic. However, these effects may not be able to be transferred to long-term adaptations to offer benefits in cardiovascular functions.

No significant effects were identified in haematological variables by using IRS compared to passive recovery in the present study. Increases in HGB and Hct induced by training or group effect may suggest a better ability for oxygen utilization for athletes thence benefit their aerobic capacity. In this study, significant differences were shown in HGB_{post} and Hct_{post} between groups. Higher HGB_{post} (IRS: 137 ± 8 g/dl; CON:126 ± 11 g/dl) and Hct_{post} (IRS: 41.4 ± 2.3 %; CON: 38.5 ± 2.9 %) were found in IRS compared to CON while the baseline measurements of HGB and CON were not found statistically different between groups. This suggests that some other interaction factors apart from training and recovery type may have an impact on the HGB and Hct which should be further investigated. Compared to previous studies, only trivial increases with large standard deviations were found in estimated plasma volume changes (IRS: 0.85 ± 1.73%; CON: 0.36 ± 2.05%) in the present study. A large increase in plasma volume was observed in Stanley et al.'s study (2015), with plasma volume increasing 17.8% after 4 days post-exercise sauna bathing (87.0 ± 13.7 ℃, 30 min). Additionally, a moderate increase in plasma volume (7.1%) was reported by Scoon et al. (2007) following 3-week intermittent post-exercise sauna exposures (89.9 ± 2.0 ℃; 30 min). This may be explained by the short duration of sauna exposure in the present study i.e., only 10 min, and the inconsistency of the method to estimate plasma volume changes in this study to other studies (Stanley et al. 2015; Scoon et al. 2007). This suggests that to induce meaningful and significant changes in haematological variables, a long duration (≥ 30 min) of heat exposure may be required. However, the participants in the present study were reported as frequent sauna users which suggests they may be acclimated to heat exposure. While the information regarding sauna uses or heat exposure was unclear in the other sauna studies (Stanley et al. 2015; Scoon et al. 2007), whether the acclimation/acclimatization status has an impact on the adaptations should be further investigated.

8.3 Strengths and limitations

One notable strength of the current study is its incorporation of comprehensive measurements encompassing diverse aspects such as physical performance, muscle morphological characteristics, cardiovascular functions, and haematological biomarkers. This inclusive approach enables a thorough assessment of the adaptations resulting from the implemented training program, as well as an evaluation of the effects of utilizing IRS as a recovery strategy on these adaptations. In addition, these measurements were well-controlled to minimize errors. For example, the position of the ultrasound probe when taking images of the PA was marked to ensure consistent probe placements for each participant from PRE to POST which mitigate the measurement errors.

Nonetheless, it is important to acknowledge the limitations of this study, as they may have compromised the validity of the results. For instance, the consistency of the temperature in the sauna chamber was affected by heat transfer in the chamber, resulting in fluctuations even though the initial temperature was uniformly set at 50 ℃ for all participants. Observations during the intervention indicated that the recorded temperature was consistently lower than 50 ℃, potentially leading to an underestimation of the effects attributed to the proposed IRS strategy. Additionally, there were instances of missing data in the measurements, introducing a greater variation in the results and potentially interfering with their interpretation. These limitations may partly account for the lack of significant effects observed when utilizing IRS as a recovery strategy for chronic adaptations to exercise training.

8.4 Perspectives and significance

Limited data have identified the effects of utilizing heating as recovery interventions (Chaillou et al. 2022), the findings of the present study added to the knowledge of utilizing heating as recovery strategies for chronic training adaptations in trained athletes. The results of the present study suggest that implementing IRS as a recovery strategy following strength and power training does not diminish the chronic training adaptations in team-sport athletes. Additionally, the results from our previous study showed that utilizing a single IRS following exercise training attenuated the decrease in explosive performance and reduced subjective muscle soreness following resistance training in basketball players (Ahokas et al. 2023). Altogether, it may suggest that IRS could be a favourable recovery strategy for team-sport players to improve their readiness for routine strength and power training without detrimental effects on chronic training adaptations. Compared to post-exercise cooling which could enhance neuromuscular recovery following a single resistance exercise session (Roberts et al. 2014) while impairing strength and muscle gains through long-term strength training (Fröhlich et al. 2014; Roberts et al. 2015), the findings from the present study suggest that post-exercise heating may be considered as a favourable recovery strategy when frequent and long-term use is required.

However, as no additional benefits resulting from utilizing the post-exercise IRS on the chronic adaptations have been shown in the present study, whether this should be put into the application is debatable due to limited resources and time. Future studies should investigate the most effective way for implementing IRS as a recovery strategy to induce additional beneficial effects (e.g., increase the exposure time, use after other types of exercise, etc.). In addition, the participants recruited in the present study were all female athletes while the previous study from our group that investigated the acute effects of using a single IRS were males (Ahokas et al. 2023). Whether there are differences between the effects of employing IRS in men and women should be further investigated.

8.5 Conclusion

Post-exercise IRS has no detrimental effect on chronic training adaptations regarding explosive physical performance, muscle morphological characteristics, cardiovascular functions, and haematological variables following 6-week strength and power training. IRS may be considered a favourable recovery method when frequent and long-term use is required, as previous evidence has indicated the benefits of IRS in acute recovery. Future studies should investigate the optimal options of employing the IRS to induce additional benefits and the potential gender effects of utilizing the IRS on recovery.

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APPENDIX

Appendix 1. Examples of training programme

Session	Exercise	Sets	Rep	Load	Recovery time
1	1.1 Trap bar deadlift	3	4	75-80%	2min
	3.1 Bench press	3	4	75-80%	2min
	2.1 Forward lunges	3	4	75-80%	2min
	2.2 Hop run	3	6+6		
	1.2 10m resisted sprints	3	4		2min
	3.2 Chess pass	3	6	3kg	2min
2	1.1 Split squat	3	4	75-80%	2min
	1.02 Drop jump	3	4		2min
	2.1 Hip thrust	3	4	75-80%	2min
	2.2 Horizontal jumps	3	4		
	3.1 Military press	3	4	75-80%	2min
	3.2 3 Landmine rotational press	3	6	75-80%	2min